2008 Programs of the Manufacturing Engineering Laboratory

March 2008

stimulating innovation and fostering U.S. manufacturing competitiveness

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

NISTIR 7491

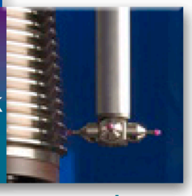
The Manufacturing Engineering Laboratory
mel.nist.gov

Howard Harary
Acting Director
hharary@nist.gov

Albert Wavering
Acting Deputy
wavering@nist.gov

Precision Engineering

Michael Postek
Chief
postek@nist.gov



Large Scale Coordinate Metrology
Steven Phillips, *sphillip@nist.gov*

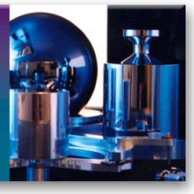
Engineering Metrology
Ted Doiron, *tdoiron@nist.gov*

Nanometer-Scale Metrology
John Kramar, *jkramar@nist.gov*

Surface and Microform Metrology
Richard Silver, Acting, *silver@nist.gov*

Manufacturing Metrology

Kevin Jurrens
Acting Chief
kjurrens@nist.gov



Mass & Force
Zeina Jabbour, *zeina@nist.gov*

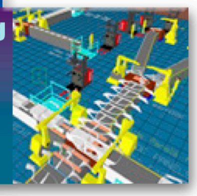
Machine Tool Metrology
Alkan Donmez, *alkan@nist.gov*

Sensor Development & Application
Kang Lee, *kang@nist.gov*

Mfg. Process Metrology
Johannes Soons, soons@nist.gov

Manufacturing Systems Integration

Steven Ray
Chief
sray@nist.gov



Deputy
Sharon Kemmerer, *kemmerer@nist.gov*

SIMA Office
Simon Frechette, *frechett@nist.gov*

Enterprise Systems
Albert Jones, *jonesa@nist.gov*

Mfg. Standards Metrology
Simon Frechette, *frechett@nist.gov*

Design & Process
Ram Sriram, *sriram@nist.gov*

Mfg. Simulation & Modeling
Chuck McLean, *mclean@nist.gov*

Intelligent Systems

Elena Messina
Acting Chief
messina@nist.gov

NIST Fellow
James Albus, *albus@nist.gov*

Control Systems
Frederick Proctor, *proctor@nist.gov*

Knowledge Systems
Craig Schlenoff, Acting, *schlenof@nist.gov*

Machine Systems
Harry Scott, Acting, *hscott@nist.gov*

Perception Systems
Michael Shneier, *shneier@nist.gov*

Systems Integration
Michael Shneier, Acting, *shneier@nist.gov*

Fabrication Technology

Mark Luce
Chief
mark.luce@nist.gov

Main Shops
Bob Wantz, Assistant, *rwantz@nist.gov*

2008

Programs of the Manufacturing Engineering Laboratory

March 2008

NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

Abstract

The National Institute of Standards and Technology's Manufacturing Engineering Laboratory (MEL) promotes innovation and the competitiveness of U.S. manufacturing through measurement science, measurement services, and critical technical contributions to standards. This report contains highlights of MEL research programs and accomplishments from April 2005 through March 2008.

Keywords

Manufacturing, manufacturing engineering, technology, measurements, metrology, standards

Disclaimer

For More Information

Manufacturing Engineering Laboratory
Stop 8200
Gaithersburg, MD 20899-8200

Phone 301-975-3400

www.mel.nist.gov

Table of Contents

A Message from the Acting Director

The Manufacturing Engineering Laboratory (MEL) at the National Institute of Standards and Technology (NIST) is pleased to present summaries of its technical work covering April 2005 through February 2008.

MEL's mission is to promote innovation and the competitiveness of U.S. manufacturing through measurement science, measurement services, and critical technical contributions to standards. We do this by performing research and development, developing and providing needed measurement services, and providing technical contributions and leadership in standards activities. Our long-term goal is best summed up by the Laboratory's core purpose — to promote a healthy U.S. manufacturing economy by solving tomorrow's measurement and standards problems today.

With a value-added contribution of $1.5 trillion, U.S. manufacturing — our customer base — directly accounts for approximately 12 percent of the U.S. gross domestic product. Manufacturing plays a central role to our Nation's economy. Dollar for dollar, manufacturing has the highest-leverage economic impact of all of the economic sectors. For every dollar of economic output produced by manufacturing, $2.44 of additional output is stimulated in the rest of industry. As such, manufacturing's ability to innovate and compete is vital to all the other sectors of the economy.

MEL brings to bear considerable resources in support of U.S. manufacturing, including numerous unique facilities, and dedicated staff and associates. The pages that follow provide an opportunity to learn more about these resources and how they are applied to solve critical industry problems.

MEL serves the manufacturing sector of the U.S. economy in a broad sense, working with partners from industry as well as other government agencies and academia to develop the measurement tools and infrastructure that enable new products, higher productivity, and improved processes. Our customers span the full range from established to emerging-technology industries — including automotive, aerospace, construction and agricultural equipment, medical devices, microelectronics, optics, telecommunications, and nanotechnology. MEL also provides mechanical design and fabrication services to other NIST operating units through its stewardship of the Fabrication Technology Division.

MEL actively develops and maintains strong relationships with its customers and stakeholders. Nearly all of the nation's manufacturers rely on MEL in some way, and we design our programs, in consonance with our mission, to respond to manufacturing's most critical current and future needs. Working collaboratively with our external partners, MEL staff members solve measurement and standards problems that allow our customers to overcome barriers to product and process innovation, to seamlessly and accurately share manufacturing information, and to take full advantage of the latest technologies essential to their competitiveness and mission success. Our customers also depend on MEL calibration services to meet their most challenging mechanical and dimensional measurement needs for research, development — and the requirements of the modern extended enterprise in commerce, and international trade.

This document will give you a sense of the challenges faced by U.S. manufacturers in areas related to the MEL mission, and how we are addressing them. As you review our portfolio of technical activities, we invite your comments and questions, we welcome opportunities to collaborate, and we thank you for your interest in our work.

Howard Harary

Acting Director

Manufacturing Engineering Laboratory

National Institute of Standards and Technology

Gaithersburg, Maryland 20899

Howard.Harary@NIST.gov

301 975 3401

Manufacturing Engineering at a Glance

www.mel.nist.gov

MEL Mission

MEL promotes innovation and the competitiveness of U.S. manufacturing through measurement science, measurement services, and critical technical contributions to standards

MEL Vision

MEL will be the world leader in creating critical measurement solutions and promoting technically rigorous, equitable standards to stimulate innovation and foster U.S. manufacturing competitiveness

MEL Core Purpose

To promote a healthy U.S. manufacturing economy by solving tomorrow's measurement and standards problems today

MEL Divisions

Precision Engineering

Provides the foundation for dimensional measurements over 12 orders of magnitude

Manufacturing Metrology

Fulfills mechanical metrology and advanced manufacturing technology measurements and standards needs

Intelligent Systems

Provides the measurement and standards infrastructure needed for the application of intelligent systems

Manufacturing Systems Integration

Develops and applies measurements and standards that advance the use of information-based manufacturing technologies

Fabrication Technology

Provides world-class instrument and specialized fabrication support for NIST researchers

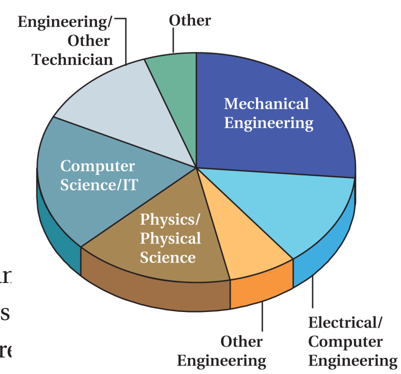
Measurement Service Areas

- Length
- Diameter and Roundness
- Complex Dimensional Standards
- Optical Reference Plane Standards
- Angular Measurements
- Surface Texture
- Laser Frequency/Wavelength and Ranging
- Mass Standards
- Force
- Vibration
- Acoustics

MEL Resources

Staff

- 174 Full-time permar
- 98 Guest Researchers
- 4 NRC postdoctoral re



Technical Specialities

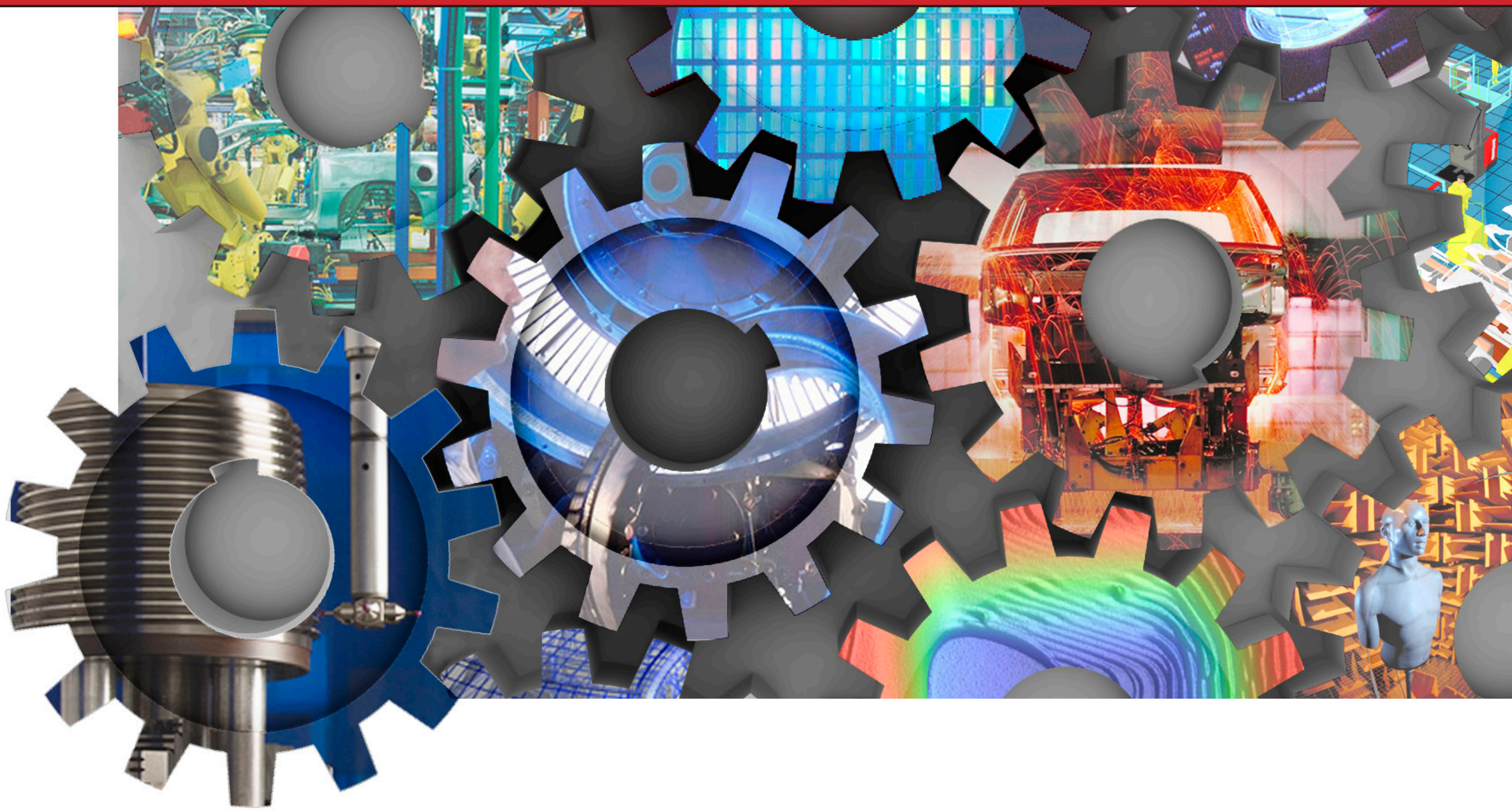
Funding

$50.4 M annual budget (FY2008 estimated)

- $37.0 M NIST Appropriations
- $8.7 M Other Agency/External R&D
- $4.7 M Calibration service Fees/Reimbursable

Representative Facilities and Testbeds

- M-48 Coordinate Measuring Machine Laboratory
- 60-meter Laser & Artifact Calibration Range
- Next-Generation Nanometrology Laboratories
- Mass Metrology and Standards Facility
- Force Metrology Laboratories
- Small Force Metrology Laboratory
- Smart Machining And Machine Tool Interoperability Testbed
- Dimensional Metrology Interoperability Testbed
- Industrial Control Networking and Cybersecurity Testbed
- Industrial Robotics Measurement Science Testbed
- Advanced Manufacturing Systems And Networking Testbed (AMSANT) and Simulation Laboratories



Chief:
Michael Postek

NIST
100 Bureau Drive
Stop 8210
Gaithersburg, MD
20899-8210

Phone:
301 975 2299

Fax:
301 869 0822

Email:
michael.postek@nist.gov

PED

Precision Engineering

Mission

The mission of the Precision Engineering Division is to provide the foundation of dimensional measurement that meets the needs of the U.S. industrial and scientific communities.

The division attains that goal by:

- Conducting research in dimensional measurements
- Developing new measurement methods
- Providing measurement services
- Developing National and International artifact and documentary standards
- Disseminating the resulting technology and length-based standards

It is also within the mission of the Precision Engineering Division to provide dimensional metrology assistance to other federal government agencies in order to address problems and needs that leverage NIST expertise, facilities, and capabilities.

Overview

The Precision Engineering Division (PED) provides the United States with the foundation for dimensional measurements ranging over 12 orders of magnitude (kilometers to nanometers). PED establishes both artifact and documentary standards through research, development, measurement services, and information dissemination. PED conducts research and development in precision-engineered length-metrology-intensive systems in instrumentation for both measurement and production. PED delivers to industry important length-related measurements, standards, and technology services that directly support U.S. manufacturing's products and processes. These standards are measured by conventional and frameless coordinate measuring machines (CMM) using both contact and optical measuring probes, machines, and systems. Features of interest range in size from one kilometer (calibrated telecommunication cables) to meters (laser trackers) to nanometers (CD metrology instruments). The spectrum of metrology instrumentation includes optical, particle beam, mechanical, electrical, and quantum-mechanical phenomena, all referred to the International System of Units (SI) unit of length (modernized metric system), which is defined through the use of stabilized lasers and displacement interferometry.

The Precision Engineering Division has developed three programs to best utilize the talents of its personnel and thus meet its mission with maximum effectiveness. These three programs are:

- Dimensional Metrology
- Nanomanufacturing Metrology
- Next-Generation Nanometrology

Core competencies and Industry Drivers

The core competencies of the PED Programs reside in measurement science and rigorous traceability in the mechanical, dimensional, and nanomanufacturing domains. The work of these programs is highly influenced by industrial drivers that reflect important trends in manufacturing, especially:

- Increased Pace of Technological Change.
    - Rapid innovation in many emerging areas, especially nanotechnology
    - Need for improved measurement accuracy and precision
    - Requirement for new and more complex measurements
- Globalization
    - Flat-world[1] supply chains require measurement traceability to the SI
    - Greater regulatory requirements
    - Harmonization of international standards that reflect and support U.S. needs

1 "The World is Flat" by Thomas L. Friedman.

The implications of these drivers for PED include:

- Technology Change, generating demand for new metrologies
- Globalization, leading to increased dependence on traceable measurements and international documentary standards
- Globalization, requiring integration and harmonization between formerly separate industry sectors, each with entrenched practices and terminologies (this is especially true for nanotechnology)

Resources

Staff

33 NIST staff

2 NRC post-doctoral researchers

35 Guest Researchers

FY2008 Estimated Funding

$9.2M STRS (excluding Innovation in Measurement Science)

$0.8M NIST Innovation in Measurement Science

$1.0M Reimbursable (calibration services)

$0.6M Other Agency

Staffing Challenges:

One of the main challenges confronting PED is a "graying" of the highly trained and specialized metrology workforce, coupled with reduced budgeting that limits the ability to train replacements in place. As a result, the contract labor pool has grown while the staff-to-contractor ratio continues to fall. Trained contractors can readily leave NIST, taking their training and experience to outside companies and further exacerbating the problem. In addition, contracting a workforce is only a partial solution since intellectual property (IP) issues and government regulations can restrain a contractor from working on particular projects.

PED is also facing a steadily decreasing technician-to-professional ratio, again for budgetary reasons. The complexity of the highly specialized metrology instrumentation within PED (helium ion microscope, scanning electron microscopes, etc.) requires dedicated instrument technical professionals to operate and maintain the instrumentation at the high levels demanded by the metrologies.

Facilities and Equipment

- World class 60 meter laser & artifact calibration range. A 60 m range with a long range interferometer system, referenced to the Iodine stabilized laser and with real time index of refraction compensation of the beam path, resulting in long range uncertainties of 3 parts in 10^7
- Large scale coordinate metrology laboratory. A large 15 m by 20 m lab with temperature controlled to 0.5 C, permitting large-scale 3D volumetric calibrations.
- LineScale Interferometer. Capable of measuring one-dimensional scales up to 1 m long, with uncertainties demonstrated to be world-class through international intercomparisons.
- World's most accurate coordinate measuring machine. The M-48 CMM has a measuring volume of 1 m by 0.5 m by 0.3 m and can gauge position to an uncertainty of 100 nm, plus 2 parts in 10^7

- World-class roundness measuring machine. A world-class roundness uncertainty of 3 nm will be verified through international comparisons that we are initiating.
- Laser frequency / wavelength laboratory with realization of the meter to an accuracy of 1 part in 10^{12}
- Molecular Measuring Machine (M^3) (research project): A two-dimensional metrology instrument based on a scanning probe microscope (SPM) with Michelson-interferometer metrology. M^3 has a 50 mm by 50 mm by 5 µm measurement range, and a goal of 1 nm combined uncertainty for point-to-point measurements.
- Five chamber atomic resolution UHV STM with picometer resolution interferometry. This unique instrument is capable of atomic resolution measurements of silicon surfaces and has a field-ion field-electron microscopy capability for atomic resolution measurements of probe tips.
- Highest resolution 193 nm wavelength fully custom scatterfield optical microscope. A world-leading optical instrument using engineering techniques that provide fully structured but flexible illumination, capable of wafer measurement in a clean room environment.
- High resolution VP-SEM Reference Measurement System: Highly customized variable pressure scanning electron microscope (SEM) with laser interferometer stage providing picometer resolution. Variable pressure permits the dissipation of electron charging. Picometer resolution laser interferometer stage provides traceability to the meter.
- Calibrated Atomic Force Microscope. Custom-built AFM with active interferometer-based metrology on X and Y axes, and *in situ* interferometer calibrated capacitance gage on Z axis.
- World's First Commercial Helium Ion Microscope. Analogous to scanning electron microscope (SEM), except that the specimen is scanned with a He^{+} ion beam instead of an electron beam. Higher resolution and complementary contrast comparable to state-of-the-art SEM have been demonstrated on some samples.
- High resolution Cold Field Emission SEM. Currently the highest resolution SEM at NIST, but will soon be replaced with a new Hitachi 5500 STEM instrument with 0.4 nm resolution.
- High-resolution dual beam Focused-ion Beam (FIB) and SEM with laser interferometer stage (being manufactured). The dual beams allow in situ cross-sectioning of samples or ion-milling during examination by the SEM. The interferometer stage has a resolution of 38 pm. Total combined measurement uncertainty not yet determined.

- World's first scatterfield optical microscope with demonstrated sub-nanometer resolution. This optical instrument gave the first demonstration of nanometer scale accuracy in imaging and measuring of 100 nm sized features using optical techniques in reflection mode.
- Optical overlay microscope Instrument capable of calibrating overlay structures 20 micrometers in size with sub-nanometer repeatability and fully characterized uncertainty statement.
- UV Transmission Microscope. Custom-built, 365 nm illumination microscope with scanning interferometer-measured stage; optimized for measuring photomask linewidths.
- Optical Tweezers (OT). Custom designed and built OT instrument with high frequency beam modulation and scanning and a convenient user interface for simultaneously trapping multiple particles, then orienting and moving them. Automated control and trapping of sub-200 nm particles is under development.

Facilities and Equipment Challenges:

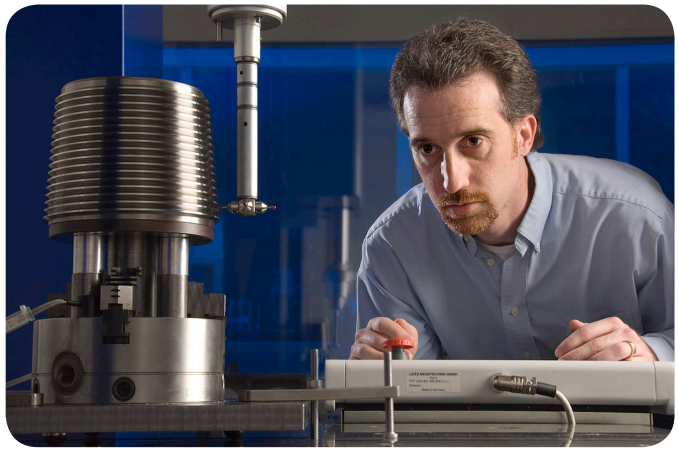
PED is continually challenged by its customers to develop metrology solutions that go beyond current capabilities. One of the most demanding customers has been the semiconductor industry, which has been pushing the metrology envelope for many years via the International Technology Roadmap for Semiconductors (ITRS). Meeting the semiconductor industry's needs gave PED a head start when the emphasis on nanotechnology became apparent. Because PED had already been developing methodologies and performing measurements at the sub-100 nanometer scale, basic infrastructural technologies were already in place to support the metrology. PED's work has been facilitated by the new laboratories now residing in the Advanced Measurement Laboratory.

- PED Advanced Measurement Laboratory (AML) Facilities. Over 20 years ago, PED proposed to NIST management a vision for an advanced measurement laboratory with stringent environmental controls to meet the future metrology needs of the United States. This facility has now been built and most of PED's metrology equipment has been installed there. Numerous metrology experiments have experienced a wide variety of improvements through this move. For example, in the new scanning electron microscope reference measurement instrument laboratory, site surveys by the instrument manufacturer prior to the microscope's installation found no measurable vibration. The instrument manufacturer's Applications Laboratory representative was quoted as saying that *"there is no environmental excuse we can use in this laboratory to blame for poor performance of our instrument."* In all cases, improved performance of the metrology instruments has been documented.

Precision Engineering Division Program

Dimensional Metrology Program

Annual FTEs:	17.5 NIST staff
	4.5 Guest Researchers/Contractors
	22 total FTEs



Measurement of API Rotary Master Gauge on CMM

Challenge:

Technological leadership in high accuracy dimensional metrology is critical to maintaining U.S. competitiveness. The challenge is to sustain MEL's core dimensional metrology capability while developing new metrological infrastructure for high value or innovative technologies that improve U.S. competitiveness.

Overview / DMP Strategic Objectives

The Dimensional Metrology Program (DMP) addresses selected needs of the U.S. industrial and standards community for dimensional metrology over a length scale of kilometers to micrometers. This includes calibrations of measuring instruments such as laser interferometers and laser trackers, a wide array of engineering gauges, standard reference materials, and specialized, e.g., high accuracy measurements by coordinated measurement machines (CMM). The program also seeks to provide expertise and representation of U.S. interests in national and international standards.

The long term external objective of the DMP is to improve US competitiveness by: (1) providing infrastructure for core metrological traceability through deep penetration of the DMP's measurements into the US metrology chain; (2) creating measurement capability for high value components; and (3) focusing new metrological activities on enabling technologies where the U.S. has a significant industrial presence.

DMP is developing unique measurement capabilities – typically a combination of extremely low uncertainty or difficult to measure measurands that differentiate MEL from other top-tier laboratories. These capabilities seek to exploit strategic fit within MEL and to take advantage of economies of experience and scope. Particular emphasis is placed on the formation of capital equipment and facilities. To implement these objectives the DMP is increasing its use of flexible CMM-based measurement systems. For example, several dedicated calibration systems are now replaced by the M-48 CMM, which provides higher accuracy and throughput. The M-48 was in measurement service for 320 days in FY-07.

Some gauge calibrations with low penetration into industry and diminishing technological value are being eliminated. Additionally, the DMP is developing calibration techniques and standards for laser trackers using absolute distance and laser radar sensors (the United States is home to two of the top three manufacturers of this rapidly growing technology). The program is also advancing fundamental metrology such as the realization of the unit of length through refractometry and the optical comb.

Program projects can be roughly categorized as either:

- Research and development (R&D) activities
- Ongoing measurement services
- National or international standardization efforts.

This categorization is somewhat artificial as all three areas strongly interact. For example, R&D activities frequently yield new measurement services and a corresponding industrial need for standardization.

Key Accomplishments and Impacts:

- Development of the world's most accurate CMM probe, capable of inspecting microfeatures.
- Development of world class 60 meter laser test range for laser tracker calibrations
- Completion of a comprehensive five part series of national standards on measurement uncertainty for industrial users.

Future Directions and Plans:

The program anticipates further culling of low penetration or low value added calibrations from our services. We will continue developing unique high accuracy equipment and facilities. For example, we are developing a second Moore M-48 CMM that will incorporate the DMP's microfeature probe. This CMM will be dedicated to high value components and reference materials with sub-millimeter features and will free up time on our existing M-48 for additional calibration volume. Continuing emphasis will be placed on enabling technology that supports U.S. industrial interests, notably optical coordinate metrology instrumentation that improves productivity.

Excellence & Leadership Recognition

Staff	Excellence & Leadership Demonstrated
Blackburn, Chris Borchardt, Bruce Estler, Tyler Phillips, Steven Sawyer, Daniel	• 2007 NIST J.D. French Award for Measurement Service Excellence for significant improvements in accuracy and extensions of range in the calibration of long length standards. Their efforts resulted in a reduction in uncertainty by more than 600% over prior capability.
Stone, Jack	• 2007 Department of Commerce Silver Medal Award for development of a unique high-accuracy optical probe for the measurement of sub-millimeter features and deep holes allowing NIST to open a new, unprecedented, realm of dimensional measurements 100 times smaller than previously available.
Doiron, Ted	• 2006 Best Paper Award, Measurement Science Conference
Estler, Tyler	• Elected Fellow of CIRP – The International Academy for Production Engineering, 2005

Projects

Dimensional Metrology Program

Research and Development Project

Challenge/Problem Addressed:

Industrial measurements continue to need increasing accuracy and component extent (both larger and smaller workpieces). The challenge is to identify new measurement areas that promote technological growth, are within the reach of the program, and deliver a significant social return on investment (SROI).

Objective(s):

Develop new dimensional measurement services that support industrial innovation, advance measurement science, and create new and unique measurement capabilities at NIST.

Accomplishments:

- 60 Meter Measurement & Test Range (Status: R&D Completed in FY-07):

  The large scale metrology industry is rapidly moving to optical measurement systems. Unlike large fixed placement CMMs, these new systems can be easily transported to different measurement sites, have significantly lower capital equipment costs, and allow factory floor space to be rapidly reconfigured.

  New optical technologies that provide absolute distance measurement (ADM) capability eliminate the need to transport retroreflectors from the system to the workpiece and the associated problems of beam breakage. For that reason, measurement technology using ADMs has exploded in recent years and numerous firms are developing new products and measurement services. The United States leads the world in this technology, particularly in the development of ADM laser trackers.

  The DMP is supporting this crucial technology through development of a high accuracy 60 meter test range that can calibrate ADM ranging systems. Direct assessment of the errors in these (often highly proprietary) ADM systems helps manufacturers of this technology to improve the accuracy of their equipment and gives users confidence in the measurements. Using our existing tape calibration facility, augmented with a newly developed high accuracy long range interferometer system, represents a unique national resource. Current test range calibration uncertainties are $U(k = 2) = 2$ µm + $3 \times 10^{-7} L$ for cooperative targets (specially made to be ADM friendly) and $U(k = 2) = 10$ µm + $1 \times 10^{-6} L$ for noncooperative targets.

  QuantaPoint Inc., a manufacturer and service provider of laser ranging metrology, was one of our first industrial collaborators to use the test range in FY-06. Darin Ingimarson, Director of Hardware Development, wrote in a letter to NIST:

  "The data we acquired at NIST on our four prototype Mark VI systems has helped us find several issues that would have remained unnoticed. With this information we are able to devise specific tests and procedures that will improve the accuracy and reliability of the ranging system. We have shaved weeks from our development schedule and are better prepared to place our systems into commercial service sooner. Furthermore, the competitive advantage gained from our testing will translate to direct financial benefits to Quantapoint and will help us keep the US laser-scanning industry one step ahead of our offshore competition."

- Microfeature CMM Probe: (Status: R&D Completed in FY-07):

  New fabrication technologies are creating an ever-expanding array of microfeature (10 µm to 1000 µm) size products. Microfeature technology can both create novel functions and enhance product value. For example, experimental fuel injectors with sub-100 µm holes have reduced emissions and improved the mileage of diesel engines. Microfeatures are increasingly common in optical fibers and their connectors, medical devices, DNA processing chips, drug delivery systems, and a myriad of other applications. These components are both too small and too delicate to inspect with conventional contact probing techniques.

  The DMP is addressing this need by developing new CMM probing technology. This new probe adapts to our M48 CMM and extends our 3D coordinate metrology capability to feature sizes below 100 µm. The probe can access bores with aspect ratios of over 50:1. We have recently extended use of the probe to measurements of knife-edge apertures that would be too fragile to measure with a traditional CMM probe. (These apertures are used as radiometry standards by the Optical Technology Division.) The aperture measurements achieve state-of-art uncertainty and provide a clear pathway toward better basic radiometry standards. We have started using the probe in conjunction with a precision spindle to do precision roundness measurements of small bores.

  The probe is better characterized than any other system in the world for microfeature measurement. We have demonstrated hole diameter measurements with expanded uncertainties below 100 nm. The probe also exerts exceptionally low measurement force (on the order of 100 nanonewtons) giving it unique measurement capability on small external features and delicate surfaces.

  We are also characterizing other microfeature capable CMMs such as the Mitutoyo Corporation for the UMAP Ultra CMM, currently on long term loan to NIST. This system, while not as accurate as the NIST probe, has greater throughput. The UMAP is currently being used in evaluating microchannels associated with fuel cell manufacturing.

- Large Scale Metrology Research and Artifacts (Status: R&D ongoing, to be completed FY-10):

  Performance testing of large scale coordinate metrology systems poses a significant challenge. Large testing volumes are needed to adequately evaluate the 3D performance of laser trackers, “indoor GPS” systems (actually an optically based technology), and laser scanners. The DMP is currently developing a facility capable of testing a wide assortment of these optically based systems.

  This facility can rapidly conduct the volumetric tests specified for laser trackers in the ASME B89.4.19 laser tracker standard. We have also collaborated with the Boeing Company and MetricVision (a U.S. manufacturer of large scale metrology equipment, now owned by Metris) to evaluate laser radar technology, an emerging technology for high accuracy noncooperative target scanning. Research also includes work on large (e.g. 3 meter) artifacts typical of industrial environments and we are developing instruments to provide high accuracy calibrations of these artifacts.

- Fundamental Length Metrology (Status: R&D ongoing, to be completed FY-10):

  The DMP is actively engaged on improving the fundamental realization of the meter. Conventionally, the meter is tied to the unit of time (the second) through a complex chain of frequency doublings that provides a few selected calibrated laser frequencies, most notably the iodine stabilized HeNe laser. The recent development of the optical comb provides ultraprecise measurements of vacuum wavelength directly tied to the definition of the second. In addition to providing tremendous accuracy, the comb can be used to calibrate a laser operating at essentially any wavelength. It may therefore help to stimulate innovative new approaches to length metrology. For example, if an application needs multiwavelength interferometry based on telecom lasers, we would have no problem providing the required wavelength calibrations at any desired level of uncertainty.

  Thus far, we have demonstrated better performance than had previously been reported for combs employing a GPS reference frequency. We have also established a complete set of internal consistency checks to guarantee that measurement results are correct. This set of checks could in principle be employed by anyone to verify performance of a comb+GPS system without the need for NMI calibrations, and hence goes a long way toward fulfilling a goal of delivering reliable "length by satellite". During the next two years, we expect to demonstrate competence for frequency measurements over much of the visible spectrum, from 540 nm (green lasers for multicolor interferometry) up to 700 nm. We also will have capability at telecom wavelengths from about 1200 nm to 1600 nm.

  The comb measurements must be supplemented by refractive index measurements to determine laser wavelength *in air*, which is the basic metric for almost all interferometer-based measurements. However, uncertainty in the value of air's refractive index sets the fundamental limitation for practical measurements, preventing us from fully utilizing the inherent high accuracy associated with the laser frequency. Using new optical materials and recent improvements in optical coating and contacting technology, we are building refractometers that should allow for refractive index measurements—and thus length measurements—with a relative uncertainty below 1 part in 10^8. Ultimately, this will lower the uncertainties in NIST calibrations and hence improve the program's competitive position by enhancing our unique measurement capability.

Planned Future Accomplishments:

- Contact Profilometer Development (Status: new project, to be completed FY-09):

  This project will deliver contact profilometry measurements with world class performance. Contact profilometry is the gold standard of microform measurements. The DMP uses contact profilometry in a wide array of measurements including surface roughness calibrations, microindentor characterization for hardness instruments (maintaining the national hardness scale), and in reference measurements for the optical metrology techniques used for standard bullets (used in law enforcement). Standard reference materials (SRMs) 2071 – 2075 are calibrated as surface roughness standards using contact profilometry and are used throughout the industry.

A new contact profilometer to replace the current obsolete system will offer significantly better resolution and accuracy. The new instrument will be metrologically characterized with a detailed uncertainty budget and cross checked against previously calibrated artifacts to ensure continuity of this measurement service. The instrument will be in use by the end of FY-09.

- CMM Metrology Capability (Status: new project, to be completed FY-10):

  This project will deliver another Moore M48 CMM as a calibration instrument with world-class performance by FY-10. The DMP's current M48 CMM is running at full capacity, providing a unique measurement capability for features ranging from 0.5 mm to 1000 mm. The new M48 CMM, acquired from Sandia National Laboratories, will be dedicated to microfeatures measurements using the new NIST probe and a vision (CCD) system. This new capability will significantly improve the DMP's capacity to calibrate this high value class of products. We will exploit our deep learning curve about M48 operations to achieve world class performance within three years.

  The new CMM will also serve as a testbed for new enhancements, including integration of glass scales for nanometer-level interpolation of the machine scales. For larger displacements, advancements made in our refractometry project should yield length-proportional uncertainty of less than five parts in 10^8.

Collaborators:

- The Boeing Company; laser trackers and laser radar performance evaluation
- Metris Inc.; Laser radar research and performance evaluation.
- QantaPoint; LIDAR development
- Faro Technologies; laser tracker research
- Inora Technologies; large scale artifact development
- Brunson Instrument Company; large scale artifact development
- Automated Precision Inc.; large scale artifact development
- Drexel University; surface roughness instrumentation
- Process Specialties Inc.; surface roughness research
- Bethesda Naval Medical Center, CMM measurements
- MSP Corporation, microfeatures

Dimensional Metrology Program

Measurement Services Project

Challenge/Problem Addressed:

The DMP's fundamental role is to provide industry with accurate and timely measurement services, including calibrations, special tests, and standard reference materials and data. Measurement services link the SI unit into almost all dimensional traceability paths in the United States. This role differentiates NIST from other calibration laboratories and from universities that also perform R&D and standardization activities.

Some measurement services focus on deep penetration into the U.S. traceability chain. For example, each gauge block calibrated at NIST explicitly provides metrological traceability to over 1000 blocks in industrial use. Other services focus on high value components which typically involve complex geometry and measurands. These complex measurands require the flexibility of coordinate measuring machines (CMMs). Calibration activity involving CMMs now represents nearly 40% of total measurement services revenue, up from less than 10% a decade ago. This increase is attributed both to our increased CMM measurement capability and the increasingly sophisticated mix of customer components.

As technology rapidly expands, so does the need for additional calibration services. However, the program's capacity to address these needs is diminishing (with respect to purchasing power) so measurement service activities must be carefully selected.

Objective(s):

To provide an optimal mix of measurement services that address both current and future dimensional measurement needs.

Accomplishments:

- Measurement services in technologically declining areas are being eliminated. For example, level rod calibrations (used in civil engineering) have been eliminated since GPS offers higher accuracy over large distances. Mechanical sieve calibrations are also being eliminated as they have relatively low value and can be performed by secondary calibration laboratories.
- We have halved the uncertainty of our long calibrations (e.g., survey tapes), and added new capability for long cables particularly for the optical fiber telecommunications industry. This new capability was highly synergistic with the improved accuracy developed for the 60 meter laser ranging facility.
- Quality assurance metrics have continuously improved over the past three years. On time delivery is now at 98%. However, turnaround time remains fixed at roughly 65 days; additional emphasis is being focused on reducing this value.
- Calibration income has steadily increased with gross revenues now at $1M / year and net revenues at $0.75M /year.
- Results from international laboratory Key Comparison (CCL-K6) for diameter show the NIST results well centered with respect to results from other major laboratories.

- The DMP is currently the pilot lab for a Key Comparison on hardness testing that aims to establish a worldwide unified Rockwell hardness scale with metrological traceability.
- The radiometric physics Key Comparison CCPR-S2 was released by the NIST Physics Laboratory, incorporating the apertures measurements made on the M48 CMM; all of the results were consistent with the reference values to within our uncertainty.

Planned Future Accomplishments:

Successful DMP R&D projects are leading to implementation of new measurement services. Laser range calibrations are now (FY-08) a listed measurement service. Similarly, microfeature measurement capability will be listed by the end of FY-08.

Customers and Collaborators:

The identities of our measurement service customers are protected by our privacy policy. From FY-05 to FY-07, DMP provided dimensional measurement services to 360 different industrial customers and 25 government entities. DMP calibrates over 5,000 master gauges, instruments, and artifacts per year, accruing gross annual revenues of approximately $1M.

National and International Standards Project

Challenge/Problem Addressed:

Documentary standards are the metrologically deepest penetrating activity of the DMP. Standards can dictate how an entire industry specifies its products and thus how those products are tested and subsequently accepted or rejected. Well written standards provide significant positive externalities to industry. Through standardized specifications and testing, manufacturers can avoid the costs of idiosyncratic individualized testing for different customers. Users of standardized technology can readily compare products from different manufacturers to common specifications and so purchase products best suited to their needs. Standards written with unbiased expert input also protect inexperienced users by providing appropriate specifications and testing. Standardization benefits industry as whole by focusing on metrologically meaningful metrics that drive innovation.

International standards are now becoming *de facto* national standards worldwide. However, many nations strongly assert their own interests at meetings that establish standards, and discrepancies among nations can result in nontariff trade barriers that put the United States at an economic disadvantage. Identifying high value technologies with a significant U.S. industrial base is critical to prioritizing standardization topics.

Objective(s):

To gain first mover advantage in new technological fields by developing new U.S. national standards that will entrench commercial specifications and lead to international standardization along U.S. guidelines.

Accomplishments:

- National Standards on Measurement Uncertainty and Traceability (status: completed FY-07).

  Over the past eight years the DMP has led the effort to develop a complete suite of five standards to address the entire measurement uncertainty issue. The suite has a strong industrial orientation. It describes not only how to compute measurement uncertainty, but its implication in specifications, testing (accept/reject decisions), product conformance, and metrological traceability. During the past three years we have completed three of these documents (B89.7.3.2, B89.7.4.1, and B89.7.5); the entire series is described below. These standards are already being cited in industry and incorporated into other metrology standards and documents.

  ASME B89.7.3.1-2001, *Guidelines to Decision Rules in Determining Conformance to Specifications*, addresses the role of measurement uncertainty when accepting or rejecting products based on a measurement result and a product specification.

  ASME B89.7.3.2-2007, *Guidelines for the Evaluation of Dimensional Measurement Uncertainty*, provides a simplified approach (relative to the GUM) to the evaluation of dimensional measurement uncertainty.

  ASME B89.7.3.3, *Guidelines For Assessing the Reliability of Dimensional Measurement Uncertainty Statements*, examines how to resolve disagreements over the magnitude of the measurement uncertainty statement.

  ASME B89.7.4-2005, *Measurement Uncertainty And Conformance Testing: Risk Analysis*, provides guidance on the risks involved in any product accept/reject decision.

  ASME B89.7.5-2006 *Metrological Traceability of Dimensional Measurements to the SI Unit of Length*, specifies a practical interpretation of traceability and details the requirements necessary to provide evidence that traceability is satisfied.

- National & International Standards on Cartesian CMMs. (Status: ongoing, to be completed in FY-11):

  Over the past eight years the DMP has led a major effort to extensively revise both the international standard (ISO 10360 parts 2, 3, 4 and 5) and the US national standard (B89.4.1) governing the specification and testing of Cartesian CMMs. In particular, the effort will include US tests in the ISO standard and also harmonize the United States with the rest of the world. In addition to the usual benefits of standardization, this will reduce U.S. industry's costs by establishing a common set of testing procedures and artifacts. This project also returns the United States to the forefront of international standards, because the U.S. version of the ISO standard includes numerous additional topics, such as how to derate CMM specifications when the customer's facility does not comply with the CMM manufacturer's thermal environment requirements.

- National & International Standards on Surface Roughness. (Status: ongoing, to be completed in FY-10)

  Recent advancements in instrumentation to evaluate surface roughness is driving a new set of national (B89.46.1) and international (ISO TC213/WG16) standards. DMP staff chair taskforces on committees to address 3D topology measurement techniques and new algorithms that extract roughness parameters. The U.S. standard is expected to be completed in FY-09. This effort will harmonize the U.S. and ISO approaches to 3D surface texture characterization.

Planned Future Accomplishments:

- National Standard on Laser Scanning Probes. (Status: new project, to be completed in FY-11)

  Laser scanning probes are increasingly used in conjunction with Cartesian CMMs, laser trackers, and articulating arm CMMs, and as stand-alone coordinate metrology systems. These probes use a variety of technologies (including triangulation, structured light, and time of flight) to densely scan workpieces in a non-contact manner. Recently, the ASTM E57 committee initiated a standardization project for this class of optical probes. DMP is leading this taskforce along with industrial and manufacturing partners. As an entry point into this project, DMP has joined a USCAR (domestic automobile manufacturers) project to characterize flexible hoses as a function of their boundary conditions.

Customers and Collaborators:

- Brown and Sharpe Corporation (now part of Hexagon Metrology): B89.7.3 series, B89.7.4
- Hutchinson Technology Inc; B89.7.3 series, B89.7.4, B89.7.5
- The Boeing Company; B89.7.3 series
- Mitutoyo of America; B89.7.3 series, B89.7.4, B89.7.5
- US Air Force; B89.7.5
- Physikalisch-Technische Bundesanstalt: B89.7.5
- Caterpillar Corporation: B89.7.3 series B89.7.5
- University of North Carolina Charlotte: B89.4.19
- Mc Donnell Douglas Co.: B89.4.19
- Arc Second Inc.: B89.4.19
- Leica Geosystems Inc.: B89.4.19
- Faro Technologies: B89.4.19

Precision Engineering Division Program

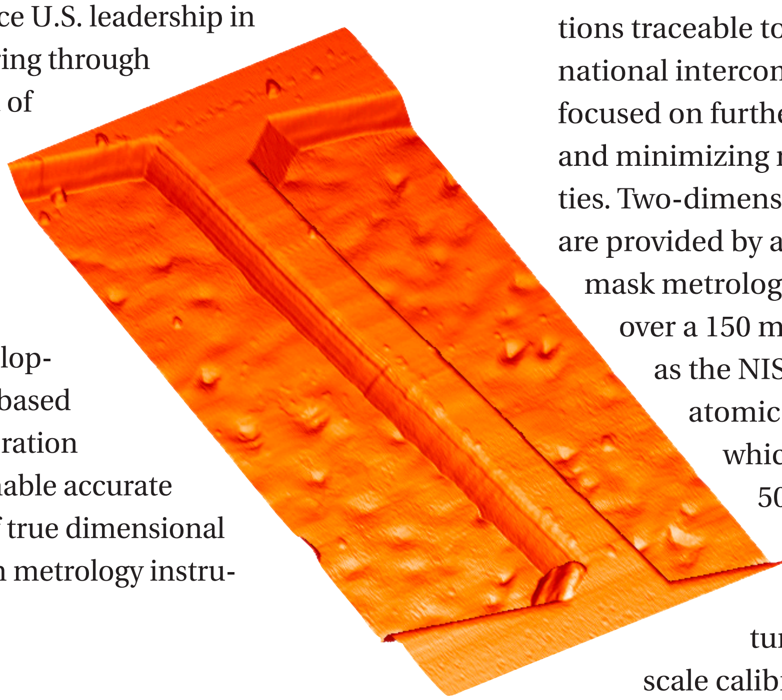
Nanomanufacturing Metrology Program

Meeting Today's Industry Needs

Annual FTEs:	11 NIST Staff
	6.5 Guest Researchers/Contractors
	17.5 total FTEs

Challenge:

To provide accurate dimensional metrology at the nanoscale level for current nanomanufacturing industries, such as semiconductor, data storage, and photonics. The challenge is to advance U.S. leadership in nanomanufacturing through the development of physical standards traceable to the International System of Units (SI) and through the development of physics-based models and calibration techniques, to enable accurate determination of true dimensional information from metrology instrumentation.



Overview

The Nanomanufacturing Metrology (NanoMet) Program aims to provide standards and measurement science to meet the current dimensional metrology needs of nanomanufacturing industries. The semiconductor manufacturing industry is a major focus. The program keeps abreast of evolving metrology needs through active interaction with industry leaders and industry consortia such as SEMATECH, as well as by reference to the International Technology Roadmap for Semiconductors (ITRS), to which the U.S. Semiconductor Industry Association (SIA) is a major contributor. The program also serves other industries, government agencies, and academic researchers that need traceable dimensional metrology at the sub-micron scale. An example is the development of traceable and repeatable metrology for bullets and casings for forensic science purposes.

The current general project areas are:

- ***Scale Metrology*** The fundamental need is for accurate scale calibration and traceability. The Linescale Interferometer provides world-class one-dimensional scale calibrations traceable to the SI as verified by international intercomparisons. Current work is focused on further increasing its reliability and minimizing measurement uncertainties. Two-dimensional scale measurements are provided by a Nikon 5i wafer and photomask metrology instrument that operates over a 150 mm by 150 mm range as well as the NIST-developed calibrated atomic force microscope (C-AFM) which operates over a 50 µm by 50 µm range.
- ***Linewidth Metrology*** For current manufacturing metrology problems, scale calibration is often just the first step. The basic need is to determine the size of physical features. In semiconductor manufacturing, this is referred to as critical dimension (CD) metrology. The central challenge is to define the position of the edge of a feature within the measuring instrument's response profile. The response profile can be sharpened by using shorter-wavelength light in optical microscopy (OM), smaller beam focus spots in scanning

electron microscopy (SEM), or sharper, better characterized tips in scanning probe microscopy (SPM) and CD atomic force microscopy (CD-AFM). Ultimately, the response profile width becomes a more and more significant fraction of the total measurement uncertainty as feature sizes continue to decrease, as is happening in semiconductor manufacturing and nano-manufacturing. Consequently, significant physics-based modeling is being under-taken to address this phenomenon and determines the response functions for the different methods. Validation of the mod-els can be accomplished only by intercom-parison between the methods. Significant modeling efforts are ongoing for OM, SEM, SPM, and CD-AFM. Standard Reference Material (SRM) calibration standards have been delivered and more are under devel-opment. We are also developing highly-engineered reference metrology instru-ments with OM, SEM, and SPM imaging probes, using interferometer-based stage motion measurements and/or mapped digital camera image capture systems.

- ***Overlay and Registration Metrology*** An additional major thrust of the program is the development of advanced techniques for overlay and registration metrology. Optical techniques are often best suited to this task. Novel overlay target structures are being patented jointly with the lead-ing industrial consortium, SEMATECH, to provide improved overlay resolution in a smaller, in-chip format of sub-resolution features. These recently developed high resolution optical overlay techniques are extensible for a number of manufacturing generations. SRMs for overlay calibration have been designed and delivered as well. The development of new target designs, instrument optimization and modeling, and calibration techniques is a continuing focus, undertaken jointly with key indus-trial partners.

Key Accomplishments and Impacts:

- Delivered SRM 5001, a 150 mm by 150 mm grid plate reference artifact. Reported measurement uncertainty is less than 30 nm with a coverage factor of two. (Nikon 5i, LSI)
- Completed experiments for next genera-tion of single crystal critical dimension reference material (SCCDRM) project. (CD-AFM)
- Delivered NIST Standard Reference Mate-rial 2059, Photomask Linewidth Standard.
- Ported SEM imaging modeling code, MONSEL, from a restricted geometry ver-sion to a general 3-D geometry version, extending the number and types of sam-ples and measurements that can benefit from the methods we have developed.

Future Directions and Plans:

The NanoMet Program is continually seek-ing new metrology opportunities to assist industry and reviewing existing projects for consistency with program objectives. An ongoing goal is to refine calibration methods and standard artifacts in order to reduce the uncer-tainty in the realization of the SI definition of the meter as it is supplied to industry. This project relies on continual improvement in instrument performance and consistency of measurements between instruments and methods.

Excellence & Leadership Recognition

Staff	Excellence & Leadership Demonstrated
Dixson, Ronald Orji, George	• 2006 Department of Commerce Bronze Medal Award for the development of the Reference Measurement System, a state of the art calibrated probe microscopy at SEMATECH, the semiconductor industry research consortium, used for pitch, height, and linewidth calibrations for the semiconductor industry.
Silver, Richard	• Elected Fellow of SPIE – The International Society for Optical Engineering, 2008
Potzick, James	• 2006 Department of Commerce Silver Medal Award for the development and certification of photmask linewidth standard reference materials and for the critical assessment and application of new optical modeling methods for the accurate determination of the true linewidth.
Villarrubia, John Postek, Michael Vladar, Andras	• Nanotech Briefs Nano 50 award for "Model-Based Library methods" in recognition of a technique that "significantly impacted or are expected to impact the state of the art in nanotechnology." Model-based metrology allows dimensional metrologists to make accurate measurements of nanometer-sized structures. 2005
Postek, Michael Villarrubia, John Vladar, Andras	• 2005 Department of Commerce Silver Medal, with Michael Postek and Andras Vladar for the NIST Model-based Metrology measurement technique and its application to industrial critical dimensional (CD) metrology.
Villarrubia, John	• Dianna Nyyssonen Metrology Best Paper for "Unbiased Estimation of Line-Edge and Line-Width Roughness," SPIE Advanced Lithography meeting, Feb. 2006

Projects

Nanomanfacturing Metrology Program

Scale Metrology Project

Challenge/Problem Addressed:

The fundamental basis for length metrology is traceability to the definition of the meter in the International System of Units (SI). The challenge is to realize this definition in practice through qualified metrology instruments and calibrated standards and reference materials that form the basis for dissemination.

This project focuses on the needs of the nanomanufacturing industry. Industry instruments to be calibrated include mask and wafer metrology microscopes, scanning electron microscopes (SEM), and atomic force microscopes (AFM).

Three instruments within the Nanomanufacturing Metrology (NanoMet) Program specifically address scale calibration. The Linescale Interferometer (LSI) provides one-dimensional scale calibrations up to one meter in length. Its performance and accuracy is validated through international comparisons, most recently the "NANO 3: Line Scale Standards" comparison, performed under the auspices of the International Bureau of Weights and Measures (BIPM). The LSI provides calibrations for customers in the nanomanufacturing industry, such as the metrology tool supplier, Nikon. It is also the traceability link for most of the other metrology instruments within the NanoMet Program.

A Nikon 5i Measuring System provides two-dimensional scale measurements applicable to photolithography masks. This instrument uses an optical microscope to locate fiducials and has laser-interferometer guided motion stages. For qualification, the scale calibration is traceable to a reference artifact measured on the LSI. Uniformity and orthogonality of the two axes are characterized through self-calibration methods, e.g., repeated measurements of the same artifact with rotations, translations, and reversal.

At the smaller length scales needed for AFM and SEM two-dimensional scale calibrations, a calibrated AFM (C-AFM) is used. The C-AFM is a custom-built instrument that has built-in metrology on all three axes of motion traceable to the SI meter through the 633 nm wavelength of a He-Ne laser. This also allows vertical scale calibrations, i.e., step height, to be provided by the C-AFM. The instrument, now in its fourth generation, provides reference measurements for commercial standards suppliers and is used to participate in international comparisons for nanometrology.

Objective(s):

- Provide accessibility to the SI unit of length to the nanomanufacturing industries, such as semiconductor manufacturing, data storage, and photonics, by means of reference metrology instruments and calibration standards that are compatible with industry metrology instrumentation.
- Push the limits of length scale measurement and identify the current limits to length scale measurement as shown by uncertainty budgets and develop new technology to reduce them.

Accomplishments:

- Delivered SRM 5001, a 150 mm by 150 mm grid plate reference artifact. Reported measurement uncertainty is less than 30 nm with a coverage factor of two. (Nikon 5i, LSI)
- Completed NIST participation in NANO 5, an international comparison of two-dimensional pitch measurements carried out under BIPM. Six measurands were reported on: *x*-axis pitch, *y*-axis pitch, and the angle of non-orthogonality on two different specimens. (C-AFM)
- Provided scale calibration for both AFM and SEM metrology that was used in the current NIST gold nanoparticle SRM. (C-AFM)
- Developed and produced RM 8820, the SEM Magnification Calibration Reference Material
- Provided measurement Services to over 45 customers over last 3 years (Line Standards 10020C–10025C) including "Golden Masters" that set the metric and traceability for many semiconductor fabs around the world.
- Designed and began commissioning new temperature measurement system for the LSI (including thermocouples in the instrument, a temperature well for the SPRT, Hart electronics, etc.) to first run in tandem with the current system then ultimately replace it.

Planned Future Accomplishments:

- Decrease the stated uncertainty of the NIST LSI – already one of the best instruments in the world – by 30% or more to maintain leadership in lengthscale measurement. (Complete by 4th Quarter 2011
- Advance the state of the art in line centering technology for the LSI by implementing high-Q scanning and lock-in amplification technology, unique to NIST, using advanced digital electronics. This will make the measurement more accurate and more accessible to other laboratories. (Complete by 1st Quarter 2011)
- Develop a wafer grid plate measuring capability and produce a reference standard. This artifact will support industry efforts to map projection field distortions. (Complete by 2nd Quarter 2012)
- Produce and certify an SEM magnification standard reference material. This is crucial for calibration of the scale of metrology SEMs. (Complete by 3rd Quarter 2010)
- Perform step height measurements with the C-AFM on a new set of internal master samples for a major commercial supplier of standards. (Complete by 3rd Quarter 2010)
- Participate in new international comparison of one-dimensional pitch measurements led by National Research Council Canada using the C-AFM. (NIST contribution complete by 3rd Quarter 2011)

Customers and Collaborators:

- SEMATECH
- VLSI Standards (customer)
- Intel, Nikon, Dupont/Toppan Photomask, Los Alamos, NASA, Boeing
- Northrop Grumman Space, Pratt & Whitney, Lockheed Martin, Corning, US DOE, Mitutoyo America, ALCOA, US Customs Lab, IBM, L.S. Starret, EuroMet (customers)
- University of North Carolina at Charlotte; LSI development collaborator

Nanomanfacturing Metrology Program

Linewidth Metrology Project

Challenge/Problem Addressed:

Measurement of linewidth or critical dimension (CD) continues to be one of the most fundamental dimensional metrology needs in the semiconductor and other nanomanufacturing industries. The demand is so complex and ubiquitous that no single metrology technique can provide the entire solution. At this scale, the largest component of measurement uncertainty is usually associated with the interaction of the specimen with the probe, which might be a mechanical stylus, photons, or a beam of charged particles. The probe interacts with the sample over some characteristic distance, dictated by its size or by diffraction or scattering. The image of any sharp edge is broadened by this interaction. The true edge position might be anywhere within the broadened signal. The result is linewidth measurement uncertainty comparable to the broadening—often tens of nanometers or more. In order to reduce this uncertainty, new techniques with sharper edge profiles can be adopted, or existing techniques can be refined. But ultimately, no method is able to achieve the required resolution, and it becomes necessary to assign the physical edge to a definite position within the broadened signal. This in turn requires understanding and modeling the physical process that produces the broadening so that it can be compensated.

Three major techniques are used within the Linewidth Metrology Project (LMP), critical-dimension AFM (CD-AFM), SEM, and optical microscopy. CD-AFM reference metrology presently offers the most straightforward and highest resolution traceability path for the physical linewidth determination, and is a leading source of reference metrology. However, CD-AFM also has some major disadvantages, including much lower throughput than SEM and optical metrology methods. A reference measurement system (RMS) based on CD-AFMs has been established at both NIST and SEMATECH. Both of these tools were calibrated using NIST methodologies, standards, and measurements on other NIST instruments. Tip widths with standard uncertainties less than 1 nm are achieved through reference to the NIST-developed single crystal critical dimension reference material (SCCDRM). Modeling of the AFM imaging process is also important. Techniques developed by NIST in the 1990's for reconstruction of tip shape from calibration images have now been expanded to include applicability to undercut tips and samples.

In the semiconductor manufacturing industry, routine linewidths for process monitoring are measured using CD-SEMs. NIST is developing a reference SEM for calibration of transfer artifacts that are measured using the same imaging physics. The metrology for this reference instrument is based on a laser interferometer stage with sub-nanometer resolution. Of equal or greater importance, however, is NIST's work on SEM image modeling. Monte Carlo simulations of the beam-specimen interactions determine the instrument response profile from various line-edge shapes. To quickly solve the intransigent inverse problem in a production setting—that is, determining the line-edge shape from the image intensity profile—a library of images is modeled that can be quickly scanned and interpolated for the best match. This is known as the model-based library (MBL) method

For photomask linewidth measurements, transmission optical UV microscopy is the ideal technique, because transmission imaging produces relatively simple high contrast images with a well-defined baseline. Also, transmission microscopy morphologically emulates the photomask application in the wafer exposure process. The NIST scanning UV microscope uses on-axis sampling to reduce aberration and distortion effects. The position of the scanning stage is measured by a laser interferometer. Accurate physics-based modeling is necessary to deduce the object dimensions from the microscope image. Image modeling also extends the limits of optical metrology to feature sizes well below the wavelength of light used, as demonstrated by Dianna Nyyssonen at NIST in the 1980s.

Objective(s):

- Develop fully characterized metrology instruments with state-of-the-art uncertainties for linewidth measurements. These instruments should ideally use the same probes (light, particle beam, mechanical tip) that industry uses, so that the strengths and limitations of each method can be understood and exploited.
- Develop accurate physics-based models of the probe-specimen interaction and image forming process so that the true linewidth, with an accurate estimate of uncertainty, can be determined from the data acquired from linewidth measuring instruments.
- Perform inter-method comparisons for the validation of the respective instruments and models.

Accomplishments:

- Completed experiments for next generation of single crystal critical dimension reference material (SCCDRM) project. (CD-AFM)
- Delivered NIST Standard Reference Material 2059, Photomask Linewidth Standard.
- Validated and compared different methods of solving Maxwell's equations for optical image modeling, using nominal but realistic parameters.
- Completed testing of Model-based library method for CD-SEM, allowing application of instrument models to metrology.
- Ported SEM imaging modeling code, MONSEL, from a restricted geometry version to a general 3-D geometry version, extending the number and types of samples and measurements that can benefit from the methods we have developed.
- Extended SPM modeling dilation (image simulation) and erosion (sample or tip reconstruction) methods to general 3-D objects, including reentrant or undercut objects. Results of these studies, applicable to CD-AFM, were published in Ultramicroscopy.
- Collaborated with industry users of SCCDRM at IBM and Intel to minimize application uncertainties in the calibration of CD-AFM tip width and step height.
- Completed a new transmission electron microscope (TEM) transfer experiment, allowing a comparison of two methods of TEM reference metrology, high resolution TEM (HRTEM) and high-angle annular dark-field scanning TEM (HAADF-STEM).

- Collaborated with University of Edinburgh on mask metrology, publishing a comparison of NIST AFM reference measurements obtained by optical and electrical methods. (CD-AFM)
- Moved the UV Microscope into a new laboratory in the Advanced Metrology Laboratory, where ambient vibration and temperature variations are smaller than in its previous home. The largely rebuilt system and will soon be operational again. A relatively clean environment has been established around the UV microscope, and an improved specimen stage with a greater range of motion allows access to the entire quality area of a 150 mm (6 inch) photomask and gives better motion control.
- Modeled SEM beam shape effects (with Hitachi guest researcher, who has taken copies of our modeling codes back to Hitachi).
- Proposed and promoted at industry meetings an improved unbiased metric for linewidth roughness.
- Improved some of the physics employed by our SEM models, in particular the barrier penetration model (how electrons change energy and direction when they cross an interface between materials) and the stopping power model (the rate at which electrons lose energy in materials)

Planned Future Accomplishments:

- Improve our model of secondary electron generation. The new model will include many-body effects (e.g., screening) and exhibit better agreement with NIST's database of inelastic mean free paths (standard reference database 71). (Completion by 1st Quarter 2011)
- Extend our blind reconstruction method to dexel-represented objects. This is important because of the difficulty of obtaining accurately known tip characterizers. (Completion by 3rd Quarter 2011)
- Serve as the pilot laboratory for a preliminary key comparison of the nanoscale linewidth measurement capabilities of national measurement institutes around the world, sponsored by the *Bureau International des Poids et Mesures* (BIPM) in Paris. (Begin by 4th Quarter 2008; key comparison expected to run through 4th Quarter 2012)
- Use the CD-AFM to evaluate prototype polysilicon linewidth standards, and perform new linewidth measurements of SRM 2059 and the photomask that will be used for the BIPM intercomparison. (Completion by 4th Quarter 2009)
- Evaluate uniformity of new SCCDRM prototype specimens during CY08.
- Incorporate a gas-scattering model into JMONSEL that will allow us to model imaging in variable pressure SEMs. (These instruments employ a low pressure ambient gas, some of which becomes ionized and neutralizes charges that accumulate on the sample surface. The new modeling capability is intended to permit measurements on insulating samples.)
- Collaborate with researchers at the Illinois Institute of Technology to develop methods to speed up these calculations through hardware acceleration, using the computer's graphics processor.
- Work with representatives of the photomask industry and the SEMATECH Mask Advisory Steering Council to determine their requirements in the next generation

NIST photomask linewidth standard. This standard will likely contain, in addition to isolated lines, spaces, and pitch patterns from approximately100 nm wide, a set of iso/dense line/space arrays as well as large scale 2-dimensional features in response to requests from the machine vision industry. Improve optical image modeling capability to better agree with real microscope images. Our AFM photomask measurements will then be used for confirmation of optical measurements instead of as reference measurements. In addition, we will incorporate the new specimen stage into the UV Microscope and make many other improvements.

Customers and Collaborators:

- NuFlare, e-beam writer manufacturer
- Hitachi
- Illinois Institute of Technology
- Veeco Instruments modeling.
- SEMATECH
- VLSI Standards
- IBM
- Intel
- SEMI International Standards

Nanomanfacturing Metrology Program

Overlay and Registration Metrology Project

Challenge/Problem Addressed:

A significant challenge for the semiconductor manufacturing industry is to develop advanced metrology techniques for overlay and registration. The recent advance of double patterning techniques, which directly couple overlay and line measurements, has made this metrology more urgent still.

Currently, optical techniques are most widely used for this kind of metrology, and recent advances in this high resolution optical techniques have made novel overlay target designs possible. A technical collaboration between NIST and SEMATECH has led to the patenting of new overlay structures. Calibrated overlay SRMs wafers designed jointly with the industry are now available. The development of new target designs, instrument optimization and modeling, and calibration techniques is a continuing task.

The overlay metrology project is an internationally recognized effort with the goal of developing techniques and targets for improved overlay metrology, primarily for the semiconductor industry. The project has relied on close collaboration with industry leaders in optical tool development and users of overlay metrology tool sets as well as with SEMATECH. Results include the adoption of several overlay measurement techniques and calibration strategies by industry as well as the new Overlay SRM.

Numerous technical accomplishments include CCD mapping methods, optical reversal methods, advanced optics simulation, SRMs 5000 and 5001, sub-50 nm optical imaging, engineered target design, and recently the scatterfield optical technique. The overlay project has developed into a leading international effort in high-resolution optical imaging techniques for overlay metrology.

The project hardware utilizes three optical systems built from the ground up, including a system that combines confocal optical microscopy and interferometry with advanced high resolution CCD acquisition. This system was the primary optical tool in the NIST overlay metrology project and has generated numerous publications on optical microscope design, automated edge detection and focus methods, interferometer and optical system alignment, and self calibration methods applied to overlay measurements and standards.

This project has also been a leader in the comprehensive evaluation of edge detection methods and automated focus algorithms. These methods have been adopted by leading industrial users as well as the SEMATECH overlay metrology advisory group, and have led to the development of "self-calibration" methods applicable to overlay metrology systems. This methodology has shown significant quantitative performance improvements in optical systems and charge-coupled camera (CCD) data acquisition systems that are widely used in the industry. The methods are now being adopted by industry tool manufacturers, with significant long range impact on tool performance.

The optics project has the lead role in the development of two Standard Reference Materials. SRM 5000, a comprehensive set of overlay target standards on 203 mm (8 inch) wafers developed in close contact with industry representatives, is now available to the semiconductor industry. SRM 5001, also developed in close collaboration with industry, has applied a novel approach to the production of 150 mm (6 inch) photomask standards, calibrated on the NIST Nikon 5i/linescale interferometer metrology tools. Several of these standards have been fabricated, calibrated and sold by NIST's SRM office – a demonstration of industry's interest in these artifacts. The SRM 5000 overlay artifact has been used to evaluate optical tool performance and improve tool set performance at leading semiconductor manufacturers, and has also served as the artifact for the development of reference metrology for overlay at SEMATECH.

Objective(s):

- Fully characterize and develop new metrology instruments with state-of-the-art uncertainties for overlay measurements. Multiple technologies are now being implemented using different probe technologies such as light, particle beam, and mechanical tips.
- Develop physics-based models which accurately and comprehensively model the sample probe interactions and the instrumentation. Model the image forming process accurately for uncertainty determination.
- Develop reference metrology for the validation and development of physical models and multiple technique metrology.

Accomplishments:

- Optics project staff led the design for the first overlay metrology advisory group (OMAG) reticle set, in collaboration with SEMATECH and OMAG.
- Key new designs fabricated with the OMAG 4 reticle set and AMAG 5 reticle set that were used in the fabrication of the new overlay SRM.
- Calibrated overlay wafers used by leading semiconductor manufacturers and provided the central traceability measurement for SEMATECH overlay reference metrology effort.
- Several of the new overlay techniques developed and published by this NIST project have been adopted by leading optical tool manufacturers.

Planned Future Accomplishments:

- Work closely with SEMATECH and the industry to implement reference metrology and validate optical overlay measurements using optical, particle beam, and AFM probes. (3rd Quarter 2010)
- Identify and calibrate the next generation of overlay wafers standards. Quantitatively evaluate the scatterfield targets for use as overlay standards. (1st Quarter 2009)
- Model and evaluate the new super-target overlay designs in collaboration with SEMATECH. Fabricate wafers for use by the industry and test target performance. (4th Quarter 2008)
- Develop and make available to the industry optical techniques for use in overlay metrology. This includes optical alignment and characterization techniques as well as improved optical configurations. (2nd Quarter 2011)

Customers and Collaborators:

- Collaborating with several leading optical metrology tool manufacturers.
- AMD
- SEMATECH, ISMI
- IBM
- Intel
- SEMI International Standards

Precision Engineering Division Program

Next-Generation Nanometrology

Solving Industry Needs of Tomorrow

Annual FTEs:	9.5 NIST Staff
	8.5 Guest Researchers/Contractors
	18 total FTEs

Challenge:

To develop or create new measurement techniques and standards to meet the needs of next-generation advanced manufacturing, which will rely on nanometer scale materials and technologies. The needs for measurement and characterization of new sample structures and characteristics far exceed the capabilities of current measurement science. Anticipated advances in emerging U.S. nanotechnology industries will require revolutionary metrology with higher resolution and accuracy than has previously been envisioned.

Overview

The Next-Generation Nanometrology (NextGen) Program seeks to advance the science of dimensional metrology in order to achieve higher-resolution measurements of increasingly complex samples. This essential research will provide measurement technology in support of emerging U.S nanotechnology industries. The program designs, invents, and develops new metrology instruments for this purpose. Preparation methods for samples and have also become vital research and development challenges, because at these length scales, the sample and the measuring instrument must be treated as integral metrology system. An additional effort is focused on particular challenges presented by certain specific but important advanced measurement needs.

The current general project areas are:

- ***Advanced Optics.*** Although optical microscopy and metrology is a mature field, it continues to see exciting new developments. The NextGen Program has patented and is developing a new technique called scatterfield microscopy that straddles the boundary between optical microscopy (OM) and scatterometry. Significant dimensional information can be extracted from far sub-wavelength features through the use of structured illumination, engineered targets, and physics-based modeling of the instrument and the imaging process. The program is also developing an advanced 193 nm illumination metrology microscope and exploring defect metrology using these methods.

- ***Advanced Particle Beam Metrology.*** The NextGen Program is developing new techniques in various forms of particle beam metrology. In scanning electron microscopy (SEM), those advances include the use of super-sharp emitter tips; active vibration-canceling control of scanned stages; development of standardized resolution-characterization targets and techniques; development of environmental-SEM methods for challenging sample types; and exploration of high-resolution three-dimensional imaging methods. The program is studying the applicability of a dual beam system for metrology problems. The most exciting new advance is the development of a scanning helium ion microscope. The extreme intensity of the single-atom source and the much smaller beam/sample interaction volume permit this technique to obtain higher resolution images than SEM can ever achieve. The different interaction physics of ions rather than electrons also leads to a complementary image contrast mechanism, and holds the potential for nanoscale resolution chemical mapping through energy analysis of emitted and backscattered particles.
- ***Nanoparticle and Materials Metrology.*** The largest existing market for nanotechnology centers on production and use of nanoparticles and nanocomposites. The NextGen Program is developing techniques for fixing soft, bio-mimetic nanoparticles on surfaces without distorting or denaturing them, so that they can be examined with atomic force microscopy (AFM). Medical applications range from imaging contrast agents to therapeutic cancer treatments. Advances in optical tweezers (OT) technology will allow manipulation of particles with sizes reaching down to the nanoscale, giving OT promise as a nanopositioning and nanoassembly tool. Carbon nanotubes, fuel cell membranes, and cellulose single crystals are among the challenging materials for which advanced SEM, OM, and AFM techniques are being investigated.
- ***Atom-based Dimensional Metrology.*** The ultimate limit of nanoscale length metrology is to develop intrinsic calibration standards, where the dimensions are based on integral numbers of atom spacings within an ordered, crystalline lattice. Step height standards have been delivered; linewidth and pitch standards are under development. An ultra-high vacuum scanning tunneling microscope (UHV-STM) plays the major role in these efforts. Validation of atomic lattice spacings as a ruler is being accomplished by comparison with interferometric length measurements in the Molecular Measuring Machine. Extensive work on the development and characterization of STM tips has been an important research area for nanolithography and nanometrology, providing the needed ability to specifically address and modify individual atomic sites.

Key Accomplishments and Impacts:

- The scatterfield microscopy research effort was recognized with the highly respected Nano 50 award for its advances in the new optical technique. Capabilities based on this technique are now being incorporated into commercial products.

- Demonstrated optimized methods for immobilizing intact liposome-based nanoparticle delivery systems (NDS) for scanning probe microscope (SPM) imaging and characterization under fluid conditions. This is a key initial result for enabling physical-property-based production control as opposed to cost-prohibitive biological assays.
- Acquired the first-in-the-world helium ion microscope (HeIM) and began to examine its performance and its capabilities for the metrology of nanoscale objects and features. This is an exciting new imaging technique that has generated significant interest in the nanotechnology community, and may be critical for next-generation semiconductor manufacturing metrology.

Future Directions and Plans:

The NextGen Program is continually seeking new metrology opportunities. The key objective is the pursuit of new dimensional metrology methods, and the application of these advanced measurement techniques to new or emerging measurands that have high value for technological innovation. Cost of ownership and throughput are important considerations as the program seeks to develop and support industrially relevant measurement solutions.

Excellence & Leadership Recognition

Staff	Excellence & Leadership Demonstrated
Silver, Richard Attota, Ravikirran Barnes, Bryan Jun, Jay Stocker, Michael	• Nano 50 Award for Scatterfield Optical Microscopy in the Technologies category for "technology breakthroughs that have, or are expected to have, a significant impact in one or more application areas," 2007
Postek, Michael	• 2007 Nano 50 Award - Nanotech Brief's Nano 50 Awards in the Innovator category "for pioneering achievements in scanning electron microscope imaging and performance improvements and in fostering accurate dimensional metrology and national standards for nanotechnology and nanomanufacturing."
Postek, Michael Villarrubia, John Vladar, Andras	• 2005 Department of Commerce Silver Medal, with John Villarrubia and Andras Vladar for the NIST Model-based Metrology measurement technique and its application to industrial CD metrology.

Projects

Next-Generation Nanometrology Program

Advanced Optics Project

Challenge/Problem Addressed:

The challenge is to advance the state-of-the-art of optical techniques for application to nanometrology problems. We are seeking to obtain dimensional information a factor of ten or more below the wavelength of the light used.

Although optics-based microscopy and metrology are mature fields, exciting new developments continue to arise. The NextGen Program has patented and is developing a new technique called scatterfield microscopy that combines the best features of optical microscopy (OM) and scatterometry. Significant dimensional information with sensitivity to features 1/20th the measurement wavelength can be extracted from the analysis of scattered light profiles through the use of structured illumination, engineered targets, and physics-based image process modeling. Correlated methods have also recently been applied to defect metrology. The project has produced several high impact results for the optical metrology community and the semiconductor industry.

This research effort has led to a number of invention disclosures, patent applications, and publications in leading international journals. Scatterfield techniques are now being developed in other leading optical laboratories and by optical metrology tool manufacturers. Working closely with industrial metrology tool suppliers, we are now implementing these concepts of engineered illumination and target design for super-resolution overlay metrology. Similar success is being achieved in applications of the technique to defect metrology and critical dimension process control and metrology.

This research has been presented at several leading optical technology forums and has helped advance the understanding of high resolution optical measurement applications for semiconductor and nanotechnology manufacturing. This work has demonstrated that the ultimate limits of optical based imaging systems lie far beyond the current state of the art. We have shown that our optical measurement techniques can extend to features 10 nm or smaller in size and that with the appropriate set of techniques could also image very dense features.

Objective(s):

- Develop leading edge optical techniques using the new scatterfield technology. Develop and transfer to industry new optical characterization approaches and methods for optical aberration and illumination control using structured illumination.
- Develop nanometer scale sensitivity using advanced optics techniques for use in next generation linewidth, overlay, and defect metrology. Implement the 193 nm scatterfield optical microscope and evaluate its performance for next generation process control applications.
- Develop advanced optical modeling and instrumentation techniques that can accurately measure sub-40 nanometer sized features or particles for application to the metrology of nanoscale composites and nanotechnology related structures needing high throughput and high resolution manufacturing process control.
- Explore applications of high throughput optical metrology for new applications such as fuel cells, large scale nanoparticles, and patterned defect metrology.

Accomplishments:

- The scatterfield microscopy research effort was recognized with the highly respected Nano 50 award for its advances in the new optical technique. The citation was for the development of a new and revolutionary measurement technique capable of extending conventional optical metrology instrumentation well beyond the current limits. Capabilities based on this technique are now being incorporated into commercial products.
- Patent Applied for on new "Zeroth Order Imaging" method. This new approach combines standard edge-based imaging with signature based methods being developed as part of the scatterfield optical competence project. The key to this approach is to image only the zero order scattered specular reflected light as a function of illumination angle. Features as small as 20 nm in size with a pitch or spacing of 50 nm can be imaged.
- Patent Applied for on new "Super resolution overlay targets". Joint NIST/SEMATECH patent has been formally applied for new super-resolution overlay target. Leading optical instrument manufacturers are very interested. These targets have the potential to change the target designs and methodology widely used by industry.
- The new 365 nm illumination scatterfield microscope has been completed. This new tool is being developed from the ground up at NIST specifically for the purpose of using illumination engineering and structured target designs. The centerpiece of the microscope is the open architecture of the illumination path, which features a breadboard-based design. This design will allow us to investigate quickly methods for engineering the illumination to probe the scattered field.
- Obtained SEMATECH contract for an investigation to the fundamental limits of optical critical dimension measurement techniques. Although largely focused on scatterometry techniques, the world-class optical modeling capabilities at NIST are now being applied to scatterfield and scatterometry optical methods.
- A recent document titled "Summary of 2006 NIST/SEMATECH Studies of Next Generation Overlay Metrology," prepared and authored by SEMATECH, has highlighted a number of recent advances by staff in the scatterfield competence project. The report goes into detail on collaborations between NIST optical researchers, SEMATECH staff, and the semiconductor industry in the overlay metrology area.

Planned Future Accomplishments:

- Complete the 193 nm optical tool platform. Demonstrate full operation in a cleanroom environment with controlled temperature. (Complete by 2nd Quarter 2009)
- Develop test patterns based on optical superstructures with applications in nanotechnology process control. (Complete by 4th Quarter 2009)
- Demonstrate the highest resolution optical measurements using scanned aperture methods for dimensional metrology of sub-15 nm sized features with measurement sensitivity significantly better than 1 nm. (Complete by 4th Quarter 2010)
- Test and implement a new class of structured illumination using automated, model-based pupil engineering with LCD or DLP back focal plane engineered illumination. (Complete by 4th Quarter 2011)

Customers and Collaborators:

- KLA-Tencor, Nanometrics and Applied Materials
- SEMATECH
- IBM, Intel, AMD, TI

Next-Generation Nanometrology Program

Advanced Particle Beam Metrology Project

Challenge/Problem Addressed:

Continuing progress in nanotechnology requires parallel improvement in measurement resolution and greater versatility in the quantities – or measurands – that can be examined. The challenge is to create new strategies and measurement techniques that go beyond those currently available. This project focuses on this challenge within the realm of particle beam imaging.

Scanning electron microscopy (SEM) is one of the workhorse techniques for imaging and characterization for nanotechnology. We are working to develop advanced methods to enhance its capabilities. We are developing sample manipulation stages with high-speed, sub-nanometer-resolution laser interferometer measurement that allow active monitoring or control of stage vibration, a major contributor to image blurring. Research is also being done on the development of super-tips for the electron emitters, to make a brighter source that will increase resolution. Significant contributions to the advancement of SEM have also come through the development of resolution standards and resolution measurement methods, which places the characterization of this most critical of SEM performance metrics on a solid metrological basis and allows objective comparison between instruments and operating conditions. New SEM tools under development include an environmental SEM (e-SEM) that allows imaging of uncoated insulating materials. We are also developing the metrology applications of a dual beam system that has a focused ion beam (FIB) for ion milling along with an SEM for concurrent imaging. This instrument allows the localized, in-situ, cross-sectioning of features of interest for 3-dimensional metrology.

The most exciting recent advance in particle beam metrology is the development of a new technique called scanning helium ion microscopy (HeIM), which is analogous SEM but uses a probing beam of He^{+} ions instead of electrons. MEL owns the world's first commercial HeIM and is working closely with the manufacturer to understand the science of He^{+} ion imaging and to optimize the instrument's metrological capabilities. HeIM results so far show competitive or better imaging capabilities than the most advanced SEMs. The sample interaction volume for He^{+} ions is significantly smaller than for electrons, leading to higher resolution. The interaction physics is also different, leading to a different contrast mechanism and the extraction of complementary information.

Objective(s):

- Develop instrumental improvements for particle-beam microscopy to enable higher resolution images with less noise.
- Develop standard methods, standard data sets, and calibration artifacts for quantifying the imaging resolution of particle beam microscopes.
- Explore the range of measurands that might be accessible with a He^{+} ion beam scanning microscope, such as nanometer-scale compositional analysis.

Accomplishments:

- Developed a SEM resolution reference material and associated algorithms for the objective characterization of SEM performance. This will allow a fair comparison between competing instruments and operating conditions.
- Developed reference simulated image data sets with known added noise types for the objective characterization and comparison of image resolution software.
- Demonstrated the acquisition of high speed stage position data correlated with secondary electron intensity. This allows sorting of the image data based on actual stage position, leading to a significant reduction in image noise.
- Developed a method to measure the 3D electron beam profile in an SEM by using thin layers of photoresist on silicon chips and exposing them using various focus settings, irradiation time, and beam current. This provides a solid experimental basis to validate the modeling of the interaction volume for electron beam exposure of specimens, leading to more accurate metrology.
- Developed new SEM image modeling software capable of performing simulations for fully 3-dimensional samples. This capability is critical for the new generation of semiconductor devices being developed in industry.

Planned Future Accomplishments:

- Reduce vibration noise effects on SEM imaging by developing real-time image data sorting capability based on the vibration data acquired by the laser stage. (Complete by 4th Quarter 2010)
- Characterize the sensitivity of the HeIM for high-resolution metrology of linewidths in silicon, photoresist, and mask materials. (Complete by 4th Quarter 2009)
- Model ion transport, ion energy loss, and secondary electron production by ions in samples. This will provide us with a metrology capability for accurate measurements with the helium ion microscope, which has the promise of higher spatial resolution than the SEM and therefore much promise as a CD metrology tool. (Complete by 4th Quarter 2013) (Initial model by 4th Quarter 2011)

Customers and Collaborators:

- Zeiss
- FEI
- Hitachi
- E. Fjeld

Next-Generation Nanometrology Program

Nanoparticle and Materials Metrology Project

Challenge/Problem Addressed:

Nanoparticles and materials containing nanoparticles represent by far the largest fraction of the current nanotechnology product market. Yet the methods available for characterization and dimensional measurement of these products are inadequate for efficient development and cost effective production. The challenge is to find reliable, repeatable, and cost effective methods for measuring nanoparticles and nanoparticle-based materials, and to provide the infrastructure needed for measurement traceability. Special challenges include the imaging of soft, deformable materials, and materials with limited sample homogeneity.

For nanoparticle metrology, we are developing measurement approaches that address the challenges of measuring soft particles. For medical applications, for example, we are developing a systematic methodology for directly determining physical and biological information about nanoparticle delivery systems (NDS) from image data. This approach uses fluid scanning probe microscopy (SPM) as a versatile tool for high-resolution imaging of biological systems in solution. Fluid SPM refers to the operation of a scanning probe microscope under solution conditions. It includes the development of specialized techniques for sample preparation, stable feedback operation of an oscillating probe tip in solution, and quantitative force measurements of chemical, mechanical, electrical, hydrodynamic, and magnetic interactions of the molecular constituents of an NDS. Appropriate preparation and measurement techniques for physical characterization of nanobioparticles have been developed in parallel with *in-vitro* and *in-vivo* efficacy studies in order to facilitate drug discovery and development. These studies were done in collaboration with the Georgetown University Medical Center (GUMC).

We are developing an optical tweezers system for the trapping and manipulation of nanoparticles. This will make possible the controlled placement of nanoparticles at predefined locations on substrates. Simultaneous trapping of multiple particles and control of the orientation of non-symmetric nanoparticles have been demonstrated. This instrument will be exercised as a test-bed for nanomanufacturing and assembly. More immediately, the controlled placement of nanoparticles will permit an ordered-array standard reference material (SRM) for nanoparticle dimensions.

The applicability of SEM, SPM and advanced optical methods for the characterization of several advanced materials, including carbon nanotubes, cellulose single crystals, and fuel cell membranes is also being examined.

Objective(s):

- Develop sample preparation techniques and instrumental improvements for accurate nanoparticle characterization and metrology.
- Develop standard methods, standard data sets, and calibration artifacts for quantifying the imaging and metrology of nanoparticles.

Accomplishments:

- Demonstrated optimized methods for immobilizing intact liposome-based nanoparticle delivery systems (NDS) for scanning probe microscope (SPM) imaging and characterization under fluid conditions. This is a key initial result for enabling physical-property-based production control as opposed to cost-prohibitive biological assays.
- Fabricated and evaluated improved magnetic coatings for fluid and dry magnetic force microscopy (MFM) for characterizing dispersed and aggregated contrast enhancement agents for magnetic resonance imaging (MRI).
- Investigated quantitative particle size analysis of gold reference nanoparticles, NDS, and superparamagnetic iron oxide nanoparticles (SPIOs) from SPM images, and compared with results from dynamic light scattering (DLS).
- Measured the size and shape of the soon-to-be-released Colloidal Gold Nano Particle Reference Materials (RM 8011, RM 8012 and RM 8013) using a reference SEM.
- Demonstrated simultaneous optical trapping and individual manipulation of multiple particles.
- Measured carbon nanotubes samples with SEM for use as a carbon nanotubes (CNT) reference material.

Planned Future Accomplishments:

- Fully implement a new technique, the rotating disk method for measuring surface zeta potentials of substrates, in order to achieve optimization of nonspecific surface binding for nanoparticle delivery systems, an essential first step in high-magnification SPM characterization. (Complete by 4th Quarter 2011)
- Apply novel preparation methods to superparamagnetic iron oxide (SPIO) nanoparticles for thorough magnetic-based characterization of the particles under dispersed and aggregated conditions. SPIOs have become a significant contrast agent for biomedical research. (Complete by 4th Quarter 2010)
- Demonstrate active, high-bandwidth control of optical trap intensity and position to enable the trapping of 200 nm diameter or smaller nanoparticles. (Complete by 4th Quarter 2011)
- Demonstrate the controlled placement of nanoparticles on a substrate for the development of a structured nanoparticle dimensional reference standard. (Complete by 4th Quarter 2010)

Customers and Collaborators:

- Georgetown University Medical Center (GUMC)
- University of Akron
- National Cancer Institute (NCI) Nanotechnology Characterization Laboratory (NCL)

Next-Generation Nanometrology Program

Atom-based Dimensional Metrology Project

Challenge/Problem Addressed:

The ultimate future for nanoscale dimensional metrology is to develop intrinsic standards based on integral numbers of atom spacings within an ordered, crystalline lattice. Single-atom step height standards have been fabricated and calibrated; linewidth and pitch standards are under development. Instrumentation requirements are very challenging, typically requiring an ultra-high vacuum environment scanning tunneling microscopes (UHV-STM). STM tip creation technology is an important aspect of this work, since nanolithography and nanometrology instruments must routinely operate with atomic-dimension resolution.

In this work we are developing a new, comprehensive approach to dimensional metrology using the atom spacings of a crystal as the underlying “ruler” or scale. Based on this metric, larger scale features are etched in the surface to serve as critical dimension or pitch references for instruments having less-than-atomic resolution.

This project has produced several important technical results, some of which have recently been published in Applied Physics Letters, Optical Engineering, and the Journal of Chemical Physics. Technical outputs include 20 pm resolution interferometry, chemically-prepared atomically-flat silicon substrates, atomic lattice-based metrology methods, 10 nm lithography, field-ion/field-electron microscope (FIFEM) and STM tip development, silicon step-flow dynamics simulations, and nanometrology test target fabrication.

Two complex multi chamber vacuum STM imaging facilities are used in this effort. The first system is a five chamber ultra high vacuum (UHV) facility regularly capable of producing 133 x 10^{-10} Pa (1 x 10^{-10} torr) base pressures, along with vibration isolation that yields a sub-angstrom noise floor. The other system has an FIFEM, which is used to image scanned probe tips on the atomic scale; this has become an essential tool for atomic resolution work as well as more recent linewidth metrology work. This system also has an STM equipped with UHV interferometry in the first application of a direct atomic imaging system with interferometry.

A second aspect of this project is the continued development of improved nanofabrication methods using the STM. A key focus in this work is the use of improved wet chemistry methods for etching and hydrogen termination of silicon substrates, hard etch mask formation using the STM, and their subsequent reactive ion etching. This research involves the writing of features on silicon substrates in hydrogen terminated substrates. The removal of hydrogen atoms and exploration of ways to improve and reduce the feature size is crucial to advancing this nanofabrication process. The hydrogen terminated written features are then processed with our newly developed reactive ion etching (RIE) process.

The project is investigating new methods for high resolution STM imaging using alternative tip materials. We have used the FIFEM to image tungsten STM tips (field emitters) and have also subsequently attached nanotubes to them.

Objective(s):

- Develop atom-based fabrication techniques for the sub-5 nm to atomic scale critical dimension domain. Use the hard etch mask oxidation technique with scanning tunneling microscopy on Si (111) and Si (100) surfaces.
- Evaluate new tip technologies for robustness based FIFEM and atomic imaging capabilities. Work closely with industry and DARPA partners to obtain state-of-the-art tips and evaluate their use with our industrial and university partners.
- Develop specific preparation and imaging requirements to determine dimensions based on the crystal lattice. Implement atom-based dimensional metrology techniques directly linked to the crystal lattice. These will be developed using STM, AFM, and transmission electron microscope (TEM) techniques as appropriate.

Accomplishments:

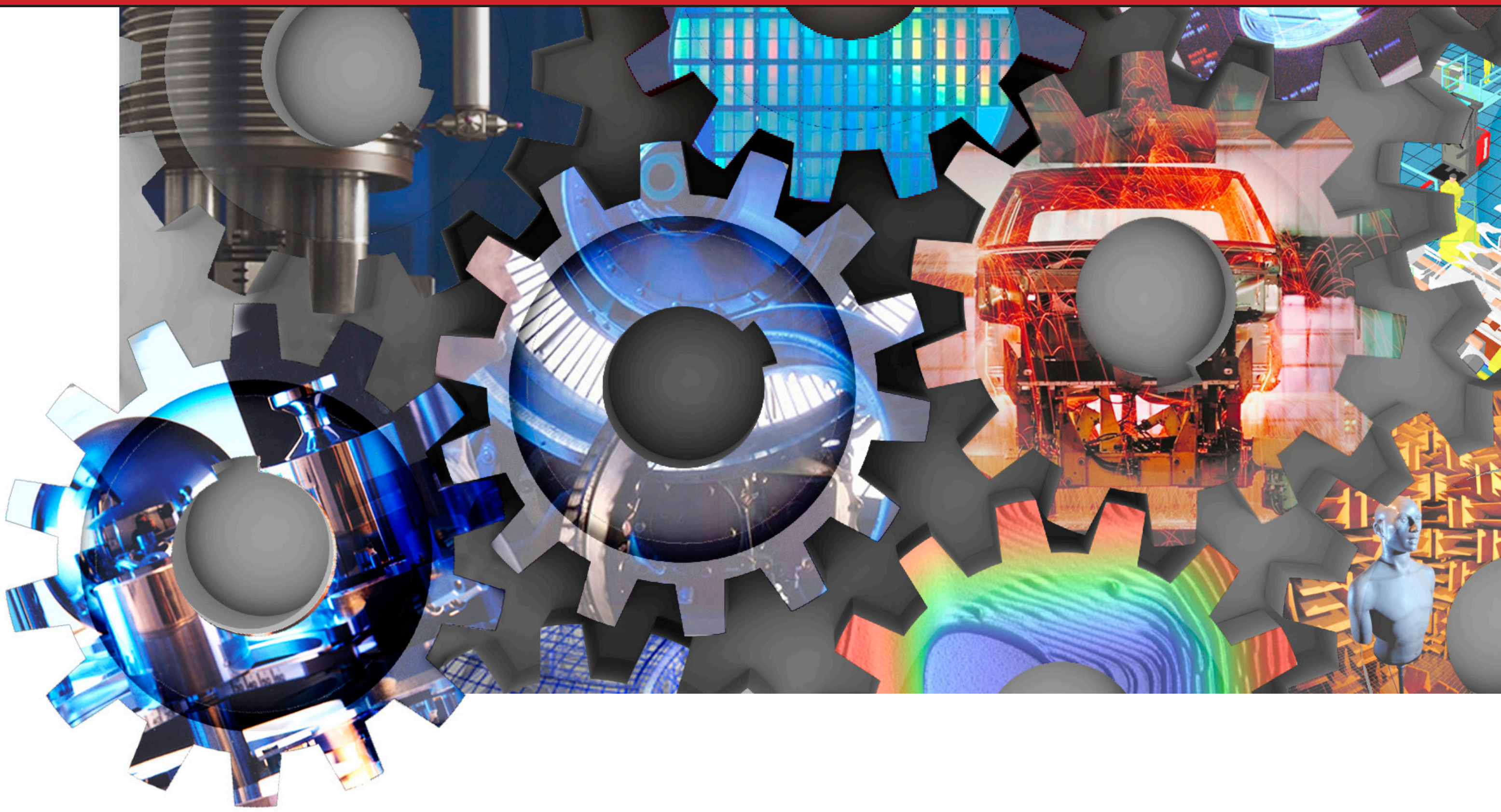
- Two leading publications in the Journal of Chemical Physics that present a detailed theoretical and experimental understanding of the preparation of Si (111) surfaces.
- Comprehensive collaborations with the University of Maryland and George Washington University have resulted in numerous publications covering much of the custom designed hardware.
- Recent collaborations with leading university and nanotechnology manufacturing concerns have recently evolved to a long term funded structure aimed at commercialization of advanced single and multi probe metrology and fabrication techniques.

Planned Future Accomplishments:

- Develop techniques for improved field emission microscopy. Image W(111) and alternative tip materials and evaluate their atomic resolution imaging capabilities. (Complete by 4^{th} Quarter 2011)
- Develop wet silicon processing methods to enable surface and atomic reconstruction on silicon etched structures at room temperature. (Completed by 4^{th} Quarter 2010)
- Demonstrate new methods for nanofabrication of silicon based structures on the nanometer scale. This includes the investigation of Si (100) for enhanced and repeatable nanomanufacturing of features with sub-10 nm dimensions. (Completed by 4^{th} Quarter 2010)

Customers and Collaborators:

- George Washington University
- University of Maryland, Depts. of Physics and Chemical Physics Program
- Zyvex and University of Illinois



Chief:
Kevin Jurrens (Acting)

NIST
100 Bureau Drive
Stop 8220
Gaithersburg, MD
20899-8220

Phone:
301 975 6600
Fax:
301 869 3536
Email:
kevin.jurrens@nist.gov

MMD

Manufacturing Metrology

Mission

To fulfill the measurements and standards needs of the United States in mechanical metrology and advanced manufacturing technology by:

- conducting research and development in realizing, maintaining, and disseminating SI mechanical units (mass, force, acoustics, vibration);
- developing methods, models, sensors, and data to improve metrology, machines, and processes;
- providing services in mechanical metrology, machine metrology, process metrology, workpiece property metrology, and sensor integration; and
- leading in the development of national and international standards.

In addition, MMD provides service to other federal government agencies to address problems and needs that leverage NIST expertise, facilities, and capabilities.

Overview

To fulfill its mission and to respond to the needs of U.S. industry and government, the Manufacturing Metrology Division (MMD) has organized its technical work into three programs. The three MEL programs led by MMD are:

- Mechanical Metrology
- Advanced Optics Metrology
- Advanced Manufacturing Systems

The division consists of a strong team of scientists, engineers, technicians, and support staff, including post-doctoral fellows, full-time guest researchers, and part-time students. The division is fortunate to have staff with expertise and skill in many disciplines, including mechanical engineering, electrical engineering, applied mechanics, physics, optics, acoustics, computer science, and chemistry. Division staff contribute to technical advancements and industry impacts in all six of the MEL core competence focus areas: mechanical metrology, dimensional metrology, nanomanufacturing metrology, manufacturing systems, manufacturing processes, and manufacturing equipment.

MMD Program	Manufacturing Industry Need
Mechanical Metrology	• Measurement traceability to the SI • Compliance with regulatory requirements • Harmonized international standards that reflect U.S. needs • Improved measurement accuracy, precision, and efficiency • Capability to cost-effectively manufacture higher quality and/or more complex parts and assemblies
Advanced Optics Metrology	• Measurement traceability to the SI • Harmonized international standards that reflect U.S. needs • Improved measurement accuracy, precision, and efficiency • Ability to make new and more complex measurements • Capability to cost-effectively manufacture higher quality and/or more complex parts and assemblies
Advanced Manufacturing Systems	• Harmonized international standards that reflect U.S. needs • Ability to make new and more complex measurements • Capability to cost-effectively manufacture higher quality and/or more complex parts and assemblies • Model-based manufacturing systems and processes • Integration and management of manufacturing systems, processes, and equipment • Predictable, well-characterized manufacturing processes, equipment, and systems • Flexible, reconfigurable manufacturing systems

Several drivers for U.S. manufacturing have influenced the selection, direction, and content of the MMD programs, in particular:

- Growth of international trade
- Global and distributed manufacturing
- Continual push for higher quality, better performing, customized products
- Pressures to increase productivity and reduce costs
- Increased pace of technological change

Through frequent interactions and collaborations, the division ensures that our measurements and standards activities address the needs and priorities of our customers. Informed by these interactions, the MMD programs are structured to respond to key, high-priority manufacturing industry needs that result from the above drivers.

Resources

Staff

35 NIST staff
1 NRC post-doctoral researcher
14 guest researchers

FY2008 Estimated Funding

$6600K	STRS (excluding NIST IMS)
$ 900K	NIST Innovation in Measurement Science (IMS)
$1200K	Reimbursable (calibration services)
$1500K	Other Agency

Staffing Challenges

The primary challenge in effective management of MMD staffing and financial resources arises from the division's broad, multi-faceted technical mission. In each of the division's technical areas, MMD staff supply world-class expertise, experience, and knowledge. However, staffing numbers in each area are relatively small, particularly in comparison to National Measurement Institutes in other countries or to parts of NIST that have a more singular mission. The division's challenge is to meet today's demands while also preparing resources and technical expertise for the future. Future retirements and staff departures must be constantly kept in mind, since the specialized metrology and standards expertise required by MMD are not readily available and may take years for newly-hired staff to develop. The typical MMD metrology expert has deep knowledge in a very specialized field; crossover of the specialized expertise to different areas of metrology – even within the division – is rare. Currently the division's professional staffing is very lean, with some metrology areas having only one or two permanent employees. High-quality guest researchers and contractors provide tremendous benefit. MMD continues to encourage and pursue additional NRC post-doctoral researchers for the division.

Facilities and Equipment

MMD manages technical laboratories in several buildings across the NIST campus. NIST's newest building, the Advanced Measurement Laboratory (AML), provides world-leading environmental control for air quality, temperature, humidity, vibration, and electrical shielding – all critical for MEL precision measurement capabilities. MMD facilities typically include one or more of the following characteristics:

- Single-purpose facilities that are too expensive for one company to develop or maintain
- State-of-the-art metrology and research
- Support for next-generation instruments or technology
- Provision of effective access to NIST equipment and expertise
- Neutral location for industry competitors to come to develop tests and standards that benefit the whole industry

MMD Facilities – Mechanical Metrology Program

- Mass Metrology and Standards Facility: Home of the U.S. National Standard for the Kilogram. Custom clean-room environment that provides the U.S. measurement system with the most accurate calibrations available, traceable to the national standard of mass.
- Small Force Metrology Laboratory: World-leading facility devoted to measuring forces as small as 10^{-8} N – the force needed to break three covalent bonds. Application to measurements of coatings, thin films, magnetic disk-drive spring constants, and future mechanical nanodevices.
- Low Frequency Vibration Laboratory: Environmentally-controlled facility devoted to next-generation low-frequency vibration metrology (approximately 0.2 Hz to 200 Hz) to meet increasing customer needs for traceable calibrations of accelerometers in this range.
- Force Metrology Laboratories: Custom-built, multi-story facility that houses force metrology deadweight machines for SI-traceable calibration of force sensors (load cells, proving rings). Home of the 4.45 MN (1 million lbf) deadweight machine – the world's largest machine with the ability to perform direct, high-accuracy calibration of high-load force sensors.
- Acoustic Anechoic Chamber: A large, well-characterized, ultra-quiet chamber used to precisely characterize sound sensors (hearing aids, sound level meters, microphones) and to perform high-precision acoustic measurements.

MMD Facilities – Advanced Optics Metrology Program

- Extremely Accurate Calibration Interferometer (XCALIBIR): A unique multi-configuration, phase-shifting interferometry system with an aperture of 300 mm that can perform demanding measurements and calibrations of optical figure, wavefront, and radius of curvature. The instrument is located in a class 1000 clean room with temperature control to ± 0.02 °C.
- Infrared Interferometer (IR^3): Custom-designed infrared interferometer with an aperture of 300 mm for measuring the thickness variation of silicon wafers.

- Geometric Measuring Machine (GEMM): Custom-built experimental system for estimating the form errors of aspheric and freeform surfaces from measurements of local curvature.
- Wyko 6000 Interferometer: Commercial phase-shifting interferometer with an aperture of 150 mm for measurement and calibration of optical elements.

MMD Facilities – Advanced Manufacturing Systems Program

- DMG 5-axis High-Speed Machining Center: Research platform for machine tool metrology, process metrology, and next-generation machine control. Shared resource with the MEL Fabrication Technology Division.
- Makino 4-axis High-Speed Machining Center: Research platform for high-speed machining. Shared resource with the MEL Fabrication Technology Division.
- Edgetek Machining Center: Instrumented testbed for measuring process phenomena (e.g., cutting forces, temperatures, chip formation) during orthogonal cutting. The testbed has a unique high-speed, dual-spectrum (infrared and visible) micro-videography system for measuring material flow and temperature distribution.
- Mazak 5-axis Turning Center: Research platform for machine tool metrology, process metrology, and smart machining concepts.
- Pulse-Heated Kolsky Bar Facility: A unique, NIST-built device that measures the stress-strain properties of materials undergoing rapid heating and rapid increase of strain. Such data improves models for high-speed machining processes, ballistic impacts, and structural failure.
- Smart and Wireless Sensors Laboratory: A unique facility for testing reference implementations of interoperability standards for smart and wireless sensors.
- Micro-Machining Laboratory: Research facility for development of new metrology concepts relevant to meso-scale machine tools for fabricating micro- and meso-scale parts.
- Diamond Turning Laboratory: Moore M-18 3-axis diamond turning machine for high-precision machine tool metrology and machining process metrology.

Facilities and Equipment Challenges

The division's existing laboratory facilities are generally sufficient to meet today's customer needs, although we have seen a noticeable decrease in environmental control for the optics metrology laboratory after it was relocated from the AML to the Technology Building. Aging of the NIST general purpose laboratories and their environmental systems remain a liability for NIST (and the division) to continue to serve our customers and to meet future, higher-precision metrology demands. Divisions with space outside of the AML will likely need future investments in specialized laboratory renovations to meet ever-increasing environmental requirements for state-of-the-art metrology. Another challenge for the division is to upgrade calibration system equipment and components to take advantage of current technologies while maintaining complete traceability and confidence in measurements for customer calibrations.

Manufacturing Metrology Programs

Mechanical Metrology Program

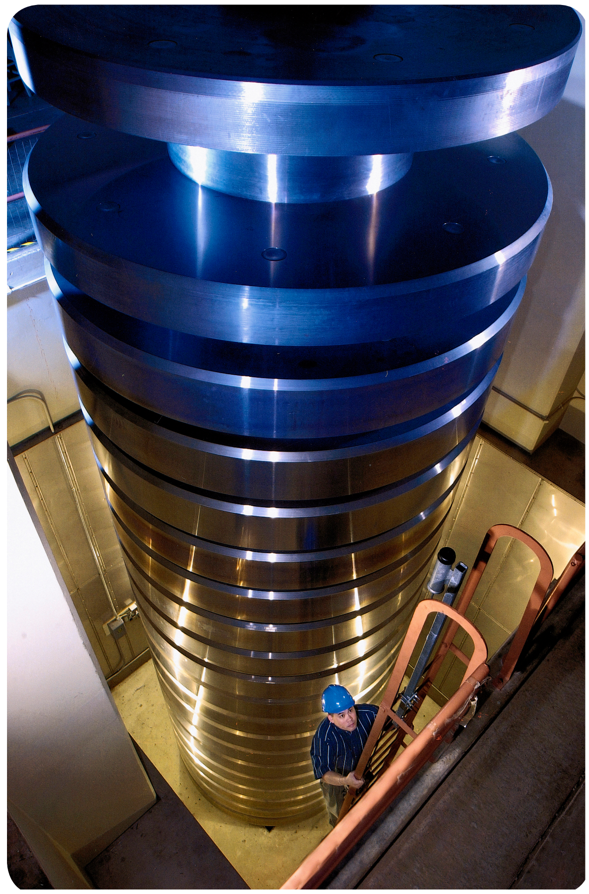
Annual FTEs: 19.0 NIST staff
5.5 guest researchers
24.5 total FTEs

Challenge

Develop and deliver timely measurements and standards to address critical U.S. industry needs for traceable mechanical metrology in the areas of acoustics, force, mass, and vibration, particularly for the support of trade and innovation, process-control, and manufacturing quality.

Overview

Mechanical metrology plays a critical role in nearly all sectors of the U.S. economy and in everyday life. Accurate and traceable measurements of mechanical quantities and standardized metrology methods are crucial to domestic and international trade, to cost-effective manufacture of innovative new products, to distributed and global manufacturing, and to ensuring compliance with regulatory requirements. This program provides the metrology infrastructure to satisfy the current and future needs of the U.S. government and industry for SI-traceable measurements of acoustics, force, mass, and vibration. The program realizes, maintains, and disseminates the basic SI unit of mass and the quantities of acoustics, force, and vibration for a broad customer base. To ensure U.S. competitiveness in world markets, the program represents the U.S. through active participation in international metrology organizations and associated international comparisons of measurement capabilities. NIST-developed



The 4.448 MN (1,000,000 lbf) deadweight machine

measurement and uncertainty evaluation techniques are transferred to U.S. industry and other government agencies through leadership in national and international standards activities, partnerships and collaborations, and other direct outreach activities.

This program addresses the mechanical metrology challenges and needs faced by U.S. industry and government through:

1. Research and development to anticipate long-term, short-term, and current needs of fundamental SI metrology, government, and industry, and to drive future advancements in the areas of mass, acoustics, force, and vibration;
2. Contacts with customers from U.S. industry, government agencies, and academia to evaluate and assess future research and development needs in mechanical metrology;

3. Measurement services in conformance with an ISO 17025 compliant quality system to meet the needs of U.S. government and industry in acoustics, force, mass, and vibration;
4. International comparisons to ensure U.S. compliance with the Mutual Recognition Arrangement (MRA) and the competitiveness of U.S. industry in world markets;
5. High-level technical expertise for acoustics, force, mass, and vibration standards to ensure traceability and comparability of U.S. physical and documentary standards in mechanical metrology to those of other nations, and to represent and protect the interests of U.S. industry in global markets.

Key Accomplishments and Impacts:

- Successfully completed crucial initial steps towards the redefinition of the Kilogram:
  - Demonstrated ability to magnetically levitate and weigh a 1 kg mass. Completed design and began construction of system to directly relate, for the first time, air to vacuum weighing using magnetic levitation principles. This will provide the link between the existing artifact-based definition realized in air and the future realization of mass based on fundamental constants in vacuum. This link is essential to guarantee continuity and equivalency of mass measurements.
  - Completed manufacturing of first prototype stable 1 kg mass standard. Chemically inert and resistant to wear, this standard will eliminate most sources of instability in the dissemination of the unit of mass.
  - Provided major contributions and direction to activities and decisions of the Consultative Committee on Mass and Related Quantities (CCM) to establish proper guidelines and methodologies for a timely and successful redefinition of the Kilogram.
- Established technical foundation and leadership in the metrology of small forces ranging from micronewtons to piconewtons:
  - Established NIST Electrostatic Force Balance as an SI-traceable tool for the measurement and dissemination of accurate values of atomic force microscope cantilever stiffness.
  - Collaborated with other NIST laboratories to produce a prototype standard reference material consisting of an array of precisely machined microcantilevers with accurately known stiffness values that are traceable to the NIST Electrostatic Force Balance.
- Completed the research and development foundation for the establishment of new measurement capabilities in low-frequency vibration and next-generation microphones, in accordance with customer demands for extension of the low-frequency vibration calibration range and for reduction in measurement uncertainty for new types of microphones.
- Provided critical and state-of-the-art measurement services to the U.S. government and industry through nearly 3000 tests performed annually for over 100 customers.

Future Directions and Plans:

This program will continue to emphasize practical access to state-of-the-art measurement accuracy for high-impact SI mechanical metrology and the advancement of measurement science to meet future and unmet present needs. Specific emphasis will be on U.S. contributions for redefinition of the Kilogram, development of intrinsic force standards based on fundamental nanoscale forces, establishment of new measurement services in low-frequency vibration, next-generation microphones, and robotic mass measurements, and representation of U.S. interests in international metrology communities and in national and international standards to ensure open markets for U.S. industry.

Awards and Recognition

- Dave Evans, Victor Nedzelnitsky, and Randy Wagner received the 2007 NIST Edward Bennett Rosa Award for outstanding achievements in development of standards and measurement practices to assure the quality and performance of acoustical devices and measuring instruments used by the public and laboratories worldwide.
- Jon Pratt received the 2006 *Measurement Science and Technology* Outstanding Paper Award in the Precision Measurement category for his article "Prototype Cantilevers for SI-traceable Nanonewton Force Calibration" [Meas. Sci. Tech., Vol. 17, Issue 10, pp. 2852-2860].
- The Director of NIST selected the following projects for FY2006 NIST Innovation in Measurement Science (IMS) funding (formerly known as NIST Competence projects):
  - An Alternative Approach to Mass Metrology (Zeina Jabbour)
  - Intrinsic Force Standards Based on Atomic and Molecular Interactions (Jon Pratt)
- Zeina Jabbour was chosen to represent the U.S. mass metrology community as invited member of the CIPM Consultative Committee on Mass and Related Quantities (CCM) ad hoc working group on redefinition of the SI units. [2005-2008]
- David Evans was recognized by the Acoustical Society of America (ASA) for outstanding contributions to standards activities, including service as Chair of the ANSI-accredited standards committee S2 on Mechanical Vibration and Shock from 1993-2000 and as Vice-Chair from 2000-2006. [October 2006]

Projects

Mechanical Metrology Program

Research and Development for Next-Generation Mechanical Metrology

(Status: to be completed in FY2011)

Challenge/Problem Addressed:

NIST metrology programs strive constantly to pioneer technology that will improve upon the state-of-the-art in order to provide the peak of the measurement traceability chain. NIST customers continually need new measurement capabilities, lower measurement uncertainties, and expanded ranges for measured quantities to meet their technical demands for innovative and more complex products and scientific applications. NIST measurements must undergo rigorous uncertainty assessments to ensure customer confidence in measurement results. The challenges in the Mechanical Metrology Program are no exception, and advancement of NIST mechanical metrology capabilities in response to identified and anticipated needs requires cutting edge research and development. As the country's National Measurement Institute, NIST must represent U.S. mass metrology interests in the current international effort to prepare for a redefinition of the unit of mass – the Kilogram – away from a physical artifact. NIST's expertise will be essential in developing the necessary technical advancements to allow the U.S. (and the world) to adopt the Kilogram redefinition.

Objective

Conduct research and development to anticipate long-term, short-term, and current needs of fundamental SI metrology, government, and industry, and to drive future advancements in the areas of mass, acoustics, force, and vibration.

Accomplishments:

- Successfully completed crucial initial steps towards the redefinition of the Kilogram:
  - Demonstrated ability to magnetically levitate and weigh a 1 kg mass. Completed design and began construction of system to directly relate, for the first time, air to vacuum weighing using magnetic levitation principles. This will provide the link between the existing artifact-based definition realized in air and the future realization of mass based on fundamental constants in vacuum. This link is essential to guarantee continuity and equivalency of mass measurements.
  - Completed manufacturing of first prototype stable 1 kg mass standard. Chemically inert and resistant to wear, this standard will eliminate most sources of instability in the dissemination of the unit of mass. Began studies of long-term stability.
  - Provided major contributions and direction to activities and decisions of the Consultative Committee on Mass and Related Quantities (CCM) to establish proper guidelines and methodologies for a timely and successful redefinition of the Kilogram.

- Established technical foundation and leadership in metrology of small forces ranging from micronewtons to piconewtons:
  - Established NIST Electrostatic Force Balance as an SI-traceable tool for the measurement and dissemination of accurate values of atomic force microscope cantilever stiffness.
  - Collaborated with other NIST laboratories to produce a prototype standard reference material consisting of an array of precisely machined microcantilevers with accurately known stiffness values that are traceable to the NIST Electrostatic Force Balance.
- Completed the research and development foundation for the establishment of new measurement capabilities in low-frequency vibration and next-generation microphones, in accordance with customer demands for extension of the low-frequency vibration calibration range and for reduction in measurement uncertainty for new types of microphones.
- Developed, integrated, and delivered to the U.S. Air Force Metrology Calibration Laboratories (AFMETCAL) a new vibration exciter and primary calibration system to calibrate accelerometers. The new system uses a quadrature laser interferometer and a new measurement approach to calibrate accelerometers over a wide frequency range, enabling AFMETCAL to carry out their own primary accelerometer calibrations with uncertainties similar to NIST measurement capabilities.

Planned Future Accomplishments:

- Establish the first direct link between the current SI Kilogram defined in air and the future vacuum-based definition of mass.
- Establish a mass metrology dissemination mechanism based on the new realization and the stable artifacts.
- Establish intrinsic force standards based on fundamental nanoscale forces that can supplant artifact-based force metrology to affix SI-traceable values to atomic and molecular force interactions.
- Complete research and development required to establish new calibration services and standard operating procedures in infrasonic metrology.

Customers and Collaborators:

- State Weights & Measures Laboratories
- Boeing Company
- Pratt & Whitney
- Lockheed Martin
- United Technologies Corp.
- U.S. Army; U.S. Air Force; U.S. Navy
- U.S. Department of Veterans Affairs (VA)
- NASA
- Los Alamos National Laboratory
- Amgen
- Morehouse Instruments
- Asylum Research
- Veeco Products
- Instron
- Tovey Engineering
- MKS Instruments
- Intercomp
- Interface Inc.
- University of Illinois at Urbana-Champaign
- University of Florida
- Southern California Edison
- Duke Power
- Bruel & Kjaer

Mechanical Metrology Program

Measurement Services

(Status: to be completed in FY2011)

Challenge/Problem Addressed:

This project provides high-accuracy measurement services and special tests for NIST customers in the areas of acoustics, force, mass, and vibration, with traceability to the International System of Units (SI) and with measurement uncertainties equal to or better than those specified in NIST Special Publication (SP) 250. NIST measurement services must maintain and adhere to a quality system that is in compliance with the ISO 17025 standard for all administrative and technical aspects of the measurement services. Quality system requirements include maintenance of control charts, regular calibration of NIST reference and working standards, and calibration of all calibration equipment or associated instrumentation, with direct traceability to NIST. An ongoing project emphasis is to continually monitor and improve the delivery of measurement services for NIST customers. The goal is to provide 90% or better on-time delivery of reports of calibrations and special tests to all customers.

Objective

Provide high-accuracy measurement services in conformance with an ISO 17025-compliant quality system to calibrate devices submitted by NIST customers in the areas of acoustics, force, mass, and vibration.

Accomplishments:

- Provided critical and state-of-the-art measurement services to the U.S. government and industry through nearly 3000 tests performed annually for over 100 customers.
- Developed new measurement methodology and new weighing designs to establish robotic mass calibrations that will improve the delivery of mass calibrations, minimize human error, reduce statistical uncertainty, eliminate temperature effects caused by operators, and reduce the turn-around time for customer calibrations.
- Automated and upgraded several force deadweight machines to improve the delivery of force calibrations, reduce the risk of equipment failure, minimize human error, and reduce the turn-around time for customer calibrations.

Planned Future Accomplishments:

- Provide critical and state-of-the-art measurement services to NIST customers in the mechanical metrology areas of mass, force, acoustics, and vibration.
- Develop quality system documentation and implement new measurement capabilities to provide new measurement services in low-frequency vibration, next-generation microphones, and robotic mass measurements.

Customers and Collaborators:

- State Weights & Measures Laboratories
- Boeing Company
- Pratt & Whitney
- Lockheed Martin
- United Technologies Corp.
- U.S. Army, U.S. Air Force, & U.S. Navy
- U.S. Department of Veterans Affairs (VA)
- NASA
- Los Alamos National Laboratory
- Amgen
- Morehouse Instruments
- Instron
- Tovey Engineering
- MKS Instruments
- Intercomp
- Interface Inc.
- Southern California Edison
- Duke Power
- Bruel & Kjaer

Mechanical Metrology Program

International Comparisons and Standards (Status: to be completed in FY2011)

Challenge/Problem Addressed:

An elaborate system of international comparisons, performed in accordance with the international Mutual Recognition Arrangement (MRA), allows measurement capabilities among different countries to be recognized and accepted as the foundation for international trade. Some comparisons are on a global scale, such as those conducted through committees of the International Committee on Weights and Measures (CIPM), while others are regional, such as those done through the Interamerican Metrology System (SIM), which coordinates metrology activities within the Americas. NIST represents and defends U.S. interests in these international metrology communities, particularly through the CIPM consultative committees and SIM working groups. The Mechanical Metrology Program interacts primarily with the CIPM Consultative Committee on Mass and Related Quantities (CCM) and the Consultative Committee on Acoustics, Ultrasound, and Vibration (CCAUV), and the corresponding working groups of SIM. The program's challenges are (1) to determine the appropriate level of U.S. representation and participation in the planning and execution of international comparisons necessary to meet U.S. requirements and (2) to develop and implement effective comparisons that evaluate high-priority measurement capabilities and obtain reliable results that promote U.S. competitiveness. In addition, expert-level representation and technical contributions to national and international standards are necessary to ensure traceability of U.S. physical and documentary standards in mechanical metrology and comparability of U.S. standards to those of other nations.

Objective

Ensure the competitiveness of U.S. industry in world markets and U.S. compliance with the international Mutual Recognition Arrangement (MRA) by conducting international comparisons of measurement capability and providing high-level technical expertise for national and international standards in acoustics, force, mass, and vibration.

Accomplishments:

- Piloted international comparison in force (CCM, 2MN to 4 MN), analyzed results, and published initial report. Provided participating countries a direct link to the highest precision force measurements available worldwide above 2 MN, thereby establishing greater confidence and reliability in the equivalence of the measurements.
- Piloted international (regional) comparison in vibration (SIM, 50 Hz to 50 kHz), analyzed results, and published initial report. Provided SIM participants, through NIST, a link to other countries that participated in CCAUV comparisons with NIST. This guarantees the recognition and validity of the calibration and measurement capabilities of the participating countries under the mutual recognition arrangement (MRA), thereby supporting international trade.
- Completed measurements for CCM key comparisons in force metrology (1 MN, PTB pilot and 100 kN, NPL pilot) to guarantee mutual recognition of measurement capabilities and to facilitate international trade.
- Completed analysis of CCAUV key comparison for microphones in 31.5 Hz to 25 kHz range and published results in Metrologia.

- Provided technical expert knowledge to numerous national (ANSI, ASTM) and international (ISO, IEC, CIPM, OIML, SIM) standards in the mechanical metrology areas of acoustics, force, mass, and vibration to ensure traceability of U.S. physical and documentary standards in mechanical metrology and comparability of U.S. standards to those of other nations. (See attached table: *Standards Leadership and Participation*)

Planned Future Accomplishments:

- Represent U.S. interests in the Consultative Committee on Mass and Related Quantities (CCM) related to the redefinition of the Kilogram.
- Define the measurement protocol and conduct measurements as part of the U.S. participation in the regional comparison for low frequency vibration metrology.
- Represent U.S. interests in international metrology communities, international comparisons of measurement capability, and national and international standards activities in the mechanical metrology areas of mass, force, acoustics, and vibration to ensure open markets for U.S. industry.

Customers and Collaborators:

- State Weights & Measures Laboratories
- Boeing Company
- Pratt & Whitney
- Lockheed Martin
- United Technologies Corp.
- U.S. Army, U.S. Air Force, U.S. Navy and U.S. Department of Veterans Affairs (VA)
- NASA
- Los Alamos National Laboratory
- Amgen
- Morehouse Instruments
- Asylum Research
- Veeco Products
- Instron
- Tovey Engineering
- MKS Instruments
- Intercomp
- Interface Inc.
- Universities of Illinois at Urbana-Champaign and Florida
- Southern California Edison
- Duke Power
- Bruel & Kjaer

Mechanical Metrology Program

Customer Outreach and Interactions (Status: targeted activity completed in FY2007)

Challenge/Problem Addressed:

The Mechanical Metrology Program must establish and maintain the appropriate level of technical contacts within our customer organizations. The primary contact with NIST's measurement services is frequently in the customer's calibration or procurement office. This contact understands the calibration to be performed, but most often does not know the intended end-use or application of the device being calibrated. At times there is no insight into how NIST metrology services impact the company's bottom line or their next innovative product or application. This deeper level of technical information is very important for NIST planning, for understanding customer needs, and for determining how best to represent U.S. interests in the international community. For these reasons, this project must perform targeted customer outreach activities and interactions to reach the necessary technical contacts within our customer base.

Objective

Establish and maintain contacts with NIST customers from U.S. industry, government agencies, and academia to identify and assess future research and development needs in mechanical metrology.

Accomplishments:

- Organized and conducted an industry workshop on U.S. torque metrology requirements. The workshop uncovered major discrepancies in torque measurements and pointed to the need for establishing uniformity in the realization and dissemination of the SI unit of torque.
- Received direct feedback from customers about their current and future needs in mechanical metrology through several site visits and other interactions. Received information about how measurements services performed at NIST are used by the customers and about the crucial role of NIST measurement services in manufacturing and in satisfying regulatory requirements.

Customers and Collaborators:

- State Weights & Measures Laboratories
- Boeing Company
- Pratt & Whitney
- Lockheed Martin
- United Technologies Corp
- U.S. Army
- U.S. Air Force
- U.S. Navy
- NASA
- Amgen
- Morehouse Instruments
- Instron
- Tovey Engineering
- MKS Instruments
- Intercomp
- Interface Inc.
- University of Illinois at Urbana-Champaign
- Southern California Edison
- Duke Power
- Bruel & Kjaer

Manufacturing Metrology Programs

Advanced Optics Metrology Program

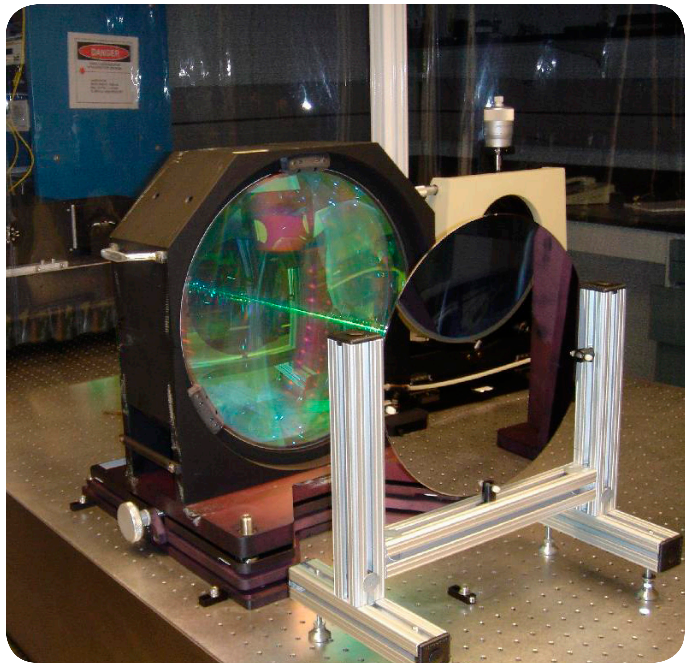
Annual FTEs:	2.0 NIST staff
	3.0 guest researchers
	5.0 total FTEs

Challenge:

Provide methods, measurement services, and standards for SI-traceable metrology of optical figure and wavefront that contribute to innovations in the application and manufacture of optical elements and precision surfaces.

Overview

Optical technology is an enabling technology in many areas. Communication, bio-medical imaging, defense, astronomy, nano-scale manufacturing, semiconductor manufacturing, and many other applications depend crucially on optical systems. Manufacturing these optical systems depends in turn on the ability to measure their performance, which requires traceable metrology for optical figure and wavefront. In high-impact applications such as semiconductor lithography, uncertainties are at the demanding sub-nanometer level. Few standards exist in this area. Traceability requires standards-compliant uncertainty statements (i.e., based on the GUM – Guide to Uncertainty in Measurement) that are rare in the U.S. optics industry, but increasingly mandated for ISO-certified quality systems and export. Only a small number of very specialized optical companies practice the metrology of aspheric and nano-structured optical elements. No general, widely-recognized, validated way exists to calibrate these optical elements, and the application range and



uncertainty of existing methods are poorly understood. This has hindered the manufacture and adoption of these optical elements, despite their ability for game-changing product innovations.

The program addresses infrastructural metrology challenges faced by U.S. industry and other federal agencies through:

1. Measurement methods and calibration services for optical figure of flat, spherical, and aspherical precision surfaces that provide innovation leverage, have deep metrological penetration into the U.S. metrology chain, or are mission critical. Where possible, we develop protocols that allow users to make (absolute) calibrations in their own facilities.
2. International comparisons and harmonized standards for optical figure and wavefront metrology that ensure effective access to international markets by the U.S. optics industry.
3. Measurement methods and reference artifacts for silicon wafer flatness and extreme ultraviolet lithography (EUVL) optical elements that address future

requirements of the International Technology Roadmap for the Semiconductor Industry (ITRS).

4. Measurements and calibrations that support the manufacture and adoption of nanostructured optical components by U.S. industry.

Key Accomplishments and Impacts:

- Developed and characterized methods for absolute calibration of optical flats, taking into account variability of mounting induced deformations, in response to requests from leading U.S. optics manufacturers and research institutions for full-surface flat calibrations with low uncertainties. Realized ability to calibrate 300 mm flats with a standard uncertainty of 0.2 nm rms, and executed NIST special tests for customers.
- Initiated an international comparison of flatness metrology and developed the corresponding protocol and test artifact.
- Characterized and improved uncertainty of radius of curvature measurements (20 nm for 100 mm radius) and absolute measurement of sphericity in response to customer requests, and provided special tests for customers.
- Developed and characterized an experimental system for estimating form errors of freeform and aspheric surfaces from measurements of local curvature.
- Developed and characterized an infrared interferometer (1552 nm) for measuring the thickness variation of 300 mm silicon wafers with a standard uncertainty of 5 nm in response to the needs of manufacturers of silicon wafers and related metrology tools. We produced reference wafers with a calibrated thickness variation that enable users and manufacturers of wafer inspection tools to evaluate and improve measurement performance. Using our measurements, a U.S. company developed a process to manufacture ultra-flat wafers that meet ITRS site flatness requirements well into the next decade.
- In collaboration with NASA, developed metrology methods and designed diffractive optical elements to calibrate the form of mandrels used to shape aspheric mirrors for future X-ray telescopes, and conducted process characterization experiments for their fabrication in the NIST NanoFabrication facility.

Future Directions and Plans:

Our measurement capability for flatness, sphericity, radius of curvature, and wafer thickness variation is mature. Future work will focus on the uncertainty analysis and comparison of measurement techniques for aspheres and nano-structured optical elements, and will address needs of collaborators such as NASA that are currently not met by industry.

Awards and Recognition

- Ulf Griesmann joined the Optics and Electro-Optics Standards Council, a forum of technical experts that provides guidance on behalf of the U.S. for national and international standards in the areas of optics and optical measurements. [November 2007]
- Ulf Griesmann served as the General Chair of the Optical Society of America (OSA) Topical Meeting on Optical Fabrication and Testing, 2006, Rochester, NY. He will Co-Chair this meeting in 2008.

Projects

Advanced Optics Metrology Program

Measurement Methods and Calibrations

(Status: to be completed in FY2010)

Challenge/Problem Addressed:

Flat and spherical reference surfaces are key components in the traceability chain of interferometric measurements of optical figure and wavefront. The ability to perform absolute calibrations of these surfaces with uncertainties at the nanometer-level or below powerfully enhances the ability of the optics industry to manufacture and measure high-performance optical systems.

To achieve high optical performance, low system weight, and low cost, modern optical systems increasingly use aspheric surfaces. However, measuring aspheric surfaces poses formidable metrology problems because of the difficulty of obtaining a reference wavefront that closely matches the desired form of the asphere. No single, widely recognized, general, validated way exists for calibrating or measuring complex surfaces with nm-level uncertainties. Common techniques are general interferometry using "stitching" methodology or refractive or diffractive "null" optics (e.g., computer generated holograms (CGH)). The application range and uncertainties of these techniques are poorly understood.

Objective

Provide full-aperture measurement methods and calibration services for optical figure of flat, spherical, and aspherical precision surfaces with state-of-the-art accuracies, focusing on calibration services for flatness, sphericity, and radius of curvature of optical surfaces with an aperture up to 300 mm, and specifications for the application range and achievable uncertainties of various measurement methods, including stitching, computer generated holograms, shearing interferometry, and measurements of local curvature.

Accomplishments:

- Developed, characterized, and published methods for the absolute calibration of optical flats based on the three-flat concept, including the effect of gravity-induced flat deformations on calibration uncertainty. Measurements were augmented with finite element analyses of the variation in flatness errors that occur in a rotated flat due to rotational asymmetries in the flat mount and flat geometry.
- Characterized the uncertainty of absolute sphericity measurements using the ball averaging method and published the results.
- Completed phase I of the experimental geometric measuring machine (GEMM) system to estimate form errors of freeform and aspheric surfaces from measurements of local curvature. Published an uncertainty evaluation for profile measurements which included a comparison showing excellent consistency in measurements of the form of an elliptical synchrotron mirror obtained with the NIST Moore M48 CMM, stitching interferometry, and slope-based optical profiling. Developed a new algo-

rithm for the estimation of 3D surfaces from curvature measurements. Realized a novel curvature measurement sensor with integrated standoff measurement capability to reduce measurement uncertainties; the sensor is being integrated into the GEMM system.

- Provided full-aperture calibrations (NIST special tests) for flatness, sphericity, and radius of curvature to customers.

Planned Future Accomplishments:

- Realize capability for the calibration of radius and form errors of spherical reference surfaces with radii larger than 100 mm as requested by leading optics companies. Characterize the uncertainty of common calibration methods for reference spheres.
- Address the challenge of characterizing, with low uncertainties, the radius and form errors of spherical surfaces with large radii (10 m to 1000 m) through the application of diffractive optics.
- Complete study to resolve conflicting opinions in industry on the uncertainties of the stitching approach used to extend measurement area or enable asphere measurement (including effects of retrace errors and errors in reference wavefront and image registration).

Customers and Collaborators:

- QED Technologies
- Argonne National Laboratory / Advanced Photon Source
- NASA
- Zygo
- Zeiss IMT
- ITT Space Systems Division

Advanced Optics Metrology Program

International Comparisons and Standards

(Status: to be completed in FY2009)

Challenge/Problem Addressed:

Controversies on measurement procedures, specification compliance, and traceability continue to hamper international commerce in advanced optical elements. Standards-compliant uncertainty assessments (i.e., based on the GUM – Guide to Uncertainty in Measurement) are rare in the optics industry. Companies increasingly need to adopt ISO-certified quality procedures, especially for goods that are exported. Having traceable in-house metrology with well-documented uncertainty statements is thus becoming essential to optics and precision engineering companies.

Objective

Ensure effective access to international markets by the U.S. optics industry through international comparisons and harmonized standards for optical figure and wavefront.

Accomplishments:

- Initiated an international comparison of flatness measurements of 300 mm diameter optical flats, with NIST acting as the pilot laboratory. Procured and characterized the comparison artifact. Designed and realized an instrumented shipping container and a test mount sleeve that allows the artifact to be measured in both vertical and horizontal orientations.

Planned Future Accomplishments:

- Complete international comparison of flatness measurements (FY2009)
- Contribute to the ANSI Optics and Electro-Optics Standards Council (OEOSC) Technical Advisory Group to ensure that international standards reflect the state-of-the-art.

Customers and Collaborators:

Comparison Participants

- CSIRO (Australia)
- NPL (UK)
- NMIJ (Japan)
- KRISS (Rep. of Korea)
- and PTB (Germany)

Advanced Optics Metrology Program

Optical Metrology for the Semiconductor Industry

(Status: to be completed in FY2010)

Challenge/Problem Addressed:

As exposure tools for optical lithography evolve toward larger numerical apertures, the semiconductor industry expects continued demand for improved wafer flatness at the exposure site. The allowable site flatness error for 300 mm wafers is expected to be less than 50 nm by 2010 and may be as low as 25 nm by 2015, according to the International Technology Roadmap for Semiconductors (ITRS 2006). These goals present a challenge for both wafer polishing and metrology tools.

Advances in lithography are crucial to continued growth in the semiconductor industry. The introduction of extreme ultraviolet lithography (EUVL) as the manufacturing process for next-generation semiconductors has been delayed by the low lifetime of EUVL reflective optics (more than a factor of 100 below what is required). Since optimal resolution requires the figure of the optics to be within a fraction of the operational wavelength, EUVL optical components must be fabricated to sub-nanometer tolerances and retain stability over several years of exposure. The effects of EUV exposure on long-term dimensional stability and phase change characteristics of EUV-reflective surfaces are largely unknown.

Objective

Provide measurement methods and reference artifacts for silicon wafer thickness variation and EUVL optical elements that address requirements of the International Technology Roadmap for the Semiconductor Industry (ITRS).

Accomplishments:

- Completed development and characterization of the NIST infrared interferometer (1552 nm) for measuring the thickness variation of 300 mm silicon wafers with an uncertainty of 5 nm.
- Produced reference wafers with calibrated thickness variation that enable users and manufacturers of wafer inspection tools to evaluate and improve measurement performance.
- Provided measurements that enabled a U.S. company to develop a corrective sub-aperture polishing process to manufacture ultra-flat wafers that meet ITRS site flatness requirements well into the next decade.

Planned Future Accomplishments:

- Evaluate the uncertainty that can be achieved with a shearing interferometer operating at EUV wavelengths by building a prototype interferometer working with visible light and comparing its performance against phase shifting interferometry.
- Produce measurement data to clarify the effects of EUV exposure on the lifetime of EUV reflective optics (anticipated future activity).

Customers and Collaborators:

- QED Technologies
- MEMC Electronic Materials Inc.
- Wavefront Sciences

Advanced Optics Metrology Program

Measurement and Calibration of Nano-Structured Optical Elements

(Status: to be completed in FY2010)

Challenge/Problem Addressed:

Modern micro-fabrication technology has made possible the precise fabrication of three-dimensional structures that are small compared to the wavelength of light. This capacity opens up new ways to engineer the phase and amplitude of light waves to create light waves with unique properties, leading to the emergence of a new class of optics commonly referred to as "diffractive optics" to emphasize that device function is achieved through the scattering of light by microscopic structures with dimensions comparable to the wavelength of light. Diffractive optical elements (DOEs) have properties that traditionally polished optics cannot achieve. For example, a diffractive lens can focus a light wave at several points in space simultaneously. DOEs are therefore important components in many novel optics products and they have become a vibrant field of research. They can also improve the calibration of optical elements with aspheric surfaces. The NIST NanoFabrication facility provides unique resources for the fabrication of DOEs.

Objectives

Provide methods and capability for traceable measurement of wavefronts using customized diffractive optical elements. Provide documented methods to calibrate wavefronts generated by nano-structured optical elements that support the manufacture and adoption of nanostructured elements by U.S. industry.

Accomplishments:

- In collaboration with NASA, developed metrology methods and designed diffractive optical elements to calibrate the form of mandrels used to shape aspheric mirrors for future X-ray telescopes. Conducted preliminary process characterization experiments for fabrication of the diffractive optical elements in the NIST NanoFabrication facility.
- In collaboration with NASA, fabricated and characterized a phase resolution target to evaluate the spatial frequency response of surface interferometers.

Planned Future Accomplishments:

- Develop a prototype optical test based on computer-generated holograms to calibrate the form errors of mandrels used to shape aspheric mirrors for future X-ray telescopes.
- Develop methods to calibrate wavefronts generated by nano-structured optical elements and characterize the relation between wavefront and fabrication errors.

Customers and Collaborators:

- NASA Goddard Space Flight Center

Manufacturing Metrology Programs

Advanced Manufacturing Systems

Annual FTEs: 14.0 NIST staff
4.0 guest researchers
18.0 total FTEs

NIST Kolsky Bar Lab

© Robert Rathe

Challenge:

Develop, validate, and demonstrate the critical metrology, standards, and infrastructural tools needed by U.S. industry to realize cost-effective, knowledge-integrated, autonomous intelligent manufacturing systems.

Overview

U.S. manufacturing is undergoing fundamental changes in response to global economic forces. Industry trends are shaping a new future for U.S. manufacturers – one where high-value, knowledge-intensive, highly-customized products and processes will be the new cornerstones for growth and prosperity. In labor-intensive commodity sectors, U.S. manufacturers currently face substantial competitive and cost disadvantages. To remain competitive and promote growth, manufacturers must adapt to new challenges and market demands that require more complex and individually customized products with improved quality, functionality, and performance. Such rapidly changing market demands necessitate shorter innovation cycles, more flexible and rapidly reconfigurable manufacturing systems, integrated and streamlined communications and supply chains, reduced environmental impacts, and improved energy efficiencies. In the future, U.S. manufacturing processes must be accurate, agile, automated, flexible, intelligent, interoperable, reconfigurable, and sustainable. For this vision to come about, an underlying foundation and infrastructure must be developed and implemented so that U.S. manufacturers can quickly capitalize on future game-changing opportunities and technological innovations.

This program considers three themes as the fundamental areas of contribution:

1. Knowledge generation and improvement related to manufacturing processes and equipment
2. Unambiguous representation and communication of such knowledge and information
3. Methods and tools that can combine and integrate knowledge and information in order to make possible cost-effective decisions in response to changing conditions in manufacturing environment (including customer demand, operating conditions, and other economic and technical drivers)

Specific projects address technical challenges in one or more of these themes.

Key Accomplishments and Impacts:

- Developed a prototype robust optimizer for process parameters that incorporates modeling uncertainties, and demonstrated its use for a contoured turned part, resulting in 50% cycle time improvement.
- Completed development of a model-based, real-time error compensation system for machines in a typical shop environment at both NIST and U.S. Army Picatinny Arsenal, resulting in a 65% reduction of geometric and thermal machine errors.
- Achieved the first-ever harmonization of U.S. national and ISO standards for machine tool performance evaluation, giving U.S. industry a new ability to unambiguously compare and specify machine tools, establish mutual obligations between buyers and sellers, and improve manufacturing productivity and product quality.
- Completed development of a pulse-heated Kolsky bar facility to measure material properties during rapid heating and rapid increase of strain. Data obtained for AISI 1045 steel improved the ability of finite element-based machining simulations to predict process phenomena such as cutting forces and temperatures observed during machining experiments.
- Completed development of a high-speed, dual-spectrum (visible and infrared) micro-videography system to measure material flow and temperature distribution during orthogonal cutting. Collaborators, including Los Alamos National Laboratory and Third Wave Systems, are using data obtained in this way to validate and improve models and simulations of machining processes.
- Initiated and led a new standards activity that developed the IEEE 1588 standard, the highest-precision clock synchronization protocol for networked measurement and control.

Future Directions and Plans:

The measurements and standards scope of this program is in transition – from a prior MEL emphasis on smart machining systems to a focus on high-priority, advanced manufacturing systems needed by U.S. industry in the global economy. Industry needs and priorities will be a primary driver for future programmatic choices.

Awards and Recognition

- Alkan Donmez and Hans Soons received the 2006 Department of Commerce Silver Medal Award for Exceptional Federal Service for outstanding leadership and achievements leading to the first-ever harmonization of national and international standards for machine tool performance.
- Kang Lee received the 2006 NIST Equal Employment Opportunity / Diversity Award for 25 years (e.g., 1,500 Saturdays) of dedication to education and inspiration of middle and early high school students through hands-on science with the "Adventures in Science" program.
- Michael McGlauflin received the 2007 NIST Bronze Medal Award for Superior Federal Service for sustained achievements and excellence in providing outstanding technical support for machine tool metrology and performance standards.

- Hans Soons received a Certificate of Appreciation from the ASME Council on Codes and Standards for his major contributions to the work of the ASME B5/TC52 Standards Committee on machine tool performance evaluation. [February 2005]
- Kang Lee was profiled in a special issue of the EE Times publication on "Great Minds, Great Ideas" about people and technologies that change marketplaces and open new opportunities. The issue profiled 29 innovators in the world who make a difference in their field, transform markets, and change the way people work, live, and play.

  The story "Paving the Road to Ubiquitous Computing" recognized Kang as an innovator in that area. [December 2005]
- Kang Lee received the 2006 Society Award from the IEEE Instrumentation and Measurement Society for his dedicated contribution and services as Chair of the Technical Committee on Sensor Technology. Under Kang's leadership, this committee developed the IEEE 1451 smart transducer interface standards and IEEE 1588 standard for precision clock synchronization. [April 2006]
- Kang Lee was selected by the IEEE Instrumentation and Measurement Society as an IEEE Distinguished Lecturer on the topics of smart sensors and distributed measurement and control systems. [June 2007]
- Kang Lee was recognized in the preface of a book written by Dr. John Eidson of Agilent Technologies about the IEEE 1588 standard for precision clock synchronization. Kang chairs the IEEE Committee on Sensor Technology that was responsible for developing this standard. According to Dr. Eidson, "Everyone using IEEE 1588, including myself, owes special thanks to Kang Lee of NIST not only for his work as the IEEE sponsor of the standard, but also for his tireless efforts in its promotion."
- Program activities and results were highlighted in several trade magazines, including Industrial Engineering (July 2005), Fabrication and Metalworking Magazine (October 2006), Manufacturing Engineering (November 2006), and Mechanical Engineering (upcoming in 2008).

Projects

Advanced Manufacturing Systems Program

Physics-based Modeling of Machining

(Status: to be completed in FY2010)

Challenge/Problem Addressed:

Machining models have not yet reached their full potential as robust tools for process planners and tool designers, despite many academic studies and commercially available (finite element) simulation tools that predict machining performance. Existing models suffer from a lack of constitutive models to describe material behavior during the rapid increase of strain and rapid heating encountered in (high-speed) machining. Commercial modeling packages provide proprietary solutions to compensate for this missing information, but with variable success. Furthermore, there are no reliable methods to assess the performance of these models for generic applications. Fine-tuning such models for specific applications defeats the original purpose of using models to predict machining performance. One specific challenge related to assessment of machining models is to obtain an accurate measure of material flow and temperature distribution at the tool-workpiece interface. Although significant efforts have been pursued to measure cutting temperatures, the uncertainties associated with such measurements (reported or unreported) make the assessment of machining models very difficult.

Objective

Develop measurement methods and reference data to assess and improve the uncertainty of state-of-the-art physics-based machining models.

Accomplishments:

- Completed development of a pulse-heated Kolsky bar facility to measure material properties during rapid heating and rapid increase of strain. Capabilities include: strain rates up to 10^4 s^{-1}; a rapid heating capability of 1000 °C in 0.5 s; network-based database and data processing; and finite element models of sample behavior. Recent advances include compensation for the behavior of the graphite layer between the sample and the instrument, measurement and improvement of sample temperature uniformity, and heating rate control.
- Applied Kolsky bar data obtained for AISI 1045 steel to finite element machining simulations and improved the ability to predict cutting forces and temperatures observed during machining experiments.
- Developed a new orthogonal machining setup to validate physics-based machining models. Completed development of a high-speed, dual-spectrum (infrared and visible) micro-videography system to measure material flow and temperature distribution.
- Characterized and improved the uncertainties of thermal measurements during orthogonal cutting (e.g., camera calibration, stray reflections, emissivity changes during machining).

- Demonstrated the applicability of digital image correlation analysis in estimating the velocity and strain field during orthogonal cutting. Developed automated data acquisition system for chip segmentation frequency. Obtained micro-videography data for interrupted cutting.
- Collaborators such as Los Alamos National Laboratories and Third Wave Systems are using the data from these tests to validate and improve predictions of physics-based machining models.

Planned Future Accomplishments:

- Conduct Kolsky bar and orthogonal machining experiments to improve process parameter recommendations and cutting inserts for challenging alloys with high economic importance, such as titanium (planned collaboration with Kennametal).
- Perform further reduction and characterization of thermal measurement uncertainties (e.g., effects of the oxide layer on emissivity).
- Publish a guide on uncertainty assessment during thermal imaging of machining processes to improve machining process research by academia and industry.
- Lead international comparison of thermal measurements sponsored by the International Academy of Production Sciences (CIRP) to improve agreement of measurements and uncertainty statements.
- Develop strain measurement capability for the cutting shear zone to improve predictive models of machining phenomena.
- Develop new measurement method for material properties at higher strain rates than currently achieved with the Kolsky bar to better approximate conditions during high-speed machining.
- Develop a visual and thermal micro-videography measurement capability for other machining processes important to industry, such as milling.

Customers and Collaborators:

- Kennametal
- Los Alamos National Laboratory
- Third Wave Systems
- University of North Carolina at Charlotte

We provide regular updates to many companies and universities interested in our work through e.g., the annual Third Wave Systems User Conference.

Advanced Manufacturing Systems Program

Robust Optimization of Machining

(Status: to be completed in FY2009)

Challenge/Problem Addressed:

Although methods to optimize machining exist in the research community and in practical use, there is no unified methodology that combines all the information available related to process capability, machine capability, cutting tool characteristics, material properties, and other factors. Furthermore, the available knowledge and information suffers from significant uncertainties since the underlying data are often incomplete and ill-defined. Optimization that accounts for such uncertainties, providing "robust" optimum machining conditions, may require novel mathematical tools. Existing optimization tools are developed using certain objective functions and sets of constraints, but in a typical manufacturing environment requirements and conditions change frequently. Any generic optimization system should be able to adapt to these changes by allowing modifications to constraints and objective functions. Such flexibility would require all information to be represented in an unambiguous standard form, which currently does not exist.

Objective

Develop and test a prototype of a flexible and robust optimization framework that integrates all available process, machine performance, part design specifications, and associated time and cost information. This framework would help identify needs and opportunities for proper representation of knowledge and information to make possible construction of autonomous decision making tools in manufacturing.

Accomplishments

- Developed a prototype robust optimizer incorporating empirical modeling uncertainties and used the system to demonstrate 50% cycle time improvement for turning contoured production parts.
- Demonstrated integration of the robust optimizer with the STEP-NC standard, opening up possibilities for STEP-NC to deliver the much-promised capabilities surpassing those of the current RS-274 machine control language.
- Demonstrated a flexible capability for constructing optimization objectives and constraints based on business priorities, economic or technical considerations, or design specifications.
- Developed genetic algorithms to overcome difficulties in handling highly non-linear characteristics of process and equipment models in robust optimization, and obtained promising preliminary results.
- Developed preliminary interface specification for exchanging data between process planning and process optimization, paving the way for future standardization efforts.
- Developed a multi-layered framework for generalized machining optimization which includes facilities for strategic analysis (of preliminary process plans), translation of the analysis results to a set of objective functions and constraints, as well as the actual robust optimization based on these objective functions and constraints.

Planned Future Accomplishments:

- Test the interface specifications with a commercial computer-aided manufacturing system to demonstrate the validation of knowledge integration capabilities.
- Adapt the existing system to the newly acquired turning center.
- Investigate other methods of integrating machine and process information for modeling and decision making in follow-up projects.

Customers and Collaborators:

- Caterpillar
- United Technologies Corp.
- Agilent Technologies
- Techsolve
- Association for Manufacturing Technology
- Remmele Engineering
- Sikorsky Aircraft
- General Electric
- U.S. Army
- Los Alamos National Laboratory
- Oak Ridge National Laboratories
- Alcoa
- Third Wave Systems
- General Motors
- Ford Motor
- Cincinnati Lamb
- Hurco
- Hardinge Brothers
- Automated Precision Inc.
- Lion Precision
- VulcanCraft
- University of North Carolina at Charlotte
- University of Florida
- University of Maryland
- DP Technologies

Model-Based Control of Turning

(Status: completed in 2006)

Challenge/Problem Addressed:

The U.S. Army Armament Research, Development, and Engineering Center (ARDEC) located at Picatinny Arsenal required an improved machining capability to increase the accuracy of turned parts for Army products. Army personnel desired a science-based solution using adaptive machine control that incorporated sensor feedback and models of the machining process. A testbed was needed to support the integration, demonstration, and validation of prototype smart machine concepts for realistic applications on actual machine tools. Prior NIST work developed and implemented methods and software to improve the accuracy of machine tools and coordinate measuring machines. Candidate types of machines for effective error compensation generally have highly repeatable motions and are located in stable environments. This project applied and extended prior concepts to address the more common low-cost machine tools operating in a regular machine shop environment. The project's success demanded the demonstration of a functional, real-time model-based control system that improved machining performance in the real production environment.

Objective

Improve the efficiency of turning operations at the U.S. Army Picatinny Arsenal and its supplier base through the application of open-architecture model-based machine control.

Accomplishments:

- Completed real-time error compensation on two separate but similar machine tools (one at NIST, one at Picatinny Arsenal) resulting in 65% reduction of machine errors.
- Fully integrated the model-based software into the machine's open architecture controller to compensate for geometric and thermal errors, using real-time data from seven temperature sensors.
- Demonstrated machining process optimization using machining models and machine performance data, yielding a 50% improvement in productivity.
- Improved the efficiency and performance of turning operations for the manufacture of Army products through an upgraded machine tool and machining capability.

Customers and Collaborators:

- U.S. Army Armament Research Development, and Engineering Center (ARDEC)
- U.S. Army Picatinny Arsenal
- Fryer Machine Tools

Advanced Manufacturing Systems Program

Machine Tool Performance Characterization and Communication

(Status: to be completed in FY2010)

Challenge/Problem Addressed:

Performance characterization of machine tools and other manufacturing equipment is difficult due to the many geometric, dynamic, and thermal sources of errors that change over time and have complex impacts on part accuracy. Existing national and international standards address various aspects of machine performance testing, but can provide ambiguous and sometimes inconsistent guidance. U.S. manufacturers and users of machine tools urgently need harmonization of the standards for performance parameters and testing methods. Since machine performance data is difficult to obtain and analyze, full-scale performance characterization is not a common practice in industry. Instead, machine vendors and users typically rely on a limited set of tests to characterize their machines. A challenge is to identify and develop ways to maximize the information obtained by the limited tests. A further complication is the need for unambiguous and comprehensive measurement methods that have an intuitive relation to the capability of a machine. Current established performance tests are designed for "unloaded" conditions when the machine tool is not cutting the workpiece. Performance tests under operating conditions must be developed such that the loads can be applied during measurement while not influencing the measurement setup or methods. Once the machine performance information is obtained, no standards exist to communicate a machine's capability throughout the manufacturing enterprise. Standardized data models and specifications to represent machine performance information would have enormous utility in resource allocation, process planning, maintenance planning, supplier selection, and business decisions. The ultimate challenge is development and validation of procedures to translate generic performance parameters into machined tolerances of specific parts, so that knowledge about machine capabilities can be used for improved product design, diagnosis of product errors, and product quality assurance in agile manufacturing environments.

Objectives:

- Harmonize national and international standards for machine tool performance testing and characterization
- Develop updated test methods and standards that address technological advances of machine tools and testing equipment
- Develop standards for representing and communicating machine tool performance and machine tool specifications
- Develop in-situ measurement systems for characterization of cutting tools and workpieces
- Develop test methods, models, and standards to characterize the performance of machine tools under operating conditions
- Develop virtual machining algorithms to evaluate machine tool capability for machining parts to specification
- Create statistical machine performance models that incorporate uncertainties about machine performance and operating conditions typical of industrial environments

Accomplishments:

- Achieved the first-ever harmonization of U.S. national and ISO standards for machine tool performance evaluation, resulting in new capabilities for U.S. industry to unambiguously compare and specify machine tools, establish mutual obligations between buyers and sellers, and improve manufacturing productivity and product quality.
- Completed ISO 230-7:2006 "Test code for machine tools – Part 7: Geometric accuracy of axes of rotation," the first-ever international (ISO) standard for evaluating the accuracy of machine tool rotary axes and spindles. This standard makes possible consistent comparison and assessment of these most critical contributors of machine tool performance.
- Completed ISO 230-2:2006 "Test code for machine tools – Part 2: Determination of accuracy and repeatability of positioning of numerically controlled machine tool axes," introducing the concepts of measurement uncertainty associated with instruments and providing guidance for how to estimate and deal with such uncertainties in assessing machine positioning performance.

- Completed ISO 230-3:2007 "Test code for machine tools – Part 3: Determination of thermal effects," introducing test methods to assess structure deformations due to thermal gradients and other operating characteristics beyond just spindle drift and linear axis growth to make possible more comprehensive assessment of machine thermal behavior.
- Contributed to development of the draft ISO/TR 230-8 "Test code for machine tools – Part 8: Vibrations," first-ever ISO technical report outlining the theoretical basis for testing machine tool dynamic characteristics, applications, and test methods. Publication by ISO is expected in the first half of 2008.
- Contributed to development of the draft ISO 230-10 "Test code for machine tools – Part 10: Determination of the measuring performance of machine tools," providing tools to assess the validity and uncertainty of on-machine touch-trigger probe-based coordinate measurements, eventually leading toward minimization of costly post-process part inspections. Publication by ISO is expected by the end of 2009.
- Developed a new automated in-situ measurement system to characterize the dynamic properties of cutting tools for chatter avoidance, reducing the need for experienced test technicians and overcoming a key barrier for widespread use of dynamic testing.
- Completed a detailed analytical study on the properties of the proposed step-diagonal test for machine tool performance evaluation and presented the results at the International Lamdamap Conference, This study provides a scientific and neutral basis for competing instrument vendors to resolve their differences.
- Designed, fabricated, and integrated an invar metrology frame to a meso-scale machine tool to permit direct measurement of cutting tool position with respect to the workpiece, eliminating Abbe offsets and thermal influences on machine performance.
- Completed the draft ANSI/ASME B5.59-1 "Data specification for machine performance tests," and obtained ASME committee approval for initiating the ballot process. This standard will be the first-ever data specification standard for the properties and results of machine tool performance tests. It will facilitate the specification, exchange, and archiving of machine tool performance data, improving manufacturing applications ranging from resource allocation decisions to performance tracking, maintenance planning, and quality control.
- Completed the draft ANSI/ASME B5.59-2 "Data specification for properties of machine tools for milling and turning," and obtained ASME committee approval for initiating the ballot process. This standard will be the first-ever data specification standard describing the properties and performance of machine tools for unambiguous communication of machine capabilities among manufacturing applications. It will facilitate better resource allocation decisions, integration of design and manufacturing, and e-commerce for more efficient supply chains.

- Developed and implemented virtual machining software algorithms to analyze the effects of machine tool and setup errors on the accuracy of hemispherical parts at Los Alamos National Laboratory. Results are used to establish selection criteria and test procedures for machine tools.

Planned Future Accomplishments:

- Develop test methods and standards to characterize 5-axis machining centers and multi-tasking turning centers.
- Finalize test methods to assess the measuring capability of machine tools using touch-trigger probes and other measuring instruments.
- Develop measuring instruments and methods to enable machine tools to self-assess their errors.
- Develop statistical tools to estimate part quality based on a small set of machine tool performance data and associated uncertainties.
- Implement and validate an in-situ measuring system for tool dynamics in high-speed machining applications.
- Validate the effectiveness of the metrology frame on the meso-scale milling machine by demonstrating improvement in machined part accuracy.
- Develop new measuring systems to enable on-machine part inspection and verification.

Customers and Collaborators:

- Caterpillar
- United Technologies Corp.
- Agilent Technologies
- Techsolve
- Association for Manufacturing Technology
- Remmele Engineering
- Sikorsky Aircraft
- General Electric
- U.S. Army
- Los Alamos National Laboratory
- Oak Ridge National Laboratories
- General Motors
- Ford Motor
- MAG Cincinnati Machine
- Hurco
- Hardinge Brothers
- Automated Precision Inc.
- Lion Precision
- VulcanCraft
- University of North Carolina at Charlotte
- University of Florida

Advanced Manufacturing Systems Program

Condition Monitoring of Machine Tools (Status: to be completed in FY2009)

Challenge/Problem Addressed:

Machine tools are complex structures with many potential sources of failure. Incompleteness of data and a low signal-to-noise ratio make it difficult to identify and diagnose the conditions of machine components in "noisy" machining environments, often leading to expensive false alarms. Data obtained from multiple sensors that monitor different aspects of the system or operation must be integrated and continuously correlated with expected signatures from the properly functioning operation.

Objectives

Develop measurement, sensing, and analysis methods and associated data specifications and metrics to verify that machine tools and machining processes are operating within expected design limits and to optimize maintenance tasks. Specifically:

- Develop optimal sensor placement methodology for condition monitoring of machine spindles
- Develop wavelet-based envelope algorithm to process sensor data for diagnostics
- Develop output-only modal analysis method for testing spindle condition
- Demonstrate remote monitoring to detect and analyze abnormal machine conditions
- Develop a framework to integrate information related to machine condition and maintenance planning
- Develop standards for smart sensor interfaces and networks

Accomplishments:

- Developed a structural dynamics-based approach for optimization of sensor placement on machine spindles using the Effective Independence (EfI) method, providing the capability to minimize the number of sensors needed to obtain all critical information for a given spindle design.
- Developed and verified a new signal processing technique using an analytic wavelet transform to extract the envelope of the defect-related vibration for diagnosis of spindle condition, increasing sensitivity to small systematic variations in bearing signatures and leading to early fault detection capabilities that prevent costly spindle failures.
- Demonstrated a method of testing spindle condition using the output-only modal analysis technique, enabling modal analysis to be a fast, non-intrusive, and cost-effective fault detection tool.
- Developed a framework to organize the cause-and-effect relationships of potential machine failures and remedial actions, leading towards more comprehensive systematic analysis, planning, and optimization of machine maintenance operations.
- Led the development and completion of two parts of the IEEE 1451 series of standards for smart sensor interfaces and networks, enabling interoperability among a variety of sensors and sensor networks.
- Initiated and led a new standards activity leading to release of the first version of the IEEE 1588 standard for precision clock synchronization for networked measurement and control.

Planned Future Accomplishments:

- Develop a suite of parameters based on combinations of waveform analysis techniques optimized for spindle condition monitoring.
- Validate optimal parameters by correlating them with metrics of spindle condition throughout its useful life.
- Expand the IEEE 1588 standard to extend precision clock synchronization to applications for industries such as aerospace, industrial automation and control, power and utility, and telecommunication.

Customers and Collaborators:

- University of Massachusetts-Amherst
- Timken
- Boeing Commercial Airplane
- Caterpillar
- United Technologies Corp.
- Agilent Technologies
- Techsolve
- Association for Manufacturing Technology
- Remmele Engineering
- Sikorsky Aircraft
- General Electric
- U.S. Army
- General Motors
- Ford Motor Company
- MAG Cincinnati Machine
- Hurco; Hardinge Brothers
- VulcanCraft
- University of Florida
- University of Maryland

Manufacturability of Fuel Cells

(Status: to be completed in FY2008)

Challenge/Problem Addressed:

Manufacturers of fuel cells are under tremendous pressure to increase production rates and improve fuel cell performance while significantly reducing the cost of production. For automotive applications, fuel cell manufacturers must be able to produce a high-performing bipolar plate every few seconds. No data exists on the influence of fabrication variations on fuel cell performance. As a result, fuel cell manufacturers and their second tier suppliers are continually searching for better fabrication methods to increase production rates and improve cell performance.

Objective

Generate a knowledge base providing the relationship between fabrication variations in bipolar plate production and single cell performance.

Accomplishments:

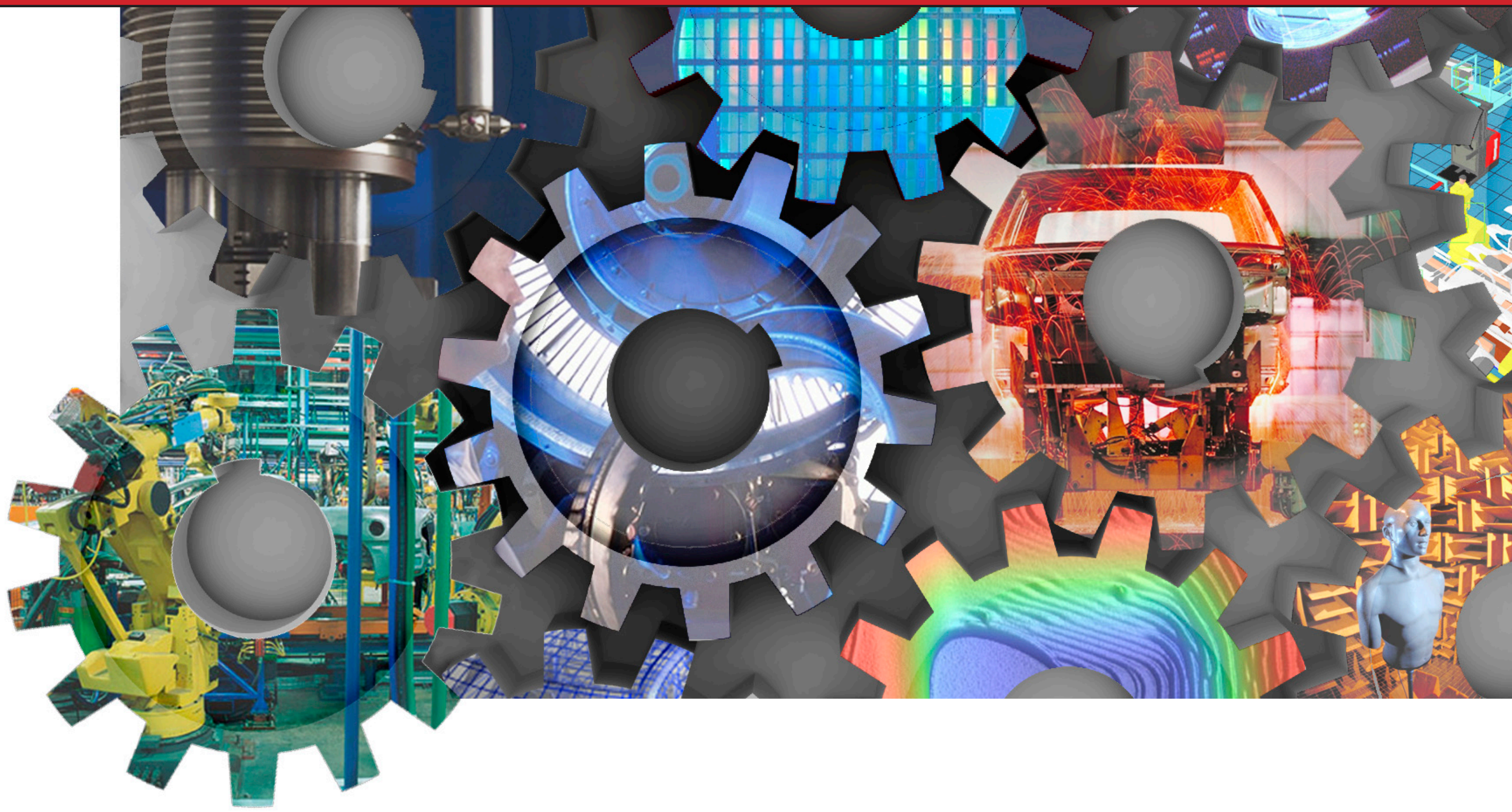
- Designed statistical factorial experiments (4 factors, 2 levels) for conducting and analyzing test results in order to identify relationships between fabrication variations and fuel cell performance.
- Machined a set of graphite bipolar plates with simulated errors in the flow field geometry and performed detailed dimensional inspection.
- Assembled the NIST-fabricated plates with original Teledyne plates (on anode side) and successfully completed leak testing in accordance with U.S. Fuel Cell Council test protocols.
- Conducted electrical testing of single cells according to the factorial design to identify relationships to fuel cell performance.

Customers and collaborators:

- U.S. Fuel Cell Council (USFCC)
- Los Alamos National Laboratory
- National Renewable Energy Laboratory
- Department of Energy
- General Motors
- Teledyne Corporation
- Rensselear Polytechnic Institute
- Japanese Automobile Research Institute (JARI)
- Korean Institute for Energy Research (KIER)

Standards Leadership And Participation

	Mass	Force	Acceleration	Acoustics	Optics	Manufacturing Technology
National Standards	- ASTM E41.06 Weighing Devices	- ASTM E28 Mechanical Testing	- ANSI S2 Mechanical Vibration & Shock (Vice-Chair) WG2 Terminology (Chair) WG5 Calibration & Use of Instruments (Chair) - ANSI/ASA US TAG for ISO TC108 (Chair) - ANSI/ASA US TAG for ISO TC108/SC3 Use and Calibration of Mechanical Vibration & Shock Measuring Instruments (Chair)	- ANSI/ASA S1 Acoustics - WG 1 Standard Microphones & Their Calibration (Chair) - WG21 EMS of Acoustical Instruments - ANSI/ASA S3 Bioacoustics - WG48 Hearing Aids - ASA Committee on Standards (ASACOS) - SAE Emergency Vehicle Siren (J1849) Task Force (Vice-Chair) - SAE Emergency Warning Lights and Devices - ANSI US TAG for IEC TC87 Ultrasonics	- Optics and Electro-Optics Standards Council (OEOSC) - ANSI/OEOSC US TAG for ISO TC 172 Optics and Photonics	- ANSI/ASME B5 Machine Tools - ANSI/ASME B5/TC52 Machining & Turning Centers - ANSI/ASME B5/TC56 Information Technology for Machine Tools (Chair) - ANSI/ASME B89.3.4 Axes of Rotation - IEEE P1451 Smart Transducer Interface for Sensors & Actuators; P1451.0, .1, .2, .3, .4, .5, .6 & .7 WGs - IEEE 1588 Precision Synchronization for Networked Measurement & Control WG - IEEE I&M Society TC9 Sensor Technology Committee (Chair) - IEEE-SA Standards Committee (I&M Society liaison)
SIM	- Metrology Working Group 7 Mass & Related Quantities	- Metrology Working Group 7 Mass & Related Quantities	- Metrology Working Group 9 Acoustics & Vibration	- Metrology Working Group 9 Acoustics & Vibration	Not generally applicable	Not generally applicable
OIML	- OIML TC9 Instruments for Measuring Mass & Density - OIML TC9 SC3 Weights (Tech Advisor)	- USNWG / OIML TC9 / WG1 Load Cells		- US National WG for OIML TC13 Measuring Instruments for Acoustics and Vibration (Technical Advisor)	Not generally applicable	Not generally applicable
CIPM Consultative Committees (CC)	- CC for Mass and Related Quantities (CCM) WG on Mass & Density	- CC for Mass and Related Quantities (CCM) WG on Force	- CC for Acoustics, Ultrasound, and Vibration (CCAUV)	- CC for Acoustics, Ultrasound, and Vibration (CCAUV)	Not generally applicable	Not generally applicable
ISO/IEC	Not generally applicable	- ISO TC 201 SC9 Scanning Probe Microscopy	- ISO TC 108 Mechanical Vibration & Shock (Chair of US Delegation) - WG 1 Terminology - WG 26 Signal processing methods for analysis of mech. vibration & shock (Convener) - SC3 Use and Calibration of Vibration & Shock Instrumentation (Chair of US Delegation) - SC3/WG6 Calibration of Vibration & Shock Transducers - SC3/WG10 Vibration Condition Monitoring Transducers and Instrumentation	- IEC TC 29 Electroacoustics (Chair of US Delegation) - IEC TC 29/WG5 Measurement Microphones - US National Committee for IEC (Member, as Technical Advisor for TC 29 Electroacoustics) - ISO TC 135/SC3 Acoustic Methods (Chair)	- ISO TC 172 Optics and Photonics	- ISO TC 39 Machine Tools - ISO TC 39/SC2 Test Conditions for Machine Tools (Secretariat) - ISO TC 39/SC2/WG1 Geometric Accuracy of Machine Tools - ISO TC 39/SC2/WG3 Test Conditions for Machining Centers - ISO TC39/SC2/WG4 Test Conditions for Turning Centers - ISO TC 39/SC2/WG6 Thermal Effects (Convener) - ISO TC39/SC2/WG7 Capability of Machine Tools - ISO TC 184/SC4 Industrial Data



Chief:
Elena Messina (Acting)

NIST
100 Bureau Drive
Stop 8230
Gaithersburg, MD
20899-8230

Phone:
(301) 975-3510

Fax:
301 990 9688

Email:
elena.messina@nist.gov

ISD

Intelligent Systems

Mission

To develop the measurements and standards infrastructure needed for the application of intelligent systems

Overview

The Intelligent Systems Division supports a future in which U. S. manufacturing grows more accurate, agile, intelligent, interoperable, and reconfigurable through constant innovation. Our work promotes the development of measurement science and interoperability standards that will enhance manufacturing robotics and automation equipment and the underlying industrial control systems.

Federal and industry groups have specifically stressed the importance of innovation in robotics, manufacturing automation, and control systems for maintaining U. S. primacy in innovation and high-value-added manufacturing. The American Competitiveness Initiative (ACI) lists advancements in manufacturing as a key priority. The President's Council of Advisors for Science and Technology (PCAST) has said that "the big winners ... will be those who develop talent, techniques, and tools so advanced that there is no competition" and warns that "where product cycles mature and the costs of labor come to dominate … the United States loses its competitive advantages." The National Academy of Engineering report on the Transformation of Manufacturing in the 21st Century articulates a vision in which "… parts can be produced, without tooling or programming, in a single, highly flexible production cell, thus eliminating the need for, or even the advantage of, scale, including volume scale." Smart systems, reconfigurable tools and systems, and sensors are among the eight "Categories of Innovative and Potentially Disruptive Advanced Manufacturing Technologies" documented by a National Council for Advance Manufacturing (NACFAM) Report. In particular, robotics holds tremendous untapped potential in manufacturing. A Robotics in Manufacturing Roadmap sponsored by Department of Energy (DOE) estimated that 90% of potential users have not yet adopted robotics. The same study found that manufacturers need robots that can be more "aware" of their environments and their workpieces so that they no longer require tremendous investments in highly controlled infrastructure, including safety zones for pedestal robots and guided pathways with no obstacles for mobile robots. A lack of adequate sensing of surroundings limits robots' ability to respond to any changes,

Target user communities lack any means whatsoever of specifying quantitatively what performance they need from a robot. Nor are there any means of objectively and reproducibly measuring how well robots or their components meet a given set of requirements. As robots and other manufacturing equipment become more flexible and adaptable, and work in closer unison with humans, safe operations become a paramount issue. As factory equipment becomes more tightly networked within the work cells[1] as well as with external systems, security issues grow in importance. Referring to the Drivers and Needs for U. S. Manufacturing Innovation and Competitiveness identified by the Manufacturing Engineering Laboratory, our division seeks to address the increasing pace of technological change, which encompasses product and process innovation, as well as reduction in time to market, higher quality and better performance of customized products, increased productivity and reduced costs, and new safety and security challenges.

1 A physical grouping of equipment that produces similar products

The Intelligent Systems Division tackles the challenges posed in attaining this vision of the future by partnering with industry and academia to ensure that innovation in manufacturing systems is well-characterized and quantifiable (through development of a measurement science), open, extensible, and reconfigurable (through development of interoperability standards), as well as safe and secure (through industrial control network security standards). To target these challenges, our Division's work is organized into three programs. The Measurement Science for Manufacturing Robotics and Automation Program provides means of characterizing, measuring, and assuring the performance of advances in technologies that make possible manufacture of higher quality and more complex parts and assemblies through predictable, well-characterized manufacturing equipment. Flexible, reconfigurable manufacturing systems and model-based manufacturing require well-defined and rich information transfer, which is addressed by the Robotics and Automation Interoperability Standards Program. The Intelligent Manufacturing Industrial Control Systems and Network Standards Program responds to the need for safe, secure, and reliable manufacturing systems. The Intelligent Systems Division is world-renowned for its accomplishments in development of measurement science, tools, and interoperability solutions for leading-edge mobile robots and other complex automation that has been applied to defense, transportation, and security. We bring this core competence to bear in our work within the manufacturing domain.

Resources

Staff

35 NIST staff

9 guest researchers

FY2008 Estimated Funding

$5,515K STRS (excluding Innovation in Measurement Science)

$5,327K Other Agency

Facilities and Equipment

ISD is expanding the set of equipment and facilities that support its measurements and infrastructure mission. ISD uses unique facilities and tools to define performance metrics and measurement methods and to serve as testbeds for industry and researchers.

- Dimensional Metrology Interoperability Testbed: Supports development and validation of new data and interface protocols and test suites for quality measurement information.Smart Machining And Machine Tool Interoperability Testbed: Supports validation and testing of emerging data standards for machining equipment.

- Industrial Control Networking and Cybersecurity Testbed: Supports development and testing of new network performance standards Industrial Robotics Measurement Science Testbed: Supports development and validation of new performance test methods for advanced industrial robot arms and mobile robots (under construction).
- Micro- through Nano-devices 3D Metrology Testbed: Provides 1D, 2D, and 3D assembly and positioning metrology and test facilities using high-precision MEMS stages, controllers, nanoprobes and calibration devices.
- Indoor and Outdoor Position Measurement And Tracking Facilities: Permits evaluation of sensors and algorithms for mobile robots through a variety of dynamic vehicle and sensor data collection efforts. This set of facilities also includes several unique buildings and outdoor areas appropriate for application-specific scenarios for evaluating robot performance. Examples include military and bomb squad operations. Facilities include draft and approved standard test methods for urban search and rescue and bomb-disposal robots.
- State-of-the art 3D and 6D sensors: Support characterization and development of test methods and reference data sets (ground truth) against which to measure sensing and positioning accuracy, both statically and dynamically.

Facilities and Equipment Challenges:

NIST is currently slated to relinquish the site that houses the Indoor and Outdoor Position Measurement And Tracking Facilities in the coming years. We will have to find similar space (especially indoor).

Intelligent Systems Program

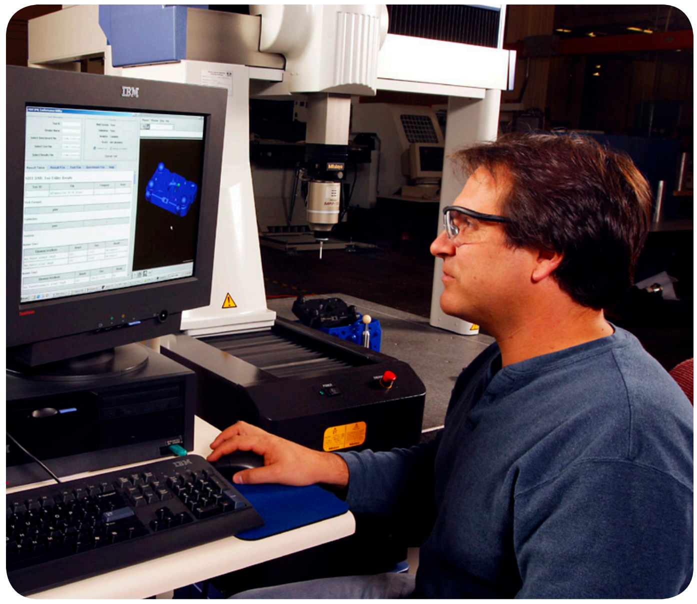
Robotics and Automation Interoperability Standards Program

Annual FTEs: 7 NIST staff
1 guest researcher
8 total FTEs

Challenge:

The increasing pace of technological change and expectations of shorter time-to-market for new products represent growing challenges for U.S. manufacturers. These pressures, combined with the push for distributed manufacturing facilities, create an urgent need for shop floor robots and automation equipment that offer:

- Real-time integration between engineering, production, and business function, which may be geographically dispersed. Information and instructions need to be transmitted and acted upon without the delays that currently occur because of missing or misinterpreted data.
- Faster, more accurate, and more autonomous onboard planning, re-planning, and execution abilities that are driven by product and process models and respond to changes elsewhere in the manufacturing enterprise. Machine tools, robots, and coordinate measurement machines currently require extensive trial-and-error debugging whenever a new program is downloaded. This rework and tuning by human operators results from the hard-coded nature of the programs, which cannot adapt to individual differences in each piece of equipment. The challenge is to provide the necessary information about the part design (features, tolerances, etc.) as well as the machine's own characteristics so that it can automatically adjust for its own motion errors and other variations.
- Interoperability of products from diverse vendors. Manufacturing enterprises must be able to buy the best equipment for their needs and to outsource production of various components. For these options to be economically viable, data must be reliably transferred among machine tools, robots, and coordinate measurement machines. U.S. manufacturers must be able to buy equipment with confidence that it will integrate with the rest of their enterprise.



Testing standard interfaces for dimensional metrology equipment

Overview

The Intelligent Systems Division is working on interoperability standards that will meet the challenges listed above. We are working to achieve a vision of the seamless transfer of "smarter" data. This is an essential prerequisite not only for reliable transfer of information between equipment controllers, but also for providing enough richness in the information to enable the shop floor equipment to make in situ decisions when new programs are received and when conditions change. This vision of seamless smart data transfer presents business and technical challenges. To address the business challenge, which is rooted in resistance to standards, ISD involves vendors and end users in the definition of requirements, standards, and validation. The technical challenges center on the definition of the data models and interface protocols themselves: are they complete, efficient, unambiguous, and correct? MEL is addressing the technical challenges by developing measures of the correctness (syntactic and semantic) of interface language specifications and by implementing standards validation tools and processes.

Thus far, we have focused on interoperability standards for metrology equipment and next generation machine tools. The metrology equipment standards cover interfaces between computer aided-design (CAD) and Product Life Cycle Management Software, Inspection Process Planning Software, Inspection Execution Software, Coordinate Measuring Machines, and Reporting and Analysis Software. In the next generation machine tools interoperability front, NIST has been focusing on the ISO 10103 AP 238 ("STEP NC – Standards for the Exchange of Product model data – Numerical Control") and on the Open Modular Architecture Controller Human-Machine Interface (OMAC HMI).

Key Accomplishments and Impacts:

- With industry partners, NIST has conducted numerous tests and pilot experiments that demonstrate facets of STEP-NC (such as feature-based steps, and the ability to support dynamic optimization and compensation) in action and validate that the data contained in the standard can be interpreted in real-time. Successful tests of this sort are necessary to build industry confidence and participation in these new standards.
- Thanks in great part to NIST efforts in developing validation test suites and bringing the stakeholder community together, several metrology standards are gaining wide acceptance. Examples include the I++ DME (Dimensional Measuring Equipment) specification, the DML (Dimensional Markup Language) specification, and QMD (Quality Measurement Data).

Future Directions and Plans:

Looking ahead, NIST will continue to strengthen its ties to the different communities in the broader metrology landscape and among the users of advanced machining technologies. Additional opportunities for NIST to apply its expertise include interface standards for nanoscale metrology, material transport vehicles, and industrial robots.

Awards and Recognition

Board Membership

Staff	Board Membership
John Horst	• Advisory Board, Quality Expo • Advisory Board, 3D Collaboration and Interoperability Conference • Board of Directors, Dimensional Metrology Standards Consortium Board of Directors

Leadership

Staff	Leadership
Fred Proctor	• Executive Committee of the Computers and Information in Engineering (CIE) Division of the American Society of Mechanical Engineers.
John Horst	• Chair, Dimensional Metrology Standards Consortium High-Level Measurements Process Planning (HIPP) Subcommittee • Executive Committee member, AIAG Metrology Interoperability Project Team
John Michaloski	• Chair, Open Modular Architecture Controller Human-Machine Interface
Hui-Min Huang	• Invited plenary on architectural perspective for a robotics standards technical framework at the OMG Robotics Domain Special Interest Group meeting

Excellence

Staff	Excellence Recognized
Joseph A. Falco John A. Horst Hui-Min Huang Willlam G. Rippey Keith A. Stouffer	• Department of Commerce Bronze Medal Award for Superior Federal Service (2006): For technical leadership and engineering achievement demonstrating outstanding initiative, commitment, and technical competence in developing critically-needed software testing tools for the I++ Dimensional Measurement Equipment and Dimensional Markup Language data exchange standards.
John Horst	• Automotive Industry Action Group (AIAG) Outstanding Achievement Award for efforts to enable metrology systems interface standards in the automotive industry. (2005)
Frederick Proctor, et al.	• Guest Editorial, "STEP-Compliant Process Planning and Manufacturing," International Journal of Computer Integrated Manufacturing special issue on STEP-NC, Vol. 19, No. 6, September 2006.
John Michaloski	• ISA On-line Webinar, "Integrating CNC and ERP - A Real World Success," in June 2006
James Albus	• Keynote presentation to International Conference on Smart Machining Systems, 2007
Bill Rippey	• Invited technical coordinator for trade show interoperability demonstrations sponsored by International Association of CMM Manufacturers (iacmm), 2004-2008. The yearly demonstrations at Control involve integration of 8-14 vendor's products.

Projects

Robotics and Automation Interoperability Standards Program

Metrology Interoperability Project

(Status: to be completed in 2011)

Challenge/Problem Addressed:

The U.S. manufacturing sector is suffering significant interface language incompatibility costs, since products can talk with one another only through translators that are costly to build and maintain. For example, certain dimensional metrology product vendors must build and maintain internal translators for more than *sixty* different upstream and downstream products. All this cost is passed on to the OEM and eventually to the customer. Airbus's recently-reported anticipated $6.1 billion loss over 4 years was in large measure the result of interface language incompatibility. Besides their intrinsic cost, such translation efforts do not add to product value, are detrimental to quality, and stifle innovation.

The ideal solution to this problem is worldwide adoption of correct, complete, and unambiguous interface language standards. For the quality measurement sector of manufacturing, Figure 1 shows the number and types of interfaces along with the current and future standards at each interface.

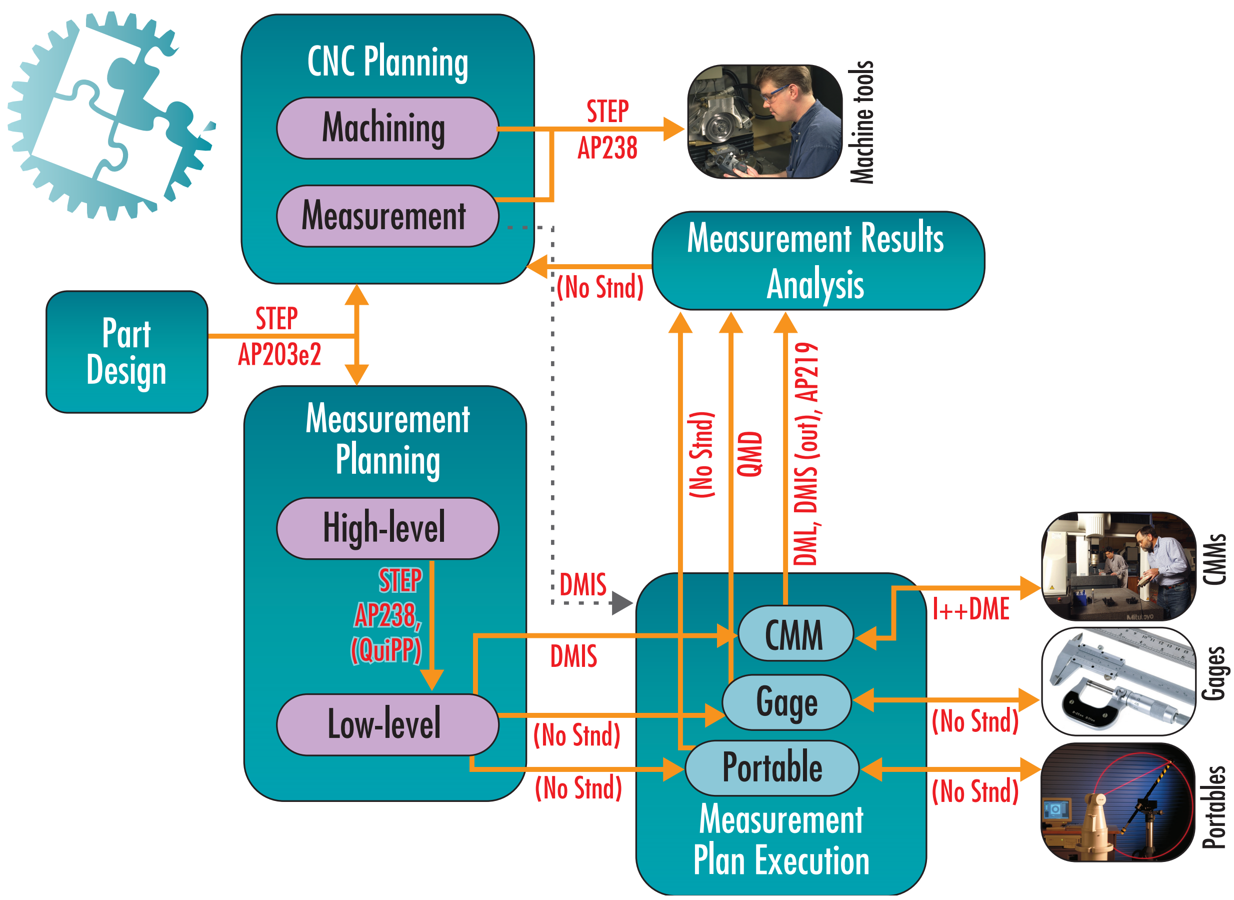


Figure 1: Quality Measurement Information Exchange Standards Infrastructure

Objectives:

- Define and update a standards infrastructure for quality measurement information at the interfaces between product design, product manufacture, measurement planning, measurement execution, measurement equipment, and measurement results analysis.
- Define complete, correct, and unambiguous quality measurement information exchange standards in appropriate information modeling languages and make possible compliant implementations of those standards worldwide.
- Define and develop implementation conformance tests for both sides of each interface defined in the standards infrastructure
- Facilitate regular public demonstrations of interoperability with vendors worldwide for each interface in the standards infrastructure.
- Act as an advocate for U.S. quality measurement systems user corporations (automotive, aerospace, defense, etc) and for quality measurement information exchange standards through meeting organization, conference talks, and board membership.
- Integrate metrology information exchange standards with information exchange standards efforts in the broader manufacturing context, including machining, forging, casting, and assembly.

Accomplishments:

- Achieved worldwide acceptance of key metrology standards through NIST specification analysis, standards development consultation, public interoperability demonstrations, and test suite development. These achievements reduce the need for standalone custom translators and the costs incurred by incomplete or erroneous information transfer. Standards that have benefited from NIST involvement include I++ DME, Automotive Industry Action Group (AIAG) Dimensional Markup Language, Dimensional Metrology Standards Consortium's Dimensional Measuring Interface Standard (DMIS), and AIAG's Quality Measurement Data specification.
- Defined information needed to generate a high-level measurement process plan as well as the high-level process plan itself for use within STEP NC (ISO STEP AP238), allowing for implementation of rich on-machine inspection.
- Organized International Metrology Interoperability Summit in 2006, which elicited input from stakeholders about industry priorities and needs. A Metrology Interoperability Roadmap was published, providing a baseline assessment of interoperability and guidance for future standards efforts.

Vendors demonstrate integration of multi-vendor products

Planned Future Accomplishments:

- Generate DMIS test utilities for all DMIS conformance classes. Generate and update compliance tests for other standards within the standards infrastructure.
- Define product certification for DMIS-generating products as the DMIS test utilities emerge. Introduce the concept of certification for other quality measurement information exchange standards.
- Define a Quality Measurement Process Planning (QuiPP) standard using the Unified Modeling Language (UML)
- Work with the manufacturing machining standards community (including ISO STEP-NC group) to integrate rich and accurate metrology information that will allow correct and complete on-machine coordinate metrology.
- Define standards or modify existing standards for portable metrology systems such as optical metrology systems and portable arm CMMs. The command and results analysis requirements of these systems have some fundamental differences from the same requirements for traditional CMMs.

Customers and Collaborators:

- Ford Motor Company
- Lockheed Martin
- Honeywell FMT
- Boeing
- General Motors
- Chrysler LLC
- Daimler
- Audi
- Volvo
- BMW
- International Association of Coordinate Measuring Machine Manufacturers
- Automotive Industry Action Group (AIAG)
- Society of Manufacturing Engineers
- Longview Associates
- Dimension Metrology Standards Consortium
- Mitutoyo
- Wenzel
- Metromec
- Hexagon Wilcox
- Hexagon Brown & Sharp
- Sheffield
- Helmel Engineering
- Siemens PLM Software
- Dassault
- Renishaw
- Faro
- Applied Precision, Inc.
- Zeiss
- Messtechnik Wetzlar
- Xspect Solutions, Inc.

Robotics and Automation Interoperability Standards Program

Next Generation Machine Tool Control Interoperability

(Status: to be completed in 2010)

"Smart data for smart machines:"

Challenge/Problem Addressed

The challenge is to make possible the development of faster, more accurate, and more autonomous machine tools that are driven by product- and process models and are responsive to the manufacturing enterprise.

Challenges to realizing the vision of smart data for smart machines are the resistance of vendors to standardization (a business challenge) and the development of the data models themselves (a technical challenge). To address the business challenge, we realize that vendors and end users must be involved in the development of standards and pull for their success. Looking at the extent of vendor- and end-user involvement and the potential markets for U.S. companies, we prioritize candidate standards and select those that we think have the most potential. Along the way, we continually assess these markers to decide whether to continue participating. STEP-NC and OMAC HMI have shown growing involvement from vendors and end users (aerospace and automotive) with more impressive demonstrations each year.

Objective(s):

Support industry groups by validating data exchange standards, specifically the ISO 10103 AP 238 "STEP-NC" standard for machine tool programs, and the Open Modular Architecture Controller Human-Machine Interface (OMAC HMI) standard for machine tool status information. Paraphrasing BASF, "We don't make the standards you use, we make the standards you use better."

Accomplishments:

- Developed prototype implementations of STEP-NC based interpreters and controllers to establish the feasibility of benefits to industry, such as:
    - real-time interpretation of STEP-NC data models
    - on-machine compensation for straightness, angularity, and squareness
    - toolpath optimization based on STEP-NC data
- Developed a real-time connection between computer-numerical control and enterprise resource planning for aerospace applications, leading to the OMAC specification. Demonstrated at a series of public tests held by Boeing.

Planned Future Accomplishments:

- Validate extensions to STEP-NC to support traceability and data logging (FY09).

Customers and Collaborators:

- Airbus
- Boeing
- Fanuc
- Gibbs CAM
- Mastercam
- Okuma
- Sandvik
- Siemens
- STEP Tools Inc.
- Unigraphics
- International Organization for Standardization (ISO)
- OMAC

Intelligent Systems Programs

Measurement Science for Manufacturing Robotics and Automation Program

Annual FTEs: 10 NIST staff
5.5 guest researchers
15.5 total FTEs

The Thermo robot with the SmartTRACK sensor attached

Challenge

Manufacturers anticipate a future in which people will work side by side on the shop floor with versatile and adaptable robots and other automation systems. For this vision to come about, equipment will need to perceive the geometry, location, color, features, and movements of items and people in its vicinity and have an intrinsic ability to adjust for variations in parts, environment, and other conditions, rather than relying on fixed automation and costly infrastructure. The long-term challenge is to build a performance measurements science to characterize constituent components for intelligent manufacturing systems, define the target performance goals, and measure how well a component or overall system meets the goals.

Overview

NIST is working with manufacturers and developers of robotics and automation systems to define performance requirements that will help manufacturers build higher quality, higher-precision and more complex parts or assemblies, in a predictable, adaptive, safe, and efficient way. These requirements are used to establish metrics and quantitative, reproducible test methods that will spur innovation in the robotics and automation systems communities and pave the way for the needed advancements in capabilities, quality, and productivity.

NIST has long been a leader in establishing performance measures for mobile and intelligent robots, components, and algorithms. ISD expertise has drawn significant external funding from defense, transportation, and security agencies. This work has given us a strong foundation from which to apply the knowledge and tools gained to manufacturing robots and automation. In addition to defining performance metrics and test methods for overall systems, ISD efforts also address sensing, planning (including navigation), human interaction, mobility, and other essential component evaluation and characterization.

Key Accomplishments and Impacts:

- Organized a workshop on Dynamic Measurement and Control for Automated Manufacturing, through which industry defined their requirements for more autonomous and responsive robots.
- Developed a testbed for evaluating sensors, particularly a new class of 3D Flash LADARs (Laser Detection and Ranging). This enabled ISD to provide characterization data to industry where none previously existed.
- Applied ISD-developed techniques for evaluating the performance of 6D sensing and motion by robots, providing researchers and industry with quantitative data about their robots, sensors, and algorithms. Obtaining high-resolution data for robots in motion within a dynamic environment had previously not been possible. ISD involvement has led to the successful adoption of non-contacting safety sensors as vehicle obstacle detection devices (ANSI B56.5), increasing the safety zone around vehicles.
- ISD's robotics expertise feeds into the development of world-class advanced control and positioning systems for nanoscale measurements and standards. A half-dozen micro-, meso-, and nanoscale positioners (some multi-axis) have been built and tested. These devices are being used to demonstrate 2D and 3D micro- and nano-assembly and to validate performance measures now under development. Such studies provide industry and researchers with knowledge about device characteristics crucial for their design and utilization.

Future Direction and Plans:

- Working with a newly-developed consortium of Automated Guided Vehicles (AGV) companies, ISD will develop requirements and standards for 3D imaging systems that can detect overhanging obstacles, which currently pose a major danger to these vehicles.
- Develop requirements for AGVs (which will become mobile robots) and robots arms to meet the flexibility, adaptability, and safety challenges articulated by users. ISD's work will focus on the next generation of sensing, planning, and control to enable robots to operate safely in unconstrained and dynamic environments and in cooperation with humans. Detailed requirements and metrics will be used to generate standard test methods for quantifying and validating the performance of components and integrated systems.

Awards and Recognition:

Board Membership

Staff	Board Membership
Roger Bostelman	• Board member on the ANSI/ITSDF B56.5 Sub-Committee for "Safety Standard for Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles."
Raj Madhavan	• IEEE Robotics and Automation Society (RAS) Conference Editorial Board (CEB)
Elena Messina	• Advisory Board, Texas A&M Engineering Extension Service (TEEX)

Leadership

Staff	Leadership
James Albus	• Editorial board for Autonomous Robots, Robotics and Autonomous Systems, Journal of Robotic Systems, Intelligent Automation and Soft Computing
Nicholas Dagalakis	• Co-organizer, 4th International Conference on Safety of Industrial Automation Systems SIAS-2005 . • Organizer, Workshop on Metrology Needs for Micro Nano Systems Technologies. • Technical Advisor, ANSI US TAG for ISO TC 184, SC 02, Robots and Robotic Devices
Raj Madhavan	• Founded the Washington DC section of the IEEE Robotics and Automation Chapter • Chair of IEEE Robotics and Automation Society Washington Chapter
Raj Madhavan, Steve Balakirsky	• Originators and Chairs, IEEE Robotics and Automation Systems New Initiatives Competition "Advancing Robotic Research through an Open Source High-Fidelity Simulation Framework and Competition" (2007).
Raj Madhavan, Elena Messina	• Co-chairs (along with Angel del Pobil) of Workshop on Performance Evaluation and Benchmarking for Intelligent Robots and Systems at IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), San Diego, U.S.A., Nov. 2007.
Craig Schlenoff and Steve Balakirsky	• Chairs, Workshop on Knowledge Representation for Autonomous Systems at the 2005 ACM Conference on Information and Knowledge Management.
Craig Schlenoff	• Chair of the NIST Research Advisory Committee, 2007

Excellence

Staff	Excellence Recognized
James Albus	• Distinguished Lecture at University of Texas, Arlington on Toward A Computational Theory of Mind, 2007
Roger Bostelman	• Defense Manufacturing Conference (DMC) 2007 award for Best Presentation at the December 07 "Gee Whiz Technologies"
Adam Jacoff, Raj Madhavan, Elena Messina	• Guest Editors, Special Issue on Quantitative Performance Evaluation of Robotic and Intelligent Systems, Journal of Field Robotics, John Wiley & Sons, Inc., 2007, Volume 24, Issue 8-9 (August - September 2007).
Elena Messina	• Guest Editor, *Integrated Computer-Aided Engineering*, Volume 12, Issue 3, 2005, Special Issue on Performance Metrics for Intelligent Systems.

Projects

Measurement Science for Manufacturing Robotics and Automation Program

Introduction

The Next Generation Robot (NGR), as defined by industry groups, is a machine that will incorporate inherent safety design and benign operating features in order to facilitate and promote lean manufacturing. ISD has worked with a broader definition of NGR, in which more advanced autonomy and intelligence is integrated into mobile vehicles and industrial arms. Work has been carried out in three complementary thrust areas. Performance Simulation for Mobile Manufacturing Robots tightly integrates real and virtual environments to develop advanced shop floor robotics concepts and creating performance requirements and test methods. Industrial Autonomous Vehicles focuses on transferring technologies from defense robotics to the materials handling and transport industries, and Next Generation Robot Safety concentrates on safety standards for industrial robots. Going forward, these projects will become more tightly connected to each other and to the division's perception and sensing standards projects, which also support the Measurement Science program.

Measurement Science for Manufacturing Robotics and Automation Program

Performance Simulation (PerfSim) Project (status: initiated in 3QFY07; to be completed in FY09)

Challenge/Problem Addressed:

This project aims to facilitate safe operation of AGVs and robots in unstructured, dynamic environments through the use of simulation to perform initial validation of safety systems against standard test methods. The use of simulation is expected to also accelerate the introduction of more advanced robotics for manufacturing (both arms and AGVs) by allowing for greater flexibility and speed in experimentation and validation.

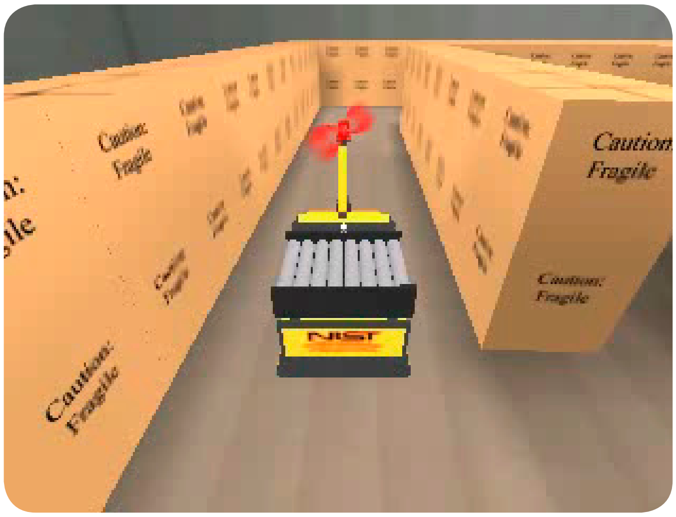
AGVs play an important role in today's manufacturing processes. Companies use them on factory floors for jobs as diverse as intra-factory transport of goods between conveyors and assembly sections, movements of parts, and loading and unloading of truck trailers. Bishop Consulting's report on AGV Industry Next-Generation Technology Priorities said that "In the eyes of the system vendors, the most prominent technology development area is in moving from today's AGVs, which require highly structured environments and reference markers installed throughout the plant, to operating in less structured or unstructured environments. In fact, the site preparation required to site and install these reference markers are a significant portion of the system cost… In implementing AGVs for unstructured environments, another need is for sophisticated simulation capability… no capability currently exists to simulate AGVs for unstructured environments."

Objectives:

- Build performance requirements and test methods for AGVs and robot arms by applying ISD's world-class expertise in performance evaluation of mobile robots.
- Develop and refine test methods in a virtual factory simulation and translate them to easily realizable physical artifacts that remain coupled to the simulation environment. This coupling will permit more rapid and less costly review of potential test methods by constituents. Use of test environments that combine real and virtual elements will allow for performance quantification of systems that are in the vicinity of humans or in collaboration with them without posing any risk to human participants.

Planned Future Accomplishments:

- Demonstrate first test method for both simulated and real AGVs. The test method will measure how narrow a passageway an AGV is able to negotiate. This type of information about AGVs is not currently available and will eventually provide users and vendors with data to help them make buying and design decisions. (FY08Q3)



- Publish a document summarizing user-articulated requirements for AGVs. ISD has begun gathering input from users, particularly small and medium enterprises that may not currently be considering use of AGVs because of their costly infrastructural requirements. A requirements document will serve as a roadmap for developing test methods. (FY09Q3)

Customers and Collaborators

- We are in the process of reaching out to manufacturers to gather their requirements. Thus far, we have established ties with Dixon Valve and Patton Electronics
- IEEE
- Georgetown University
- George Mason University
- University of Maryland Eastern Shore

Measurement Science for Manufacturing Robotics and Automation Program

Industrial Autonomous Vehicles Project (Status: to be completed in FY2010)

Challenge/Problem Addressed:

The material handling industry needs greater flexibility, efficiency, and autonomy in its automated vehicles. This project aims to transfer into the Automated Guided Vehicle (AGV) and other types of vehicles advances gained in the development of measurement methods and new technology leveraged from other agencies, notably defense (Army Research Laboratory, DARPA) and transportation (Department of Transportation).

Objective(s):

- Transfer advanced defense and transportation technology and performance metrics to the automated guided vehicle industry
- Set standards to allow the use of advanced sensor and control technology

Accomplishments:

- ISD proposals to the ANSI/ITSDF B56.5 standards sub-committee resulted in changes to the standards to allow advanced, non-contact safety sensors as vehicle obstacle detection devices.
- Developed software for and demonstrated large facility navigation on a mobile robot equipped with only a color camera and an onboard computer to sense lines or patterns on the floor. This prototype demonstration builds end-user confidence in attaining greater efficiency and worker safety.
- Demonstrated, in collaboration with Transbotics, Inc., an AGV manufacturer and integrator, a prototype system to measure and verify palletized loads and truck volumes and orientations. This verified the feasibility of a generic solution for autonomous truck loading that is expected to also lead to the more difficult task of truck unloading.
- Funded a study on the AGV industry, which includes both manufacturers and users, that documented the current state of the art and prioritized the industry's technology needs. This guides the requirements and standards development.
- In 2007, created a Consortium of three AGV companies – Danaher Motion, Egemin, and FMC – that will collaborate on advanced 3D image sensor systems to detect overhanging obstacles in the vehicle path currently requiring several 2D imaging sensors per vehicle. This addresses a major safety concern with AGVs.

Planned Future Accomplishments:

- 1st Q/2009: develop a consortium of AGV and forklift manufacturers to develop the concept for an advanced, light-duty, semi-autonomous forklift to carry relatively small loads through manufacturing and distribution facilities while posing no danger to people
- 2nd – 4th Q/2009: support design and development to build and then measure performance of a safe, light-duty, semi-autonomous forklift

Customers and Collaborators:

- Material Handling Industry of America (MHIA)
- Robotic Industries Association (RIA)
- ANSI
- Boeing
- Tranbotics
- Danaher Motion
- Egemin
- FMC

Measurement Science for Manufacturing Robotics and Automation Program

Next Generation Robot Safety (Status: to be completed in 2011)

Challenge/Problem Addressed:

Collaborative human-robot interaction holds promise for a growing number of applications, but robot technology has not changed significantly over the last ten years. Safety concerns arising in human-robot interaction are currently dealt with by restricting human access to significant portions of valuable manufacturing production floor space and investing significant resources in protective equipment. At least 100,000 industrial robots are in use in the U.S. and approximately 700,000 throughout the world, roughly 10% of which are replaced annually. Unit cost ranges from approximately $30K to $50K, but the cost of protective equipment is approaching the cost of the robotic units themselves. The Next Generation Robot (NGR), with its built-in safety technology, will promote the development of markets in those many classes of products requiring repeatable autonomous operation, handling of hazardous or heavy loads, etc. For example, this technology can reduce the cost of automobile manufacturing, microelectronic manufacturing, surgical operations, and rehabilitation and elderly care.

Objectives:

- Promote NGR inherent safety design and benign operating features in order to promote lean manufacturing.
- Develop metrology technology and sensors, which will facilitate the development of the NGR.
- Develop industrial robots safety standards.

Accomplishments:

- Produced and authenticated a USMS metrology need on "Next Generation Robots." http://www.isd.mel.nist.gov/next_generation_robots/Manu_13_30Mar06_NextGen_Robots_Final.pdf. This documents the industry need for a wide audience and serves as a platform for establishing standards development and collaboration.
- Obtained informal oral permission to install experimental NGR devices in a GM plant for the purpose of collecting performance data. This will provide real-world data for developing concrete requirements for NGR safety standards.
- Identified the source for data on the injury tolerance of human beings and biometric devices appropriate for an industrial environment. This information is a necessary prerequisite in any plans for humans to work in proximity with robots.
- Contributed to the development and balloting of the industrial robot safety standard-ISO 10218-1. This standard specifies requirements and guidelines for the inherent safe design, protective measures, and information for use of industrial robots. It describes basic hazards associated with robots, and provides requirements to eliminate or adequately reduce the risks associated with these hazards.
- Hosted four International Standardization Organization meetings on the following subjects, all of which are aimed at having the standards evolve as industry and technology advances:
    - Project Team 1 (PT1) meeting for the revision of ISO 10218 robot safety standard.
    - Advisory Group 1 (AG1) meeting for the study of mobile service robots.
    - Project Team 2 (PT2) meeting for the study of robots in personal care.
    - ISO TC184/SC2 (Robots and Robotic Devices) annual plenary meeting.

Planned Future Accomplishments:

- Contribute key technical content and facilitate collaborations to develop the industrial robot safety stan¬dard-ISO 10218-2. This standard specifies requirements and guidelines for the installation and safe operation of industrial robots.
- Contribute key technical content and facilitate collaborations to develop a Technical Report on Guidelines for Implementing ANSI/RIA/ISO 10218-1-2007.
- Contribute key technical content and facilitate collaborations to develop a Technical Report on Guidelines for Implementing ANSI/RIA/ISO 10218-2.
- Develop and test prototypes of robot safety MEMS microsensor

Collaborators and customers:

- Robotic Industries Association (RIA).
- Liaison between the RIA office of standards development and the ANSI Panel on Nanotechnology Standards (ANSI/NSP).

Measurement Science for Manufacturing Robotics and Automation Program

Perception for Advanced Intelligent Manufacturing (Status: Exploratory project completed in FY07)

Challenge/Problem Addressed:

Investigate the roles and capabilities of novel 3D range sensors for use in manufacturing environments.

General and flexible 3D vision systems would have great payoffs for manufacturers as they could be quickly adapted to new processes, would require less investment in fixtures to orient parts, and could permit new applications in tasks where perception had previously been too difficult. Standards do not yet exist by which researchers can verify their approaches, vendors certify their products, and manufacturers evaluate sensors.

Objectives

- Investigate 3D vision perception systems for manufacturing.
- Determine current practice and identify where NIST could assist in metrology and standards for these systems.
- Conduct research to better understand a new class of sensors, 3D flash LADARs.
- Establish a testbed system for 3D sensors and characterize a set of sensors.

Accomplishments

- Attended workshops and trade shows and interacted with industry representatives and leadership from the Society of Manufacturing Engineers and the Automated Imaging Association (AIA). This, together with visits to factories, informed us on the state of the art and practice of industrial vision systems.
- Established a working group of NIST and GM researchers to investigate vision methods and algorithms for flexible manufacturing with specific application to fixtureless assembly and line tracking. The result is a white paper (in progress) on "Evaluation of 3D Imaging Systems for Dynamic Sensing Applications in Manufacturing."
- Determined that no standards effort focuses on 3D sensors under general and dynamic conditions. Existing efforts emphasize 3D static metrology and not real-time applications.
- Worked with members of the Automated Guided Vehicle community on a CRADA to explore the use of flash LADARS for obstacle detection.
- Established a testbed to gather optimal data from the sensors, including work on calibration, data quality optimization, and super-resolution. The objective of the calibration work is to calibrate a heterogeneous set of sensors so as to simultaneously determine intrinsic[2] parameters and relative extrinsic[3] parameters for all the image sensors. This yielded an automatic correspondence-less[4] algorithm that simultaneously calibrates the sensors.

2 relative to the camera, e.g., focal length, lens distortion

3 location of the camera with respect to a coordinate frame tied to the external world

4 without having to compute the correspondences between images from various sensors, yielding performance efficiencies

- Developed software that computes optimal parameter settings for a general class of 3D flash LADARS and applies those settings in real-time to reduce data variance. The software runs a general interface to flash LADARS from multiple vendors so all are treated in a common framework.
- Evaluated flash LADARs from several vendors to begin to develop standards for range data. Tested the sensors for range accuracy, precision, sensitivity to material reflectance, background illumination, and uniformity of active illumination. Determined that there are aspects of these sensors that require further testing, such as cross-talk between sensors, light scattering from one object that contaminates other objects, and dynamic behavior. Found that dynamic array range sensors will need additional test protocols beyond standards for static scanning LADARs.

Customers and Collaborators

- General Motors
- Egemin
- FMC
- Danaher
- Rensselaer Polytechnic Institute (RPI)

Measurement Science for Manufacturing Robotics and Automation Program

Dynamic Metrology Project (Status: Exploratory Project to be completed in FY2008)

Challenge/Problem Addressed:

To develop performance measures and standards applicable to six degree-of-freedom (6DOF) sensors for use in dynamic manufacturing environments where parts motion is unconstrained.

The ability to measure the positions and orientations of components as they move would result in considerable cost savings by replacing expensive fixed installations with more intelligent combinations of sensing and automation, and would help U.S. manufacturers compete with foreign firms that have recently made great investments in robotic technology. The automotive and airplane industries, as well as others, would gain substantial and immediate benefits, but the technology is fundamental and could be widely applied. A reference standard would also assist the academic community in establishing clear performance metrics for research systems and algorithms.

Objective(s):

- Develop methods for continuous measurement in manufacturing situations and evaluate and minimize the sources of error in the measurements.
- Investigate candidate technologies for reference measurements.
- Organize a Dynamic Metrology workshop.

- Establish the data collection infrastructure for simultaneous continuous measurements with two systems so the measurements can be compared and validated, and work on protocols and metrics for the comparison.
- Develop techniques to calibrate the reference and test systems, to synchronize measurements for comparisons, evaluate the raw sensor data that is used to compute 6DOF pose[5], and track the contribution and propagation of errors in subsystems.

Accomplishments:

- A report on the current state of the art in LADAR sensor technology was completed, updating the previous survey (NISTIR 7117) from 2004. The report will help determine the suitability of LADAR technology for 6DOF metrology.
- Took delivery of a laser tracker during fall 2007. The laser tracker is being used in experiments as a reference standard for 6DOF position and orientation.
- Used the laser tracker to validate sensor calibration algorithms developed at General Dynamics Robotic Systems (GDRS) as a first step towards standards transfer.
- Used the laser tracker with its 6DOF dynamic pose sensor to establish a system for time stamped simultaneous data collection. This involved working with the vendor to update and modify their system so that it can work with a hardware trigger and report at a high data rate, and the development of a trigger system for simultaneous measurements from the tracker and a sensor system under test. The data collection system was prototyped at NIST using a robot arm and an off-the-shelf vision system. This led to experiments at the Robot Vision Laboratory at Purdue University where the tracker evaluated the performance of a visual servoing system controlling a robot tracking a moving, swaying engine part.
- Held a workshop in October, 2007 with the title "Dynamic Measurement and Control for Automated Manufacturing." Over 44 people attended the one and a half day event. A preliminary report on the workshop has been prepared.

Collaborators:

- General Motors
- Purdue University
- General Dynamics Robotic Systems
- NASA

5 position and orientation

Measurement Science for Manufacturing Robotics and Automation Program

Advanced Control Systems and Positioning for Nanoscale Measurements and Standards

(Status: to be completed in 2011)

Challenge/Problem Addressed:

Metrology and fabrication of micro- and nanostructures are two key technologies for nanomanufacturing. A central challenge of micro- and nanomanufacturing is the development of methods to build complex three-dimensional (3-D) structures and devices on these scales that can readily interface with the macro scale world (scale-up). The metrology of micro- and nanostructures, such as nanowires, nanoparticles, proteins, cells, etc., is crucial for the advancement of micro and nano technology and manufacturing, which presents many opportunities for novel micro and nano electromechanical and biomedical systems.

Objectives:

- Develop world-class advanced control and positioning systems, and appropriate standards, for nanoscale measurements.
- Develop world-class advanced control and positioning systems, and appropriate standards, for nanoscale manipulation.
- Develop scale-up interfaces and standards to connect micro and nano manufacturing tools to the macro scale world.

Accomplishments

- Fabricated of numerous devices that advance the state of the art for control and positioning systems at the nanoscale, including:
  - A two degrees of freedom (X-Y axes) planar dual parallel cantilever high precision meso scale micro positioner from Ti-6-4 (Ti, 6%Al, 4%V) material.
  - Several 1D high precision MEMS nano positioners and thermal actuator calibration devices.
  - Several X-Y precision MEMS nano positioners, with leaf-spring actuator coupling and single rod actuator coupling.
  - Several micro assembly MEMS artifacts, successfully tested
  - MEMS micro X-Y-Z nanopositioner, successfully tested
  - A Probe Holding MEMS Micro Stage and Micro Coil.
  - A 2 x 2 array of MEMS micro X-Y nanopositioning stages for nanoassembly operations.

Manipulating Micro-Scale Spheres

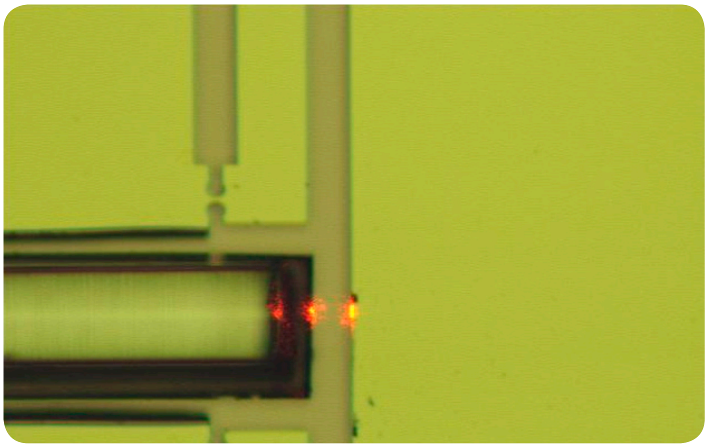
- Completed numerous difficult experiments that advance the state of the art at the meso-, micro-, and nanoscales, including
    - Tested several planar MEMS nano positioners inside a Scanning Electron Microscope (SEM) vacuum chamber.
    - Quasi static and dynamic testing of nanopositioners
    - Used MEMS Nano Positioning Devices to Perform Micro and Nano Material Testing
    - Demonstrated Manipulation and Assembly of Microspheres.
    - Collaborating RPI Researchers Demonstrated 3D Microassembly.

Planned Future Accomplishments:

- Develop embedded displacement metrology sensors for the MEL/ISD MEMS nano positioners.
- Develop embedded force metrology sensors for the MEL/ISD MEMS nano positioners.
- Advance and optimize the performance of the MEL/ISD MEMS nano positioners.
- Demonstrate the use of the MEL/ISD MEMS nano positioners for one or more nano metrology needs.
- Develop advanced metrology, control, and positioning systems, for nanoscale manipulation.

Collaborators and customers:

- RPI Center for Automation Technologies and Systems, Dept. of Electrical, Computer, & Systems Engineering
- George Washington University.
- APNanotech
- LightTime MEMS LADAR built based on NISTIR information
- Contributed to the RoboCup Nanomanufacturing Material Delivery and Removal competition demonstration in 2007



MEMS Nanopositioner Embedded Optical Sensor

Intelligent Systems Programs

Intelligent Manufacturing Industrial Control Systems and Network Standards Program

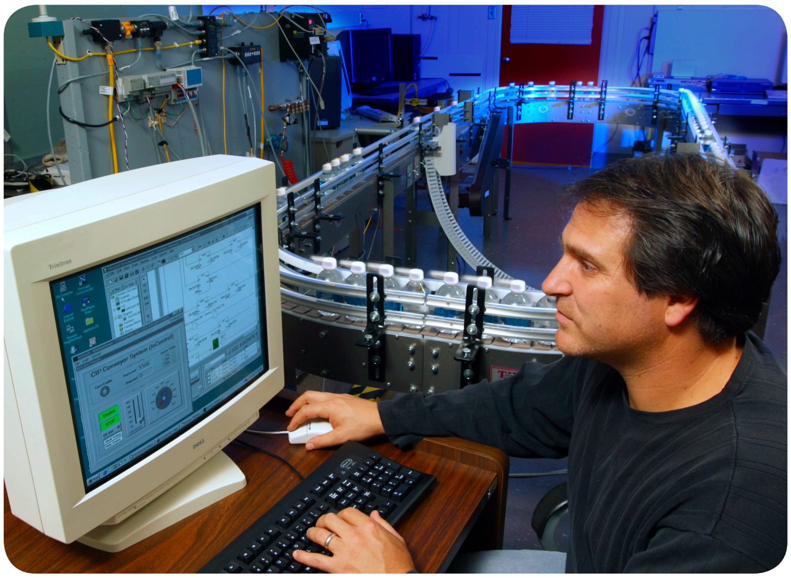
Annual FTEs: 3.5 NIST staff

Challenge

Safe, secure, and reliable industrial control systems are essential for U.S manufacturers and other critical infrastructure. As inter-connectivity grows, the challenges in guaranteeing the security of the most critical systems increase correspondingly.

Overview

Industrial control systems (ICS), including supervisory control and data acquisition (SCADA) systems and distributed control systems (DCS), are an integral part of the U.S. critical infrastructure. The widespread use of general information technologies for remote monitoring and control of electric power generation and distribution systems and pipeline distribution systems; control of industrial processes in the oil and gas, water, chemical, pharmaceutical, food and beverage, pulp and paper, and other industries; and rail and air traffic control, has unintentionally introduced security vulnerabilities. ICS often have to respond in real time and are designed to maximize performance, reliability, flexibility, and safe operation. Typically, these systems link to corporate and business networks, use Open/COTS (Commercial off-the-shelf) components, and are connected via Ethernet. Increased connectivity and use of common components offer a number of advantages, such as reduced costs, but also increase the vulnerabilities and reduce the predictability of these systems. This program capitalizes on extensive achievements from NIST Information Technology Laboratory-led programs and efforts by other agencies to respond to the manufacturing industry's need for safe, secure, reliable manufacturing systems and for predictable, well-characterized manufacturing processes and equipment.



NIST Industrial Control Security Testbed

Securing industrial control systems and networks is a challenge because they often work under real-time constraints that render standard IT security technology inapplicable. It can be difficult to balance performance, reliability, flexibility, safety and security. Safe operation is the number one concern and security requirements cannot compromise the safety requirements of the system. It is also difficult to specify requirements and testing capabilities of complex systems in operational environments. Devising technically sound industrial control system cyber security standards that gain global acceptance is also difficult because stakeholders – industry, government, standards developers – do not always have the same interests and may never have articulated their standards goals. Very few industrial sectors have undertaken efforts to develop and implement a strategic, industry-wide approach to industrial control system cyber security. NIST works cooperatively with ICS communities in the public and private sectors to develop specific guidance on the application of the security controls, gathering relevant material from a variety of sources, analyzing it, and organizing it for easy adoption by industry.

Accomplishments:

- NIST SP 800-53 *Recommended Security Controls for Federal Information System*, Rev 2 is now a security standard that addresses both general Information Technology (IT) systems as well as ICS. An additional guidance document, NIST SP 800-82 *Guide to Industrial Control Systems (ICS) Security,* was developed to provide technical guidance for the public and private sectors on how to secure ICS while addressing their unique performance, reliability and safety requirements. NIST SP 800-82 has been downloaded over 350,000 times since the initial release and is heavily referenced by the industrial control community. A likely impact will be the voluntary adoption of the same or similar security requirements and baseline security safeguards and countermeasures by the private sector industrial control community.
- NIST delivered the "EtherNet/IP Performance Test Tool" to the Open DeviceNet Vendor Association (ODVA) on December 31st, 2007. This tool helps vendors test the performance and interoperability of their Ethernet/IP devices for industrial systems. It came about through an 18-month Cooperative Research and Development Agreement (CRADA) between NIST and ODVA, and was the highest priority task of the USCAR Plant Floor Controllers Task Force. ISD ran performance testing at six PlugFests since 2005. The Plugfests provide manufacturers a place to test the performance and interoperability of their Ethernet/IP devices for industrial systems.
- NIST technical leadership within the Department of Homeland Security (DHS) Control Systems Security Program helped produce a harmonized Catalog of Security Requirements that will facilitate [the development and convergence of control system cyber security standards applicable to the Critical Infrastructures and Key Resources (CI/KR) of the United States and other nations. This Catalog of Security Requirements is being actively vetted within the ISA SP99 WG4 (Technical Requirements for Industrial Automation and Control Systems (Part 4 Standard)) and IEC TC65/WG10 (Security for industrial process measurement and control - Network and system security) standards committees.

Future Directions and Plans:

Future efforts will expand industrial performance tests and will work within the numerous related standards organizations to achieve harmonization and increase speed and breadth of adoption by the manufacturing sector and other industries. The MEL-funded work will continue to leverage results from related projects funded by the Department of Homeland Security and the Department of Energy.

Planned future accomplishments:

- ISA SP99 Part 2 *Establishing an Industrial Automation and Control System Security Program* (Q2/FY08)
- Final SP 800-82 *Guide to Industrial Control System (ICS) Security* (Q4/FY08)
- First public draft of SP 800-53A *Guide for Assessing the Security Controls in Federal Information Systems* to address ICS (FY09)
- ISA SP99 Part 3 *Operating an Industrial Automation and Control System Security Program* (FY09 – FY10)
- ISA SP99 Part 4 *Technical Security Requirements for an Industrial Automation and Control System* (FY09 – FY10)
- Prototype development of the EtherNet/IP Performance Test Laboratory (Q4/FY08)
- Plug-Fest #8, Plug-Fest #9, Plug-Fest #10 (FY08 – FY09)
- Develop the capability to conduct performance tests on other industrial Ethernet-based networks (FY09-FY10)
- Expand the current performance test lab to include other industrial network types and technologies, including wireless and OPC (FY11 – FY12)

Collaborators and customers

- Bonneville Power Administration, Portland, OR
- Bureau of Reclamation, Washington, DC
- Department of Homeland Security, Washington, DC
- Federal Aviation Administration, Washington, DC
- Federal Energy Regulatory Commission, Washington, DC
- ISA, Research Triangle Park, NC
- ODVA, Ann Arbor, MI
- Tennessee Valley Authority, Knoxville, TN
- United States Council for Automotive Research, Detroit, MI
- Western Area Power Administration, Lakewood, CO

Awards and Recognition

Board Membership

Staff	Board Membership
Jim Gilsinn	• Director, Instrumentation, Systems, and Automation (ISA) society's Standards & Practices (S&P) Board

Leadership

Staff	Leadership
Jim Gilsinn	• Editor, ISA SP99 Committee on Security for Industrial Automation & Controls Systems, Working Group 2 • Coordinator, Open DeviceNet Vendor Association (ODVA) EtherNet/IP Implementers Workshop • Leader, ODVA EtherNet/IP Performance Workgroup • Leadership committee, ISA 99
Keith Stouffer	• Coordinator, NIST Federal Industrial Control System Security Workshop, NIST, April 2006 • Coordinator, 2nd Federal Industrial Control System Security Workshop, NIST, March 2007 • Chair, NIST Process Control Security Requirements Forum (PCSRF) • Technical Advisor, US TAG for the IEC TC65 committee • Leadership committee, ISA 99 • Technical Advisor, CIGRE B5 committee • Technical Advisor, DHS Control System Security Program

Excellence

Staff	Excellence Recognized
Joseph A. Falco Frederick Proctor Keith Stouffer Albert Wavering	• Department of Commerce Gold Medal for Distinguished Service (2005): For technical leadership of the NIST Process Control Security Requirements Forum culminating in the development of a common set of information security requirements for SCADA and industrial control systems used throughout the nation's critical infrastructure.
Keith Stouffer	• Invited speaker at over 25 international conferences and forums
Jim Gilsinn	• Senior Member, ISA society • 2006 ISA Standards & Practices Department Award

Other evidence of technical excellence, not necessarily tied to above projects, but supporting Division Programs and Mission

Board Membership

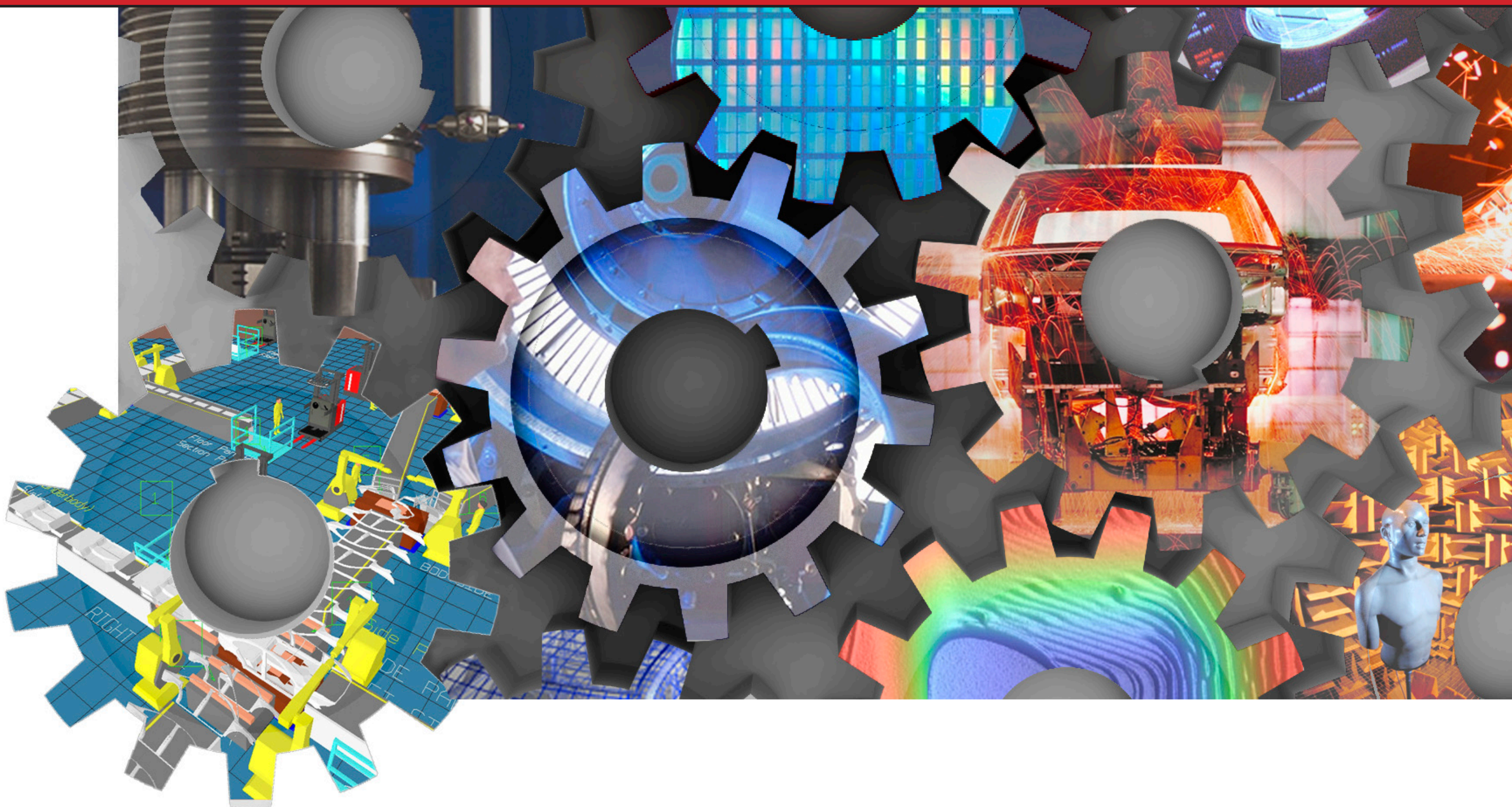
Staff	Board Membership
Raj Madhavan	• Editorial Board, the International Journal of Tomography & Statistics (IJTS) as an Associate Editor with volunteer appointment policy for two years.

Leadership

Staff	Leadership
Steve Balakirsky	• Chair, RoboCup Rescue Virtual Competition. • Organizer, tutorial, IEEE International Conference on Robotics and Automation (ICRA) 2006 describing ISD-developed simulation tools • Organizer, tutorial, AAAI 2006 describing ISD-developed control system performance and simulation tools
Hui-Min Huang	• Chair, Society of Automotive Engineers (SAE) AS4D Unmanned Systems, Committee on Performance Measures
Adam Jacoff	• Chair, RoboCup Rescue Robot League • Chair, IEEE International Workshop on Safety, Security and Rescue Robotics (SSRR) 2006
Raj Madhavan	• Program Chair, Performance Metrics for Intelligent Systems 2006, 2007, 2008
Raj Madhavan, Elena Messina	• Co-chairs (along with Angel del Pobil) of Workshop on Performance Evaluation and Benchmarking for Intelligent Robots and Systems at IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), San Diego, U.S.A., Nov. 2007.
Raj Madhavan, Steve Balakirsky	• Originators and Chairs, IEEE Robotics and Automation Systems New Initiatives Competition “Advancing Robotic Research through an Open Source High-Fidelity Simulation Framework and Competition” (2007).
Elena Messina and Adam Jacoff	• Chairs, Workshop on Performance Measures for USAR Systems at the 2006 ANS Joint topical – Emergency Preparedness and Robotics for Hazardous Environments.
Elena Messina	• General Chair, Performance Metrics for Intelligent Systems 2006, 2007, 2008 • Workshop Chair, American Nuclear Society 2008 Joint Topical Conference Emergency Preparedness and Robotics for Hazardous Environments. • Chair, ASTM Homeland Security Applications, Operational Equipment, Urban Search & Rescue Robots
Elena Messina, Raj Madhavan, and Adam Jacoff	• Chairs, workshop on “Robots for Emergency Response” at the 2008 ANS Joint Topical – Emergency Preparedness and Robotics for Hazardous Environments.

Excellence

Staff	Excellence
James S. Albus Charles H. Giauque Adam S. Jacoff Frederick M. Proctor William P. Shackleford Ann Marie Virts Brian A. Weiss	• Jacob Rabinow Award (2006) For outstanding technical achievement in the application of parallel kinematic robotics research to large aircraft maintenance operations, resulting in the first industrial production of cable-suspended, robotic platforms and tripod manipulators developed by NIST's Intelligent Systems Division.
James Albus, Tony Barbera, Craig Schlenoff, Steve Balakirsky	• Invited workshop on robot control architectures at the IDGA Military Robotics conference in Washington DC on April 18, 2005.
Hui-Min Huang	• Distinguished Service Award from E54 Homeland Security Applications Committee of ASTM International.
Adam Jacoff, James Albus	• Federal Laboratory Consortium Mid-Atlantic Regional Excellence in Technology Transfer Honorable Mention for "Innovative Robotic Crane improves Large Aircraft Maintenance Operations."
Raj Madhavan, Elena Messina, James Albus	• Editors, Intelligent Vehicle Systems: A 4D/RCS Approach, Nova Science Publishers, Inc., ISBN:1-60021-260-3, Dec. 2006.
Elena Messina	• Distinguished Service Award from E54 Homeland Security Applications Committee of ASTM International. • Invited Plenary, NIST Research Advisory Committee Summer Colloquium Series (2007) • ADVANCE Distinguished Lecturer, Case Western Reserve University (2008)
Craig Schlenoff	• Chair of the NIST Research Advisory Committee 2007 • Colleague's Choice Award: For exemplary leadership and championship of the NIST mission in the management of independent evaluation for the DARPA Advanced Solider Sensor Information System and Technology (ASSIST) and Spoken Language Communication and Translation System for Tactical Use (TransTac) programs. (2007)
Ann Virts	• Colleague's Choice Award: For dedicated contributions which supported NIST's mission, promoted effective external interactions, and enhanced division vitality.



Chief:
Steve Ray

NIST
100 Bureau Drive
Stop 8260
Gaithersburg, MD
20899-8260

Phone:
301 975 3508
Fax:
301 258-9749
Email:
steve.ray@nist.gov

Manufacturing Systems Integration

Mission

To promote economic growth by working with industry to develop and apply interoperability measurements and standards for software used in all aspects of manufacturing.

Overview

The world's economy is rapidly developing into a single interconnected entity. Successful companies are under increasing pressure to evolve into global operations as they strive to maintain their competitive edge with others around the world. An essential element of this evolution is interoperability – the ability for companies to seamlessly exchange information among their own partners around the world. Achieving, assuring, and maintaining global interoperability is too large a task for all but the biggest corporations. We at NIST are increasingly asked by our nation's companies to help address the interoperability problem at the global level.

Electronic exchange of manufacturing and business information is on the rise in nearly every industrial sector, heralding changes that could transform the dynamics of business operations and the nature of business competition. On-line business-to-business trade revenues totaled $433 billion in 2000, according to one estimate, and by 2006 that figure had risen to $8.5 trillion.

In the transportation sector for example, manufacturers are outsourcing a growing share of production, assembly, and service functions to a wide range of suppliers and contractors. By electronically linking to these partners, companies aim to reduce costs and increase efficiency throughout the automotive supply chain. But while press and business reports often claim that this globalization has already brought great success, today's reality falls far short of what networked business communities can ultimately hope to achieve. Supporting middleware[1] technologies have matured significantly, but much disagreement remains among partners on how to use that technology to share business and manufacturing information. Getting systems supplied by different vendors to work together typically requires significant and burdensome customization. In the automotive industry alone, interoperability problems of sharing just product and engineering data imposed costs totaling about $1 billion in 1998.

Working with industry, MSID is helping to devise solutions for this multifaceted and global challenge. It has led the way in developing several major international standards for exchanging product information and for managing the torrents of data that businesses now must organize and process. Notable achievements are the international Standard for the Exchange of Product model data (STEP, ISO 10303) and the Object Management Group's Systems Modeling Language, key pieces in solving the interoperability puzzle. MSID has also built on-line testing services that enable design-engineering, supply chain, and e-business software vendors to validate the conformance of their products to the STEP standard and other emerging standards, and has provided tools to the standardization community to ensure rigorous quality of the standards themselves.

1 Middleware is computer software that connects software components or applications.

In choosing our work, we have been influenced by several major industrial drivers that reflect significant trends relating to information exchange in the manufacturing industry:

- Globalization
  - Off-shoring of suppliers
  - Increases in foreign markets for U.S. manufacturers
  - Concentration on core competencies within manufacturing companies
  - Intermixing of previously separate industrial "stove-pipes" between sectors
- Sustainable manufacturing
  - Increased attention to the entire product lifecycle, including disposal or recycling
  - Growing regulatory pressure on hazardous waste production, greenhouse gas emissions, and energy consumption
- Increased complexity of manufacturing systems
  - Reliance on simulation to understand and improve complex manufacturing systems
  - Prohibitive costs of interrupting manufacturing lines to experiment with alternative manufacturing approaches

Resources

Staff

29 NIST staff
1 NRC post-doctoral researcher
40 guest researchers (equivalent to 28 FTEs)

FY2008 Estimated Funding

$9,454 K STRS
$1,045 K Other Agency

The implications of these drivers include:

- Globalization creates increased dependence on electronic information exchange
- Globalization requires integration between formerly separate industry sectors, each with entrenched practices and terminologies
- Sustainable manufacturing necessitates richer information structures to capture more than simple product geometry[2]
- Complex systems increase the difficulty of achieving interoperability

In response to these drivers, MSID has organized three complementary programs to fulfill its mission:

- Supply Chain Integration
- Sustainable and Lifecycle Information-based Manufacturing
- Simulation-based Manufacturing Interoperability Standards and Testing

2 Characteristics associated with a product such as function, behavior, composition, carbon budget, and recyclability.

Staffing Challenges:

Attracting postdoctoral researchers is increasingly difficult because of NIST's entry level salary structure relative to that of engineers and computer scientists in the private sector.

Our permanent staff has a top-heavy demographic – senior staff have topped-out salaries and we cannot replenish junior employee ranks.

Facilities and Equipment

- **Advanced Manufacturing Systems And Networking Testbed (AMSANT) and Simulation Laboratories:** these are multi-purpose computer laboratories that support the Manufacturing Engineering Laboratory staff and a host of other project-specific applications for other NIST operating units. Providing a multi-media environment of computers, audio, video, wireless, and networked distribution systems; the Simulation Laboratory complements the services provided by the AMSANT, which offers a wide variety of simulation tools, as well as a 3D laser scanner that support modeling in manufacturing and other domains. The Simulation Laboratory allows us to build manufacturing simulations to support testing objectives and work with industrial partners using the same tools they use in real-time. Both laboratories foster a collaborative physical and virtual environment for worldwide communication and demonstration.

Advanced Manufacturing Systems And Networking Testbed (AMSANT)

Manufacturing Systems Integration Programs

Supply Chain Integration

Annual FTEs:	11 NIST FTEs
	10 Guest Researcher FTEs
	21 Total FTEs

Challenge

The manufacturing sector will continue to provide the core of our nation's real wealth creation in the foreseeable future. Innovation and competition within this sector will take place at the level of supply chains or "value chains[3]," however, not at the level of individual companies. These value chains will evolve into a network of global, collaborative partnerships. These partnerships will develop rapidly when new market or technology opportunities appear. They will dissolve just as quickly when those opportunities disappear.

As part of this evolution, manufacturing will become less resource-intensive and more knowledge-intensive. This shift will require a new capability – the ability for all partners to exchange and assimilate information ***instantaneously***. The challenge for the Supply Chain Integration program is to foster and promote that capability by developing and demonstrating an infrastructure for the testing and integration of automated systems that exchange information throughout the supply chain.

Overview

The Supply Chain Integration program has produced a number of syntax- and quality-based testing and validation tools that are now available as NIST Web services or as free stand-alone tools. To address new challenges, we have begun shifting our focus to content-based testing[4]. This is necessary to ensure that the semantics of the information being exchanged is correctly understood. In addition, the program is pursuing new approaches to manufacturing standards development that facilitate, rather than hinder, the automation process. The foundation for this infrastructure comes from the completed Automated Methods for Integrating Systems (AMIS) project, which provided a fundamental basis for our information exchange and application integration.

3 Adding value to the supply chain, either through the traditional economic model of providing added value to goods, or through innovative aspects of logistics and inventory management, e.g., Dell Computers

4 Validation is a form of testing done to assess the rigor of a developing standard. Syntax-testing is easier and more quantitative than testing the semantics or content of the data. Syntax-testing checks the data, while content-based testing checks the proper use and context of information.

The AMIS project defined a general approach for automating the exchange of information semantics between any two software applications. This approach was demonstrated using a "Request-for-Quote" supply-chain scenario and standards from the Open Applications Group (OAG) and the Chemical Industry Data eXchange (CIDX).

The Inventory Visibility and Interoperability (IV&I) project used the AMIS approach to demonstrate automated exchange of inventory-on-hand data between global automotive suppliers. Working with the Automotive Industry Action Group (AIAG) and with European and Korean collaborators, MSID developed numerous semantic technologies, which provided the initial set of components for our integration infrastructure.

The Materials Off Shore Sourcing (MOSS) project began last year. It is adapting the IV&I testing infrastructure to include business processes[5]. MOSS aims to reduce the uncertainty in door-to-door shipping times by simplifying and integrating the information flow among the dozens of players involved. To date, MSID has developed a conceptual data model for all the information objects, a model for all of the messages, and a number of testing tools.

Key Accomplishments and Impacts:

- Developed syntax and quality-based tools that are routinely used by developers from both government and industry, resulting in a 30% reduction in the time to develop new e-commerce specifications. AIAG has projected more than $200M savings from suppliers using interoperable IV&I applications.
- Potential savings have not been documented for MOSS, but the impacts of poor interoperability are known. They include a substantial increase in premium shipping costs, more than 20 days of excess inventory maintained, 80% of all information re-keyed with an average cost of $20 each, and more than 40 days difference between best (21 days) and worst (63 days) shipment times from Europe. If successful, the MOSS project will have a significant impact on all of these numbers.

Future Directions and Plans:

- Enhance existing infrastructure to facilitate the exchange of manufacturing and business data and provide support for testing and validating manufacturing and business specifications. Continue the shift in testing focus from syntax-based to content-based testing. This is necessary to ensure that the content of the information being exchanged is correctly understood.
- Pursue new approaches to manufacturing standards development that will promote/ease, rather than hinder, the automation process. Launch the Virtual Supplier Network project that will enable OEMs (e.g., GM, Ford, DaimlerChrysler) and suppliers to match requirements with capabilities automatically over the Internet through the addition to the MOSS infrastructure of components that will address two important complications: the fact that the applications involved are not known in advance, and the influence of business negotiations on the exchange of technical data.

5 Business process describes a set of activities that are the recommended way to achieve the goal; directs resources and people to work towards a goal, e.g., what activities need to be accomplished to receive 300 widgets by next Wednesday.

Awards and Recognition:

Board Memberships

Staff	Board Membership
Jones, Al	• Advisory Board for the Engineering Department at Loyola College, Baltimore, MD • Advisory Board for the Industrial Engineering Department at Morgan State University.
Ray, Steve	• European Union INTEROP Network of Excellence Advisory Committee • Intelligent Manufacturing Systems U.S. Delegation • Accreditation Board for Engineering and Technology • University of Maryland Institute for System Research Strategic Advisory Board

Leadership

Staff	Leadership
Barkmeyer, Edward	• Voting representative for NIST in the Technical Committees of the Object Management Group (OMG) • Chair of two OMG Revision Task Forces, charged with maintenance and revision of the Product Data Management Enablers interface standard • Chair of two OMG Working Groups in the Manufacturing Domain Task Force, Enterprise Resource Planning and Manufacturing Business Objects • Co-Chair of two OMG independent Working Groups, Web services, and Business Rules, which became formal standards development bodies within the OMG
Denno, Peter	• Leader of the System Engineering Tool Interoperability Plugfest. The work is recognized in the plans of INCOSE, OMG and ISO TC 184/SC4 • Activity Lead of the Systems Engineering Tool Interoperability effort of INCOSE's Model Based Systems Engineering (MBSE) Initiative, which is a major initiative within INCOSE • Leader of the MOSS validation effort collaborative with the Automotive Industry Action Group and other partners
Frechette, Simon	• Co-Chair of the Software Development Productivity Working Group, National Coordination Office for Information Technology Research and Development
Morris, KC	• Chartered and led the Working Group on XML Schema Interoperability for the Federal CIO Council's Data Architecture Subcommittee
Ray, Steve	• Co-Organizer of the Ontology Forum, Ontology Summit (2006, 2007, 2008) • Committee Chair, National Center for Ontology Research (NCOR) Ontology Evaluation • Chair, IMS Vision Forum study group on "Key Technology for Manufacturing Innovation and Environmental Sustainability", 2006

Leadership (continued)

Staff	Leadership
Wallace, Evan	• Co-Chair of the Ontology Platform Special Interest Group of the OMG • Co-Chair of the Ontology Definition Metamodel Finalization Task Force of the OMG • Representative for NIST in the OWL Working Group of the World Wide Web Consortium (W3C) • Formerly represented NIST in the W3C Semantic Web Best Practices and Deployment Working Group (now closed)

Excellence

Staff	Excellence Recognized
Goyal, Puja Lubell, Josh Morris, KC	• Awarded the 2005 Bronze Medal Award for Superior Federal Service for building XML schemas and creating a collection of software tools and test case data sets to support multi-party collaboration work process for the life cycle of facilities equipment
Ivezic, Nenad	• Recipient of the 2006 Automotive Industry Action Group (AIAG) Individual Achievement Award for outstanding contributions to the automotive industry • Recipient of the 2007 AIAG Individual Achievement Award for outstanding contributions to the automotive industry
Ray, Steve	• Invited Keynote presentation entitled "Standards, Interdependence and Complexity - Developments and Trends in Standards from the Enterprise to the Shop Floor," at the International Conference on Smart Machining Systems (ICSMS), March 13-15, 2007

Projects

Supply Chain Integration

Introduction

Supply chain integration enables supply-chain partners to exchange information automatically. This exchange takes place between disparate software applications that need to work together to satisfy a unified manufacturing or business need. These applications likely run on multiple, geographically dispersed computer systems and platforms, and were generally not designed with integration in mind. These and other issues make integration projects complicated and extremely expensive.

Studies have shown that most integration efforts fail to achieve their goals. Successful integration involves four stages: (1) specification creation, (2) specification validation, (3) development of conformance and interoperability test methods, tools, and data sets, and (4) implementation. Each of these stages builds upon results of the previous stages, so problems in any stage can greatly increase the likelihood of overall failure.

MSID researchers have identified a number of such problems, including:

- Inaccurate capture and/or documentation of data interchange rules and constraints – Unreliable manual processes result in a time-consuming and error-prone cycle of interpreting and refining data processing rules and constraints.
- Inconsistent specification design quality – Often caused through lack of consistent practices, even while using formal modeling languages.
- Inadequate content validation – Primarily due to lack of appropriate content validation tools.
- Informal and unstructured specification definition – Leads to ambiguity and misinterpretation.
- Syntax-only integration standards approach – Leading analysts have estimated that 35% to 65% of system integration costs are due to semantic issues that syntax-only standards cannot address.
- Local management of data interchange rules – Results in conflicting standards.
- Non-adaptable, non-extensible implementations – Leads to the proliferation of incompatible dialects.

The Supply Chain Integration program is developing reference models and practical toolkits that will address these issues in innovative ways. Together, the program's products will make possible accurate specification creation, formal validation and testing, and rapid application integration.

Strategy

The program has two main thrusts: the development of tools for the testing and validation of existing supply-chain interface standards; and the development of an infrastructure to automate application integration.

The first thrust is based on the standards life-cycle activity model of standards, which we presented at our last meeting in 2005. That model addresses the creation, use, and maintenance of any standard. We have used this model to frame our research and the development of tools to support validation and testing of an existing standard (see Figure 1). In the following section, we provide overviews of these tools primarily in the context of the W3C XML Schema, because of its widespread adoption by industry.

The second thrust is based on the approach developed in the AMIS (Automated Methods for Integrating Systems) project, which we also presented in preliminary form in our last meeting in 2005. The AMIS strategy is to derive from the published interface specifications for a software system (application program interfaces, messages, exchange files, protocols, specifications, and documentation) an understanding of the roles in the business processes the system was built to support. That understanding must be captured in formal models that contain definitions of the business entities, properties, processes and rules in a machine-readable form suitable for automated reasoning.

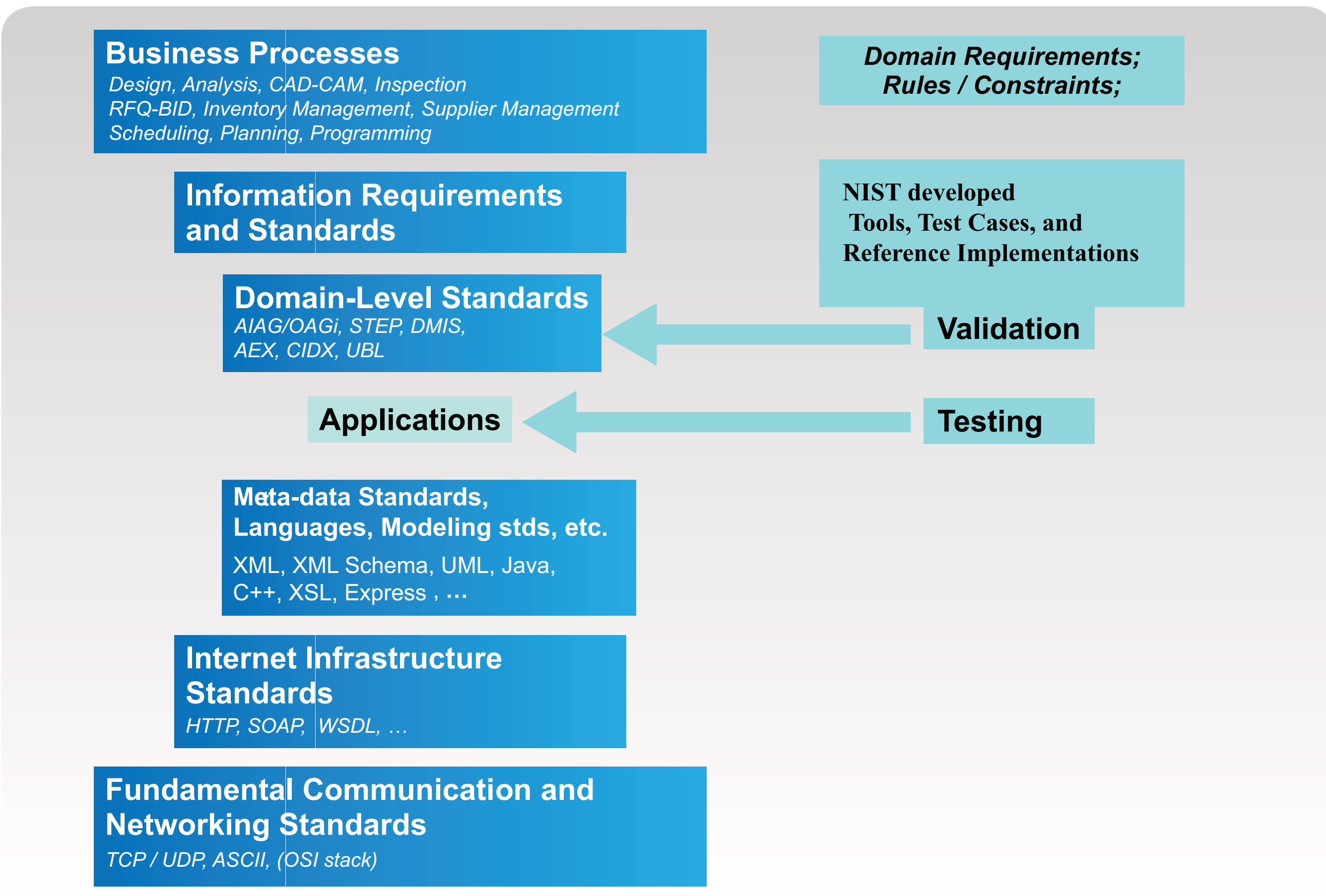


Figure 1. Conceptual View of the Supply-Chain Integration Stack

The AMIS project produced a high-level description of the major components of a semantics-based integration infrastructure for supply chains (see Figure 2). That infrastructure contains local ontologies, a reference ontology[6], mappings, translators, and connector transformations. The project also demonstrated how to build those components for a 'request-for-quote' supply-chain scenario and related standards from the automotive and chemical industries.

Lessons/ideas from AMIS became a crucial part of AIAG's Inventory Visibility and Interoperability (IV&I) project, which sought to develop an agreed-upon set of e-Kanban[7] messages that would allow suppliers to communicate inventory data to the rest of the supply chain. MSID's role was to collaborate with European and Korean partners on a semantics validation project designed to show that the automotive industry could lower cost, improve speed to market, and reuse IT investments by using emerging semantic technologies to define and implement messages among suppliers.

This project was important for four reasons. First, it applied the AMIS approach to a real integration problem using real commercial IV&I applications. Second, it demonstrated the potential of using semantic technologies to automate the integration process. Third, it showed that it may be possible to separate that process into two parts: a private part that only the users know about and a public part containing models, tools, and agents that do all the real work. Fourth, it showed the potential to further separate those models, tools, and agents into one collection that is specific to a certain branch of manufacturing and another collection that is generic.

AIAG's Material Off-Shore Sourcing (MOSS) project is an initiative designed to improve business procedures and information drivers controlling the intercontinental shipment of goods. AIAG studies assert that improvements in the accuracy of information conveyed—and agreement in how it is to be interpreted—will result in tangible reductions in overall supply-chain transit times and measurable decreases in the variation of transit times. A direct result will be reductions in buffer-stock inventory and expedited/premium transportation expenditures.

Figure 2. Conceptual View of Application Integration

In FY07, MSID began working with MOSS participants from government, AIAG, and the vendor community to develop the necessary recommendations and standards, test associated Electronic Data Interchange (EDI)[8] messages, develop a testing infrastructure, and conduct demonstrations using an ocean-shipment scenario. We will again use the AMIS approach and extend the IV&I infrastructure to evaluate a real business process.

6 Ontology is a representation of a set of concepts within a domain and the relationships between those concepts. It is used to reason about the properties of that domain, and may be used to define the domain.

7 E-Kanban is an electronic signaling system to trigger action. Of Japanese origin, Kanban is a means through which just-in-time production is achieved, originally implemented using physical tokens.

8 EDI (Electronic Data Interchange) is a widely used early set of standards for sharing business data electronically, still heavily used for off-shore shipments.

Supply Chain Integration

AMIS (Automated Methods for Integrating Systems)

(Status: complete in 2006)

Challenge/Problem Addressed:

Supply chain integration, even when it is based on existing syntactic interface standards, is an error-prone, costly, time-consuming, repeated, human-intensive engineering activity.

Objective(s):

- Reduce the effort required to exchange supply chain semantics by devising models, methods, algorithms, and tools to automate engineering activities that are now done by human systems integrators.

Accomplishments:

- Developed a reference architecture that describes the major components of a semantics-based integration infrastructure for supply chains. That infrastructure contains local ontologies, a joint reference ontology, semantic mappings and translators, and connector transformations.
- Demonstrated the reference architecture based on (1) a request-for-quote supply chain scenario, and (2) ontologies based on two different supply chain standards: one from the automotive industry and one from the chemical industry, and, (3) mappers and translators to go from one standard ontology to the other.

Customers and Collaborators:

- OAGi (Open Applications Group, Inc.)
- CIDX (Chemical Industry Data eXchange consortium)

Supply Chain Integration

ATHENA/IV&I (Inventory Visibility and Interoperability)

(Status: complete in 2007)

Challenge/Problem Addressed:

Integrating off-shore suppliers into an existing supply chain so that inventory levels are visible to all partners is costing billions of dollars a year within the transportation sector.

Objective:

- Develop and implement an integration infrastructure, based on the AMIS reference architecture, to exchange inventory information automatically between automotive supply-chain partners.

Accomplishments:

- Developed a monitoring tool to help test and validate supply chain integration implementations that use the Business Process Specification Schema (BPSS) and Collaboration Protocol Agreement (CPA) specifications. The tool checks whether each message has the right sender and receiver, message sequencing, and time constraints. The tool is implemented as a Java applet, which enables it to run in web browsers.

- Industry and government partners have adopted the Content Checker tool to aid the consistent application and validation of supply chain transaction specifications in real manufacturing transactions. This tool precisely specifies and extends conformance testing based on the semantics defined in a transaction schema, or content standard. Currently, the Content Checker works with transaction specifications based on the XML Schema language.
- Developed a collection of ontological models, semantic annotation tools, semantic reconciliation tools, and semantic translation tools based on existing OAG inventory standards and developed jointly with U.S, Korean, and European partners.

Customers and Collaborators:

- Automotive Industry Action Group
- SAP
- Open Applications Group, Inc
- KORBIT[9]

9 Created in December 2002 in South Korea, KorBIT is an open consortium formed to help enterprises develop interoperability so as to conduct business over the Internet.

Supply Chain Integration

Materials Off-Shore Supply Chains (MOSS) (Status: complete in 2009)

Challenge/Problem Addressed:

The complexity of information transfers adds substantial logistics delays forcing OEMs to use premium shipping and warehouse extra inventory, which adds billions of dollars a year in shipping costs.

Objective(s):

- Propose recommendations and standards
- Define associated EDI messages
- Develop an integration infrastructure
- Conduct demonstrations to show the automated exchange of logistics information across the entire logistics business process

Accomplishments:

- Developed a MOSS conceptual model of the objects and relationships in ocean-freight transport and messaging supporting the management of ocean-freight manufacturing supply chains.
- Defined the MOSS message type structures, which include the ~100 key properties for the management of ocean-freight manufacturing supply chains, and mappings of this information into EDIFACT[10] messages.
- Developed tools to assess the conformance of MOSS participants' messages to the MOSS recommendation. The current tools check for correct syntax formation and the presence of required information elements.

10 United Nations/Electronic Data Interchange For Administration, Commerce, and Transport (UN/EDIFACT) is the international Electronic Data Interchange standard developed under the United Nations.

- Designed a message metamodel for representing the structure of an EDI- or XML-based message type. Its use in MOSS may demonstrate a strategy for decoupling concerns of message syntax from the task of message processing.
- Built a Queries/Views/Transformations (QVT) mapping engine, which is the major component of the conformance validation tooling. It will be used to map information from EDI messages to a form consistent with the MOSS conceptual model.

Planned Future Accomplishments:

- Proof-of-concept conformance testing demonstration
- Detailed business process and interoperability demonstration

Customers and Collaborators:

- Automotive Industry Action Group
- Honda of America Manufacturing
- U.S. Customs and Border Protection
- Bosch
- Daimler Chrysler Corporation
- Ford Motor Corporation
- General Motors Corporation
- Global Commerce Systems

Integration Standards Testing Tools

(Status: complete in 2009)

Challenge/Problem Addressed:

Studies have shown that most integration efforts fail to achieve their goals. Poorly designed interface specifications and inadequate test methods and data are still major causes of these failures.

Objective(s):

- Provide industry with a suite of open tools and test methods that allow quick and easy assessment of XML-schema based interface standards.

Accomplishments:

- The Naming Assister tool is used by standards development organizations to evaluate a specification's consistent use of naming. The tool maps terms used to assemble element names or type names against a table of allowable terms. It can also check the construction of compound names against the International Organization for Standardization's ISO 11179 recommended naming convention.
- Extended the use of the Schema Validation tool that allows users to validate transaction schemas and transaction instances against the W3C standard specification for XML schemas.
- Extended the Schematron Editor tool to provide a Java-based GUI tool for business analysts to create, view and modify Schematron files easily.

The tool includes a number of wizards to (1) facilitate specification of constraints and more precise semantic definitions of business-content standards, and (2) test an XML instance file against the constraints defined by the current Schematron file.

Planned Future Accomplishments:

- Enhance instance validation tool that allows users to validate specific instance data content with either their own uploaded schemas, or from publicly available schemas including OASIS UBL v1.0, Grants.gov v1.0, and OAGIS v9.0.
- Extend the Quality of Design (QOD) tool as a more sophisticated tool suite, introducing Web 2.0 capabilities that allows users to define customized schema testing profiles based upon specific tests defined by them or collected from tests previously defined by others.

Customers and Collaborators:

- Open Applications Group Inc. (OAGi)
- Automotive Industry Action Group (AIAG)
- FIATECH[11]
- Un/CEFACT
- Navy
- IRS
- GSA
- U.S. Air Force
- OCIO Council

11 FIATECH is a consortium that provides global leadership in identifying and accelerating the development, demonstration and deployment of fully integrated and automated technologies to deliver the highest business value throughout the life cycle of all types of capital projects.

Supply Chain Integration

Supply Chain Center

(Status: complete in 2011)

Challenge/Problem Addressed

Supply chain challenges span all industrial sectors, but the solutions are typically addressed within the context of a given sector, even at NIST, resulting in duplication and inconsistency.

Objective(s):

- Create a NIST-wide interdisciplinary Supply Chain Center where multiple laboratories can come together to share results and enhance each other's work

Accomplishments:

- Developed a web-based collection point both for sharing efforts across NIST, and to provide one-stop shopping for customers looking for NIST work relevant to supply chain interoperability. All of the tools mentioned above can be accessed through this web site.

Planned Future Accomplishments:

- Enhance and evolve the web-based collection content and presentation
- Expand the user base of the web-based supply chain center

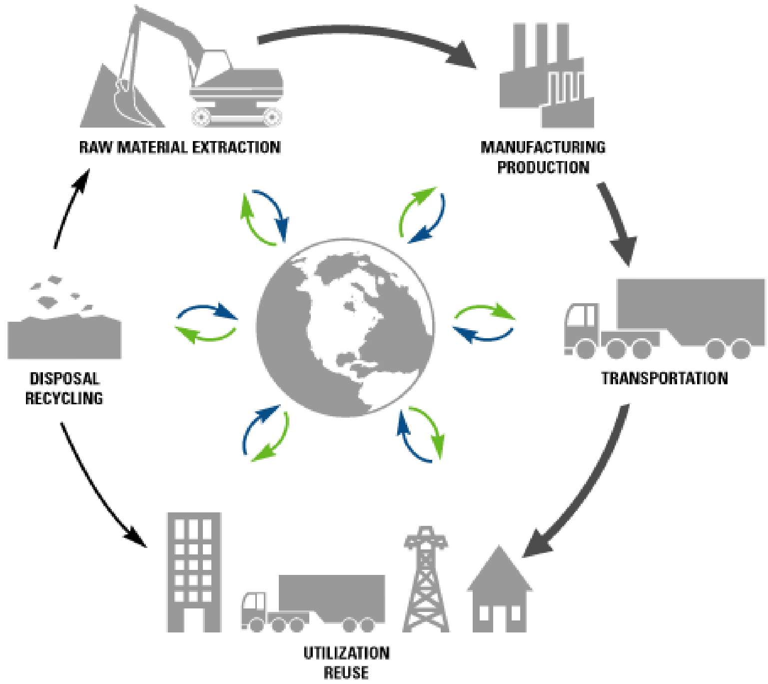
Customers and Collaborators:

Other NIST Laboratories, including:

- BFRL
- EEEL
- ITL

Manufacturing Systems Integration Programs

Sustainable and Lifecycle Information-based Manufacturing



Annual FTEs:	9 NIST FTEs
	5 Guest Researcher FTEs
	14 Total FTEs

Challenge:

Industry increasingly depends on Product Lifecycle Management (PLM)[12] systems to integrate information throughout all phases of a product's lifecycle. Well-defined standards are needed to provide both syntactic and semantic interoperability among computer systems and people. PLM systems are evolving from the exchange of product data, to the exchange of product information and knowledge throughout an enterprise; they are providing more value by adding product functionality and process information to product geometry. During the past three years, the program has worked on significant extensions to product and process data standards and PLM information models. The accomplishments are briefly sketched below.

Key Accomplishments:

- **Formalizing product and process models.** A formal description of the product beyond the representation of form (geometry and materials) is required to manage information throughout the product's lifecycle. We have developed several rigorous models that facilitate concurrent product development[13] and are amenable to automated reasoning, consistency maintenance, and semantic interoperability. This work has produced standards [ISO 10303-109 (Assembly), ISO-18629 (PSL), OMG's SysML] and product/process models in use in the aerospace and automotive industries [Airbus, Boeing, and GM].

- **STEP transition.** STEP[14] and related ISO TC 184/SC4 Industrial Data standards have been in use for two decades and provide a rich source of consensus-based domain-specific information exchange models. To take advantage of evolving Web technologies, we have developed methods and tools to integrate STEP, OMG, and W3C standards, and a process for migrating STEP data models to these more widely implemented modeling and implementation technologies. This methodology will allow the STEP, OMG, and INCOSE communities to reuse proven high-quality models.

12 PLM is the process of managing the entire lifecycle of a product from its conception, through design and manufacture, to service and disposal.

13 Concurrent activities associated with a product's design, planning, manufacturing, analysis, maintenance, and disposal.

14 STEP – Standard for the Exchange of Product model data, the informal acronym for ISO 10303, an ISO standard for the computer-interpretable representation and exchange of industrial product data.

- **Standards landscape for product lifecycle management**. PLM support requires a set of complementary and interoperable standards. In 2007, we developed a typology of standards for the exchange of product, process, operations, and supply chain information. Under a commission by the U.S. Army, we undertook a major study in 2006 to identify standards and gaps relevant to standardization, interoperability, and exchange among systems of the Army and its OEMs. The U.S. Army, OASIS, PDES Inc, IMS, and Eurostep are using this work in their deliberations on standards, patent laws, and system implementation.
- **Toward long term data and knowledge retention.** Digital models and systems built today need to be extensible and reusable by subsequent generations. Design repositories and product lifecycle management systems assume that the data will always be readable, which is not the case. We conducted several workshops to determine archival requirements for digital engineering information. This has led to an invitation by the National Archives to work with the U.S. Navy to create specific experiments for archiving product and process information.

Future Direction and Plans:

We need to prepare for a sustainable future where products are 100% recyclable, complete disassembly and sustainable disposal of a product at its end of life is routine, and manufacturing itself has a zero net impact on the environment. In support of this trend, the program looks forward to extending its work by addressing several challenges including: 1) analysis of existing and needed standards for sustainable manufacturing; 2) creation of lifecycle information models for interoperability among systems and tools that support sustainable manufacturing; and 3) validation and testing of information models for sustainable design and manufacturing.

Awards and Recognition

Board Memberships

Staff	Board Membership
Fenves, Steven	• Advisory Board, Faculty of Civil Engineering, Technion, the Israel Institute of Technology. • Advisory Board, Construction Engineering Research Laboratory, U.S. Army Corps of Engineers. • Editorial Board, Journal of Engineering with Computers (Founding Editor). • Editorial Board, Journal of Artificial Intelligence for Engineering Design, Analysis, and Manufacturing. • Editorial Board, International Journal of Computer Applications in Technology.
Frechette, Simon	• System Integration Board, PDES, Inc.
Lyons, Kevin	• Alternate, Interagency Working Group on Manufacturing R&D while at the National Science Foundation (NSF)
Sriram, Ram	• Advisory Board of the Journal of Concurrent Engineering: Research and Applications • Editorial Journal Review Board for "Research for Engineering Design," Springer Verlag • Advisory Board, Several International Conferences • Scientific Officer, National Center for Biomedical Ontologies
Subrahmanian, Eswaran	• Editorial Board, International Journal of Product Life Cycle Management, 2004-to present. • Editorial Board, Journal of Design Research, 2002-to present. • Industry Innovation Board (Science Team, Dutch Paper and Board), Netherlands, 2005.
Ray, Steve	• PDES, Inc. Executive Board • USPRO Executive Board

Leadership

Staff	Leadership
Barnard Feeney, Allison	• NIST voting member on the U.S. TAG to ISO TC 184/SC4, Industrial Automation
Bock, Conrad	• Working Group Lead for activity and action models at the Object Management Group • Working Group Lead for functional modeling in the Systems Engineering Modeling Language Submission Team at the Object Management Group • Lead for semantics of the Business Process Definition Metamodel at the Object Management Group • Lead for formal semantics of the Unified Modeling Language
Fenves, Steven	• Chair, Editorial Task Committee for the Committee on Specifications, American Institute of Steel Construction, Inc.
Lyons, Kevin	• Served a two-year detail at the National Science Foundation. Under his direction, the Nanomanufacturing Program exhibited sustained growth and added an additional Center focused on Nanomanufacturing • Co-Chair and Co-Editor for Interagency Working Group (IWG) workshop and report on Instrumentation, Metrology, and Standards for Nanomanufacturing, October 2006 • Sponsored and participated in a World Technology Evaluation Center (WTEC) study on Carbon Nanotube Production R&D at NSF. The study was initiated with a U.S. baseline workshop and concluded with travel to Japan, Korea, and China with public briefing in November 2006 • Lead NIST advisor volunteer for the FIRST (For Inspiration and Recognition of Science and Technology) robotics student group at Magruder High School, Montgomery County, MD. The regional competition was held in Annapolis, MD, March, 2007 • Invited by the Advanced Technology Program (ATP) Office to assist them during the proposal review cycle (June 2007 for 2 months).
Sriram, Ram	• Technical Co-Chair of the Imaging as a Biomarker workshop (Sept. 14-15, 2006) • Guest Co-Editor of a special issue of the ASME Journal of Computing and Information Science in Engineering, 2006 • Chair, NIST Library Advisory Board

Staff	Leadership
Sudarsan, Rachuri	• U.S. Regional Editor for the International Journal of Product Development • Associate Editor for the new International Journal of Product Lifecycle Management (IJPLM) published by the Inderscience Publishers • Conference Co-Chair for Open Standards for Manufacturing and Healthcare Informatics • Special Issue Co-Editor for ASME Journal of Computing and Information Science in Engineering on Engineering Informatics • Invited talk on "The role of standards in PLM domain" in Intellegent Manufacturing Systems Network of Excellence (IMS-NoE) SIG 1 (Special Interest Group on PLM) workshop in Lyon • Workshop Co-Chair for French-U.S. Workshop, "ICT and Standards for Supply Chains and PLM" • Member, Scientific Committee for the 16th International Conference on Engineering Design ICED 07 held in Paris France, on 28-31 August 2007 • Program Committee for the International conference on Software Knowledge Information Management and Applications (SKIMA) 2006 and 2008. • Invited lecture at PLM Summit, North America 2007 on the topic of quality issues in PLM.
Subrahmanian, Eswaran	• Program Committee Member, ACM Conference on ICT for Development, Bangalore, India, Dec. 2007 • Program Committee Member, Special Track on ICT for Development, W3C Conference, 2007 • Program Committee Member, ACM Conference on ICT for Development, Berkeley California, May 2006 • Co-chairman, Open ICT Ecosystems: Open standards for Manufacturing and health care Informatics, National Institute for Standards and technology, March 2006 • Co-Chairman, Indo-U.S. Workshop on Design Engineering, 5-7, Jan, 2006 • Program Committee, PLM06 – Product Life Cycle Management Conference, Bangalore India, 2006

Staff	Leadership
Subrahmanian, Eswaran (continued)	• Program Committee, IEEE-ACM Conference on ICT and Sustainable Development, Berkley, March 2006 • Nominating member, Japan Science Prize. 1999-to date • Founding member, Center for Science Technology and Policy, Bangalore, India, 2005 • Visiting Professor (Summer) 2007 in the Faculty of Technology Policy and Management at TU Delft Netherlands • Visiting Professor, University of Lumiere-Lyon2, Lyon, June 14- July 14, 2005 • Co-Editor, Special Issue on "Annotation and Engineering Design," Research In Engineering Design, Expected fall of 2008 • Co-Editor, Special Issue on "Engineering Informatics", JCISE. Issue to appear in March 2008

Excellence

Staff	Excellence Recognized
Barnard-Feeney, Allison	• ISO TC184-SC4 Award for Leadership in the Development of SC4 Standards, October 2006 • PDES, Inc. Bryan K. Martin Technical Excellence Award, March 2006
Bock, Conrad	• Published article, "UML 2 Activity and Action Models," translated to German by a major German consulting firm for the magazine OBJEKTspektrum. • International Council on Systems Engineering Outstanding Service Award for contribution to the development of the Systems Modeling Language. • Department of Commerce Bronze Medal for outstanding technical leadership incorporating process modeling in the Unified Modeling Language and the Systems Modeling Language
Feng, Shaw	• Invited editor for a special issue on Modeling and Optimization of Supplier-based Manufacturing and Management using Software Agents, International Journal of Manufacturing Technology and Management magazine
Fenves, Steven	• Awarded Lifetime Achievement Award from the American Institute of Steel Construction for outstanding service to the structural steel design, construction, and academic community • Honored with a special session at the 17th Analysis and Computation Specialty Conference of ASCE in Pittsburgh, Pennsylvania
Frechette, Simon Barnard-Feeney, Allison Lubell, Josh	• Awarded the 2005 Silver Medal Award for Exceptional Service for sustained leadership in the development and deployment of the STEP Application Protocol AP203 Edition 2, a new standard for computer-aided design interoperability

Staff	Excellence Recognized
Lyons, Kevin	• Presented at a public briefing of World Technology Evaluation Center (WTEC) study on Carbon Nanotubes held at the National Science Foundation on November 2-3, 2006 • Presented at 2006 NSF Grantees Conference (Dec 2006) "NIST: The U.S. Nanometrology Resource for Nanotechnology and Nanomanufacturing" • Requested by the ManTech Electronics sub-panel to present and update on Nanomanufacturing technologies, specifically those critical to the DoD, at their Winter meeting (Jan 2007) in Orlando • Principal author and editor (1 of 5) of "Manufacturing at the Nanoscale" report sponsored by the National Science and Technology Council Committee on Technology, Subcommittee on Nanoscale Science, Engineering, and Technology and the National Science Foundation • Invited panelist for 'Challenges in Micro and Nanomanufacturing' Panel Discussion held at the ASME Manufacturing Science and Engineering Conference at Georgia Institute of Technology in October 15-18 2007 • Invited Guest Editor for special nanomanufacturing issue of Journal of Nanoparticle Research to be published in Spring/Summer 2008
Sriram, Ram	• Key Note Speaker, Concurrent Engineering 2005, July 29th, 2005. • Invited Panel Chair, PLM 2005, Lyon France, July 11-15th, 2005. • Founder's Guest Editorial, 20th Anniversary Issue, AI in Engineering Journal. • Keynote Speaker, Korean Society of CAD/CAM Engineers Annual Meeting, January 2007 • Elected as the Fellow of the American Society of Mechanical Engineers (December 2006) • Keynote Speaker, TMCE, Turkey, April 2008
Subrahmanian, Eswaran	• Steven J. Fenves Award for Systems Engineering, Carnegie Mellon University, 2005 • Best Paper Award ASME Design Theory and Methodology Conference, September 2007 • Invitational workshop on Design Problem formulation, Concept Selection and design education, IIT Bombay, India, Jan 8, 2007. (with Yoram Reich, Tel Aviv Univ.)

Staff	Excellence Recognized
Sudarsan, Rachuri	• Gave invitational seminars at Indian Institute of Science (IISc) and Indian Institute of Management (IIM), and Indian Institute of Technology, India • Invited to invitational-only Product Lifecycle Management workshop held at Georgia Institute of Technology • Received a certificate of appreciation by ASME for contribution as panel member for the special session on Product Lifecycle Management held at ASME Congress
Ray, Steve	• Invited Keynote at Product Lifecycle Management '06 in Bangalore, India, July 2006, entitled "The Next Generation of Standards – A Science-Based Discipline of Information Management for Manufactured Products" • Invited "Viewpoint" interview, "International Journal of Product Lifecycle Management," Volume 2, No 3, 2007.

Projects

Sustainable and Lifecycle Information-based Manufacturing

Globalization, both of markets and of partners, is the major trend in product engineering and manufacturing today. Market globalization means that the companies will produce and sell their products in different parts of the world. Globalization of partners is the distribution of supply chain members all over the world. These trends have created extended, network-centric product engineering and manufacturing enterprises. Network-centric enterprises have become tremendously complex due to the increased number of stakeholders and the growing variety of products and production methods, all of which have led to an explosion in the amount of information sharing that must take place. It is critical to the success of companies and their suppliers that this sharing is done correctly, efficiently, and inexpensively.

A key strategy for a manufacturer seeking competitive advantage is to ensure all stakeholders rely on sharing a common product description throughout the product's lifecycle. Detailed product information cannot be kept isolated within any single entity of the extended networked enterprise but must be shared in a collaborative and secure manner across the global enterprise and its extended value chain. The overall challenge of this program is to support the creation, exchange, archiving, and management of information about product, process, people, and services within and across the networked and extended enterprise and throughout the product lifecycle.

Envisioning a lifecycle support system requires a move from product data exchange to product information and knowledge exchange across different disciplines and domains. To realize a lifecycle support system we will need both syntactic and semantic interoperability through well-defined open standards. The following projects address the challenges of lifecycle management support.

Sustainable and Lifecycle Information-based Manufacturing

STEP Evolution and Transition

(Status: complete in 2009)

Challenge/Problem Addressed:

Evolving industry needs and new technology require existing STEP standards to be extended and made compliant with emerging OMG (Object Management Group) and W3C (World Wide Web Consortium) standards. Accordingly, tools and methods are needed to allow reuse of existing manufacturing data standards within an evolving standards infrastructure, and to help manufacturers ensure that established and widely-implemented engineering and product data standards can be retooled to work with more popular implementation technologies, such as the W3C set of integration technologies.

Objective(s):

- Develop new STEP capabilities to meet evolving industry needs
- Enable the successful integration of STEP, OMG, and W3C standards
- Demonstrate a process for migrating STEP data models to more widely implemented modeling and implementation technology

Accomplishments:

- Led the project to create an OMG technical specification (Ontology Definition Metamodel – ODM) of a bidirectional mapping between EXPRESS Edition 2 and UML Version 2
- Led the project to create a UML models for inspection process planning, as extensions to STEP
- Led the project to create AP203[15] Edition 2 for CAD data, which supports GD&T specification
- Led the project to create a STEP Parametrics specification (ISO 10303-109)
- Led the project to create a STEP Construction history specification (ISO 10303-111)

Extensions to STEP allow better interoperability between traditional CAD systems to improve the efficiency of the product development cycle. The ODM technical specification will promote wider use of the STEP model, and will transfer the intellectual capital invested in the STEP standard to a new generation of technologies.

Planned Future Accomplishments:

- Develop supporting tools and methods to permit the successful integration of STEP, OMG, and W3C standards including an OMG technical specification of a bidirectional mapping between EXPRESS Edition 2 and UML Version 2.
- Demonstrate a process for migrating high-value STEP data models to more widely implemented modeling and implementation technology.
- Develop and validate an approach for transforming a STEP Application Protocol (AP) into an OWL Ontology that contains all the concepts and relationships of a STEP AP.

Customers and Collaborators:

- PDES, Inc.
- ISO TC 184/SC4
- Object Management Group (OMG)
- World Wide Web Consortium (W3C)
- EuroSTEP, Inc.

15 An application protocol (AP) is one type of standard developed within ISO 10303, and covers a particular function(s) within an industry domain

Sustainable and Lifecycle Information-based Manufacturing

Formalization of Product and Process Models

(Status: complete in 2011)

Challenge:

Lack of formal models (syntactically and semantically consistent representations) of product life cycle information makes it difficult to standardize and validate support systems for product life cycle management. Formal representations of information are needed to support the full range of the product lifecycle beyond the representation of form (geometry and material), and the standardization and validation of the OMG reference model for managing product lifecycle information

Objective(s):

- Extend the formal representation developed to date by synthesizing prior work on product, assembly and systems models, leading to comprehensive and rigorous models that facilitate automated reasoning, maintenance of consistency, semantic interoperability, and concurrent product development.
- Integrate product and process models by developing design process models using PSL, SysML and related methodologies.
- Define a clear set of conformance classes and metrics based on well defined standards and required functionalities at various stages of PLM, thus defining precise levels of interoperability among various systems and stake holders.

Accomplishments:

- ISO standard for assembly models (ISO 10303-109)
- Led the development and ongoing efforts for the Process Specification Language (PSL) family of standards (ISO 18629). This standard has been used within several other standards (OMG's UML action semantics, W3C's Semantic Web Services Language) because of the rigor it provides for representing process.
- Led the development of the OMG Systems Modeling Language (SysML) standard
- Research reports and journal papers on: Open Assembly Model; Integrated product and process models that extend ontology languages; Systems Modeling Language; ontology-based process representation; evaluation of reasoning systems
- Project underway with Boeing on ontology-based manufacturing processes.

Planned Future Accomplishments:

- Develop mechanisms for systematically evaluating, comparing, selecting and/or harmonizing a full suite of prospective PLM-related standards of overlapping scope.
- Define a clear set of conformance classes[16] and metrics based on some well defined standards, and required set of functionalities at various stages of PLM and define precise levels of interoperability among various systems and stake holders.

16 Conformance classes partition the standard's specifications to a particular range of requirements and states all the criteria must be satisfied to claim conformance.

- Identify existing and potentially needed standards in the area of failure reporting, system reliability and safety.
- Integrate existing product and process models by developing ontological representations using PSL, SysML, and related methodologies.
- Develop model-based validation and testing techniques

Customers and Collaborators:

- George Washington University (GWU)
- Syracuse University
- University of Maryland
- Carnegie Mellon University (CMU)
- University of Toronto
- University of San Jose
- Ford
- U.S. Army
- Lockheed Martin
- Boeing
- General Motors
- OMG
- ISO TC 184/SC4

Sustainable and Lifecycle Information-based Manufacturing

Standards Landscape for Lifecycle Product Management

(Status: complete in 2008)

Challenge:

Ad hoc and independent evolution of standards covering different aspects of the product lifecycle call for an understanding of the current standards coverage and gaps. Mechanisms are needed for systematically evaluating, comparing, selecting and/or harmonizing product standards of overlapping scope so as to identify a set of complementary and interoperable standards for PLM support.

Objective(s):

- Develop a typology of standards for the exchange of product, process, operations, and supply chain information.
- Conduct detailed study of standards and existing gaps or overlaps to precisely identify standards needed for lifecycle product data standardization, interoperability, and exchange among manufacturing enterprise systems as well as their clients and supply chains.

Accomplishments:

- An international workshop at NIST on open standards for manufacturing, focusing on social, economic, legal and technical perspectives, co-organized with IBM and Oracle. The U.S. Army, OASIS, PDES Inc, IMS, and Eurostep are using the reports in their deliberations on standards, patent laws, and system implementation.
- An investigative study in collaboration with Army Materiel Command personnel to assess the level of current pilot or pro-

duction use of various military, national, or international standards during the lifecycle support of any given weapon system component or part. The investigative report for the U.S. Army entitled "Analysis of Standards for Lifecycle Management of Systems for U.S. Army – a preliminary investigation" has had more than 50,000 hits on the MSID website since its publication in August 2006.

- Journal papers. The impact from these publications include: A journal paper on PLM in a networked economy and standards typology became required reading at John Deere standards division; various degrees of adoption by Standards Development Organizations (SDOs) of the concepts, analyses and recommendations presented in our reports and papers; and PLM information model journal papers ranked No. 1 and No. 3 for the most downloaded papers in Journal of CAD, July-Sept. 2007.

Customers and Collaborators:

- GWU
- Syracuse University
- CMU
- U.S. Army
- National Science Foundation
- IBM
- Oracle
- Ford
- Various other Federal agencies.

Sustainable and Lifecycle Information-based Manufacturing

Toward Long Term Data And Knowledge Retention

(Status: complete in 2010)

Challenge/Problem Addressed:

Lack of an infrastructure for archiving digital representation of manufactured artifacts impedes the ability to retrieve and use prior engineering knowledge. The nature of product and process information must be characterized to allow the development of methodologies for sustaining long-term usability of engineering information, and the definition of metrics for digital preservation of engineering information from Computer-Aided Design (CAD), Computer-Aided Engineering, Computer-Aided Manufacturing, Product Lifecycle Management (PLM) and related computer aided tools.

Objective(s):

- Gather requirements by providing a forum for information and archival specialists, domain knowledge experts from manufacturing, product engineering and other stakeholders to discuss issues such as knowledge representation, archival methods and policies, and the use of data standards to promote long term retention of manufacturing knowledge.
- Create criteria and a classification system for long term preservation of engineering information to serve as the basis for evaluating the quality of archiving practices.

Accomplishments:

- Two workshop reports, which resulted in an invitation by National Archives for NIST to work with the U.S. Navy to create specific experiments for product and process information archiving.
- An initial taxonomy of engineering information usage scenarios – presented at Digital Curation Conference, and invited for submission to the International Journal of Digital Curation. Increased awareness of digital preservation needs and of promising technologies to solve preservation problems in product design, engineering, and manufacturing.

Planned Future Accomplishments:

- Characterize engineering information in support of long-term access to lifecycle information
- Develop a digital format repository for output of CAD, PLM, and CAE systems to create a legal deposit similar to global digital format registry developed by the Library of Congress
- Implement and evaluate an archival test bed based on OAIS (Open Archival Information System) reference model, using a U.S. Navy digital ship design example

Customers and Collaborators:

- ITL
- U.S. Archives
- University of Bath
- University of Lyon
- GWU
- CMU

Sustainable and Lifecycle Information-based Manufacturing

(Status: complete in 2011)

Challenge/Problem Addressed:

Changing social demands with respect to environmentally sustainable products and manufacturing methods require the development of new information models, standards, metrics, and tools for sustainable design and manufacturing that support interoperability among tools and standards for design, analysis, lifecycle assessment and information management.

Objective(s):

- Analyze standards requirements for sustainable manufacturing
- Create lifecycle information models for interoperability among systems and tools that support sustainable manufacturing
- Validate and test information models for sustainable design and manufacturing

Accomplishments:

- None yet – project just begun

Planned Future Accomplishments:

- Perform case studies for existing sustainable manufacturing systems to generate information requirements for sustainability and characterize economic, ecological and societal interactions in a product's lifecycle.
- Develop information models and standards for products and manufacturing processes to support lifecycle management and sustainable manufacturing.
- Facilitate the creation of standards and metrics for sustainable manufacturing.
- Develop green accounting principles to trace the carbon footprint (weight) and energy use from the part level to the system level and for the full lifecycle, including assembly, disassembly, and recycling.
- Develop a testbed to validate the different aspects of the work conducted throughout this project. The testbed will apply metrics for the performance of specific applications or procedures for zero-impact manufacturing.

Customers and Collaborators:

- University of Arizona
- Other NIST laboratories
- IMS Project partners
- GWU
- CMU
- OMG
- ISO
- EPA
- DOE
- Automotive (GM, Ford, Toyota)
- Aerospace (Boeing) industries

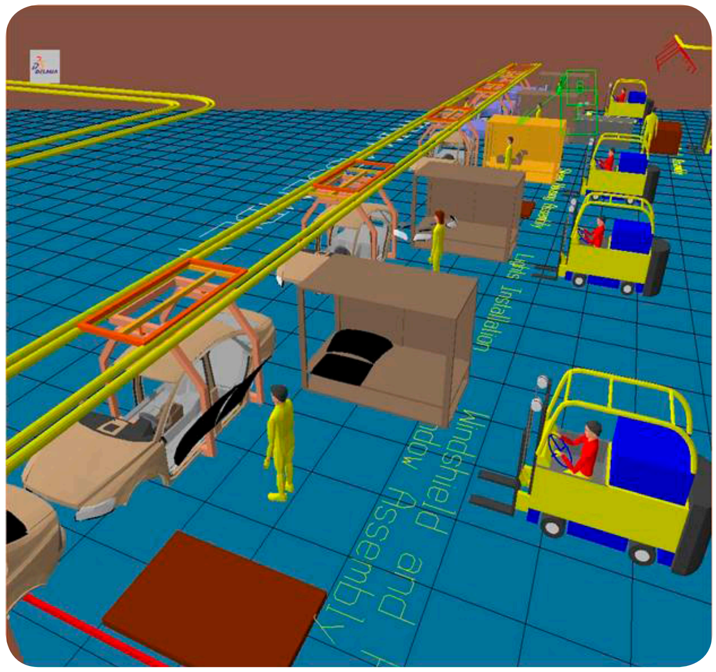
Manufacturing Systems Integration Program

Simulation-based Manufacturing Interoperability Standards and Testing

Annual FTEs:	6 NIST FTEs
	5 Guest Researcher FTEs
	11 Total FTEs

Challenge:

Manufacturing systems, often requiring large investments in capital equipment and supporting software, are costly and time-consuming to acquire, integrate, and operate. Simulation technology, which makes possible the construction of technically correct, dynamic models of organizations, systems, and processes, is a tool of proven effectiveness in reducing manufacturing costs and improving the efficiency of manufacturing system design, operation, and maintenance. Simulation models can be used to perform "what-if" analyses and make better-informed decisions. But because simulations take time as well as specialized expertise in both construction and analysis of results, they are not used as often or as effectively as they might be; manufacturing management makes decisions based on intuition or superficial analysis. Manufacturing simulations are often developed to address a narrow set of industrial issues, such as the purchase of new equipment or the improvement of an existing manufacturing process, with no thought given to reusability for other purposes.



Overview

Greater use of simulation technology and re-use of existing models can help U.S. industry improve its manufacturing systems and compete more effectively in world markets. The NIST Simulation Program focuses on simulation standards and testing issues that will enable the U.S. manufacturing industry to make more effective use of simulation technology. The Department of Homeland Security (DHS) has also recognized the value of NIST's expertise in simulation, and is giving the Program additional support to provide guidance on standards and testing for DHS modeling, simulation, and analysis applications.

There are three major components to the Program: Frameworks and Architectures; *Data Models and Standards; and Simulation Prototypes and Testing Systems.*

Frameworks and Architectures - NIST has developed distributed integration frameworks and architectures for both manufacturing and homeland security applications. The frameworks and architectures have set the direction for NIST's interface standardization, prototyping, and testing activities. As well as publishing journal articles, technical reports, and other papers, we were invited in 2007 to give the keynote at the Simulation Interoperability Standards Organization Conference (SISO) that addressed the NIST modeling and simulation architecture for incident management training.

Data Models and Standards - NIST has provided leadership and technical expertise to the Simulation Interoperability Standards Organization (SISO) to develop a Core Manufacturing Simulation Data (CMSD) model. The CMSD provides neutral data interfaces for integrating job shop software applications with manufacturing simulators. CMSD is now being extended to address flow shop[17] simulation, plant layout, and other data types. A number of major organizations – manufacturers, software vendors, research institutions and government agencies – have supported and participated in the validation of the specifications, and have provided technical contributions and reviews. Current validation efforts are being conducted with Volvo's truck engine plant, a division of the Ford Motor Company, and Chalmers University of Sweden. Unigraphics, Enterprise Dynamics, and Simul8 simulation systems are being used in the validation process.

Simulation Prototypes and Testing Systems - NIST scientists and engineers involved in the Simulation Program are using simulation technology to gain first hand experience with the problems faced by industrial users, to validate standards solutions, and to establish interoperability and other testing capabilities. A major focus is the development of a new, dynamic, simulation-based interoperability testing facility for manufacturing software applications.

NIST has developed a number of simulations to support simulation-based interoperability testing, including an automotive supply chain, a vehicle final assembly plant, and various shop floor operations. The interfaces that have so far been incorporated into these simulations include the SISO Core Manufacturing Simulation Data Model and the Open Application Group's (OAGIS) specification supporting Inventory Visibility. Future work will focus on integrating manufacturing software applications with a virtual machine shop to support validation and interoperability testing.

17 The flow structure of the process used to make or deliver a product or service impacts facility layout, resources, technology decisions, and work methods. When characterized by its flow structure, a process broadly can be classified either as a job shop or a flow shop. A job shop process uses general purpose resources and is highly flexible. A flow shop process uses specialized resources and the work follows a fixed path. Consequently, a flow shop is less flexible than a job shop. [http://www.netmba.com/operations/process/structure/]

Key Accomplishments and Impacts:

- Drafted Core Manufacturing Simulation Data (CMSD) specification, available through the standards development organization SISO – Simulation Interoperability Standards Organization.
- Validation of CMSD with Volvo and several simulation vendors.
- Completed exercise control system for homeland security training with various California agencies.

Future Directions and Plans:

The technical plan for this program is to develop manufacturing simulations that incorporate standard interfaces and instrumentation to support dynamic interoperability testing of manufacturing software applications for the automotive, aerospace, and other industries. Projects include:

1. **Standards Harmonization and Extensions:** Work with the Simulation Interoperability Standards Organization (SISO) to expand the Core Manufacturing Simulation Data Model (CMSD) to incorporate ISA 95, OAGIS IV&I, Oasis UN/CEFACT Components standards. Incorporate additional data types for plant layout, inventory, cost accounting, message transactions, equipment specifications, flow shop operations, supply chains, etc.
2. **Virtual Manufacturing System Enhancements**: Enhance current supply chain, manufacturing plant, and shop floor level simulations with functionality to support processing and interoperability testing for external inventory, process specification, bill of materials, cost accounting, product life cycle management data, etc.
3. **Testing Tool Integration:** Identify, select, and integrate appropriate testing tools developed by the Integration Standards Testing Tools project and others to instrument the Virtual Manufacturing Systems Environment, including integration infrastructures, communications channel monitors, system and module status displays, logging and reporting tools, message and file syntax checkers, system initialization, control utilities, rollback utilities, configuration management, and writing of software for testing tools and test case data sets.
4. **Testing Facility Operations:** Working with industry, research, and SDO partners to define neutral test cases, data sets; and testing policies, procedures, and checklists. Work with software vendors to set priorities and initiate interoperability testing operations for selected software products in key problem areas.

Awards and Recognition:

Board Memberships

Staff	Board Membership
Jain, Sanjay	• Editorial Board, International Journal of Industrial Engineering
Johansson, Bjorn	• Board member, Swedish Manufacturing Simulation Network • Board member, Special Interest Group Product Models • Chairman of the Board, Special Interest Group -Product Models, Sweden 2007
Leong, Swee	• SRC (Semiconductor Research Council) TAB (Technical Advisory Board) • Executive Committee of the Simulation Interoperability Standards Organization
McLean, Chuck	• Editorial Advisory Board of the International Journal of Production Planning & Control • Executive Board – Winter Simulation Conference • Editorial Board – Journal of Simulation • Editorial Board – Journal of Digital Enterprise Technology

Leadership

Staff	Leadership
Jain, Sanjay	Associate Editor, International Journal of Simulation and Process Modeling
Johansson, Bjorn	• Program Committee Secretary, Swedish Production Symposium, Gothenburg, Sweden 2007 • International Program Committee member for European Conference on Modeling and Simulation • International Program Committee member for Industrial Simulation Conference • International Program Committee member for European Simulation and Modelling Conference • International Program Committee member for Swedish Production symposium • International Program Committee member for International Middle Eastern Multiconference on Simulation and Modelling • International Program Committee member for International Conference on Flexible Automation and Intelligent Manufacturing
Lee, Tina	• Secretary, Product Development Group/Simulation Interoperability Standards Organization

Staff	Leadership
Leong, Swee	• Chair, Product Development Group/Simulation Interoperability Standards Organization. • Manager, Simulation Standards Consortium. • Co-Chair, Plenary Session Organizing Committee with theme entitled, "Modeling & Simulation in Manufacturing" at the Simulation Interoperability Standards Organization Fall Simulation Interoperability Workshop • Chair, Modeling & Simulation Standards in Manufacturing Panel discussion at the Simulation Interoperability Standards Organization Fall Simulation Interoperability Workshop
McLean, Chuck	• Secretary, Simulation Interoperability Standards Organization Crisis Management and Societal Security (CMSS) Forum • Standards Program Manager SimSummit Consortium
Riddick, Frank	• Vice-Chair, Product Development Group/Simulation Interoperability Standards Organization
Shao, Guodong	• Conference Committee and Track Chair of the Virtual Reality and Graphical Simulation for the Industrial Simulation Conference 2006 • Invited talk at Brooks Automations 13th Annual Worldwide Symposium on Simulation Prototype for Incident Management Training • Conference Program Committee and Track Chair of the Virtual Reality and Graphical Simulation for the Industrial Simulation Conference 2007

Excellence

Staff	Excellence Recognized
Jain, Sanjay	• Invited Guest Editor for a special issue on supply chain simulation and modeling of the International Journal of Simulation and Process Modeling • Invited Coordinator for Simulation Interoperability track in 2007, and Homeland Security and Emergency Response track in 2006 and 2005 Winter Simulation Conference
Johansson, Bjorn	• Invited Coordinator for Simulation based scheduling track in 2007 and Manufacturing track in 2008 Winter Simulation Conference • Invited Chair for a session on Sustainable Food Manufacturing at FOODSIM2008, Dublin, Ireland 2008
Leong, Swee	• Invited seminar at Beijing University Aeronautics & Astronautics entitled, "Modeling and Simulation in Manufacturing" in November 2007
McLean, Chuck & Jain, Sanjay	• More than 100,000 downloads of co-authored workshop report on "Modeling and Simulation for Emergency Response- Workshop Report, Standards, and Tools"
McLean, Chuck	• Invited Keynote Speaker – Simulation Interoperability Standards Consortium Fall Simulation Interoperability Workshop September 2007

Projects

Simulation-based Manufacturing Interoperability Standards and Testing

Frameworks and Architectures

(Status: complete in 2010)

Today simulation analysts typically code simulators and models from scratch and build custom data translators to import required data. As a result, developers and analysts around the world are rebuilding over and over again the same basic analytical, programming, and modeling processes. Although a simulation analyst may think that each modeling problem is unique, the component elements of many problems often have a good deal in common. Classification of different types of modeling problems according to uniform schemes or frameworks could identify and exploit such, commonalties. Frameworks make possible the establishment of modular architectures that can minimize redundant code development.

Architectures based on these frameworks divide larger systems into their component modules and identify the interfaces between those modules, allowing the assembly of more sophisticated systems from specialized modules that are independently developed by experts in each modeling area. Use of standard data input formats, as defined by commonly accepted architectures, would permit direct import of data with no need for translation.

Challenge:

Integration of simulators and other software applications and data-sharing among them are currently very difficult because no commonly accepted frameworks and architectures exist that define the simulation module functionality, boundaries, data requirements, and interfaces.

Objective(s):

- Specify frameworks and integration architectures that scope simulation module functions
- Identify interface requirements that can be used to guide future standardization efforts.

Accomplishments:

- Journal paper: An Architecture and Interfaces for Distributed Manufacturing Simulation
- Journal paper: An Architecture for Simulation-based Incident Management Training
- Report: A Data Exchange Strategy for Manufacturing Simulation of Shop Floor Systems
- Report: A Simulation and Gaming Architecture for Manufacturing Research, Testing, and Training
- Paper: A Framework for modular semiconductor simulation with experts from University of Cincinnati, OH

Planned Future Accomplishments:

- A software architecture for job shop manufacturing in the machined parts domain

Customers and Collaborators:

- Department of Homeland Security Science and Technology Directorate
- SimSummit Consortium

Simulation-based Manufacturing Interoperability Standards and Testing

Data Models and Standards

(Status: complete in 2010)

The primary reason for building manufacturing simulations is to provide support tools that aid decision-making in manufacturing processes. Simulations are typically a part of a case study that has been commissioned by manufacturing management to address a particular set of problems. The objectives of the case study determine the appropriate types of simulation models, input and output data. Translation of real world manufacturing problems into the language of manufacturing simulators requires a considerable degree of abstraction. Commercial manufacturing simulators are usually based on discrete event modeling paradigms (e.g., stations, queues, resources, processes) and do not have data interfaces that are consistent with commonly used manufacturing terminology or data structures (e.g., process plans, bill of materials, schedules). The analysis, acquisition, formatting, and translation of required data is often the most difficult part of the simulation analyst's job.

Standard data interfaces for manufacturing simulators simplify and significantly improve the inclusion of simulations in typical case studies. Standard interfaces help reduce the costs of model construction and data exchange between simulators and other software applications, and thus make simulation technology more affordable and accessible to a wide range of potential industrial users. Currently, many small manufacturers do not use simulation technology because of the difficulties of model development and data translation. These businesses typically do not have staff with the technical qualifications to develop custom simulations of their operations or custom translators to import their data from other software applications.

Challenge:

Commercially-developed simulators are typically constructed as general purpose modeling tools that require considerable efforts to input and process real world data, in part due to a lack of agreement on how to represent real world systems and data.

Objective:

- Define information models and standard interfaces for simulation modeling that make simulation technology more accessible and easy to use by conforming to real world information and permitting sharing of data between various software applications.

Accomplishments:

- Technical report: A Machine Shop Data Model
- Technical paper: A Neutral Data Interface Specification For Simulating Machine Shop Operations
- Unified Modeling Language (UML) models of job shop discrete parts manufacturing data structures
- Extensible Markup Language (XML) schemas for the job shop discrete parts manufacturing data structures
- Draft SISO standard: Core Manufacturing Simulation Data (CMSD) Model
- Emergency response simulation data model in the Unified Modeling Language (UML)

- Review of data and interface standards for incident management and emergency response simulation-based training
- Standards program leadership and plan for the SimSummit simulation industry consortium
- UML and XML shift staffing plan amendments to CMSD in cooperation with Volvo
- Analysis of Instrument Society of America (ISA) 95 ERP to MES standards compatibility with CMSD – issues noted included: detailed data formats and values not specified, lacks typing information on data, weak cross referencing scheme, no support for various simulation data types (layout, statistics, cost, inventory)
- Definition of an Radiological Dispersion Device (RDD) terrorist attack scenario and data sets for a collaborative homeland security simulation development effort

Planned Future Accomplishments:

- Draft SISO standard: Core Manufacturing Simulation Data (CMSD) Model machine shop environment
- Needs analysis for homeland security modeling simulation
- Taxonomy for homeland security modeling simulation

Customers and Collaborators:

- Volvo
- Chalmers University
- In Control
- Unigraphics
- Simul8
- Ford Motor Company
- Department of Homeland Security Science and Technology Directorate
- Wright-Patterson Air Force Base
- Doyle Center, Pittsburgh, PA
- Carnegie Mellon University
- Kurt J. Lesker
- Software Engineering Institute
- SISO

Simulation-based Manufacturing Interoperability Standards and Testing

Simulation Prototypes and Testing Systems

(Status: complete in 2011)

Manufacturing systems developed by different software vendors typically cannot work together. Development of custom integrations of manufacturing software incurs costs and delays that hurt U.S. productivity and competitiveness. As software applications continue to evolve interoperability is expected to remain a problem. Although NIST has developed static testing tools that, for example, check data formats, software applications must ultimately be tested in live operational systems. It is impractical to use real industrial systems to support dynamic interoperability testing and research due to: 1) access issues - manufacturing facilities are not open to outsiders, as proprietary data and processes may be compromised; 2) technical issues - operational systems are not instrumented to support testing; and 3) cost issues - productivity suffers when actual production systems are taken offline to allow testing.

No publicly available facility with open interfaces currently exists to support dynamic interoperability testing for a broad range of manufacturing interface standards and software applications. Prohibitive development costs and other priorities prevent most software vendors, research, and standards organizations from developing systems to support interoperability testing. Software applications from the supply chain to the shop floor must be supported. New standards now being developed to address interoperability issues often overlap and conflict with each other. Adequate testing facilities are not available for evaluating the suitability and effectiveness of existing and candidate standards for application to specific manufacturing domain areas. New, dynamic, manufacturing domain-specific testing capabilities are needed to evaluate the suitability of standards for selected applications, identify and resolve conflicts between standards, and evaluate compliance of vendor implementations with standards. Non-proprietary systems and neutral test case data sets are needed to support fair and open competition.

Challenge:

Publicly available simulations do not exist to demonstrate simulation integration issues, validate potential standards solutions, or dynamically test the interoperability of simulation systems and other software applications.

Objective(s):

- Develop simulation prototypes and testing systems with open architectures and neutral interfaces that can be use to validate simulation interface standards requirements and evaluate the interoperability of software applications with evolving standards.

Accomplishments:

- Simulation of the TDI Corporation manufacturing supply chain for a smart bomb adapter kit using Rockwell Software's Arena simulator that demonstrated the viability of new product and surge production for the Doyle Center and the U.S. Air Force.
- Generic simulation of an automobile final assembly plant using Delmia's Quest to support manufacturing interoperability testing and evaluation of the SISO CMSD and the AIAG IV&I standards specifications.
- Generic simulation of an automobile supply chain using Rockwell Software's Arena simulator to support manufacturing interoperability testing and evaluation of the AIAG IV&I standards specifications
- Distributed integration of the automobile supply chain and final assembly plant to support manufacturing interoperability testing and the evaluation of the IEEE 1516 HLA and AIAG standards specifications
- Simulation of the Volvo automobile paint shop using In Control Enterprise Dynamics simulator to validate the SISO CMSD specifications
- Simulation of the Volvo truck plant using Unigraphics' Plant Simulation and In Control Enterprise Dynamics simulators to validate the SISO CMSD specifications.
- Prototype data editor for shop data model
- Prototype database of the generic machine shop data model
- A web-based simulation called the Exercise Control System to support distributed homeland security training exercises (traditionally table top paper exercises) using the Common Alerting Protocol (CAP), Emergency Data Exchange Language (EDXL), and HLA incident management symbology standards for various response and support organizations in the State of California
- Microsoft Excel template for developing incident management training scenarios using CAP and EDXL for the Exercise Control System
- Prototype translator to convert California State Golden Guardian Exercise emergency message traffic to the Emergency Data Exchange Language (EDXL) and Common Alerting Protocol Standard (CAP)
- Set of coordinated prototype emergency response simulations, built with external collaborators, including plume behavior, vehicle movement, traffic congestion, hospital emergency room, crowd, Metro rail, triage gaming, strategy gaming, databases, and distributed message exchange for a radiological terrorist attack scenario
- Prototype wildfire gaming simulation using the Unreal game engine and a cellular automata model for fire propagation
- Draft report: Study of new alternative systems for implementation of simulation user interfaces and displays
- Simulation prototype of Washington, DC emergency response exercise using Google Earth, Common Alerting Protocol (CAP) and DHS symbology standards

Planned Future Accomplishments:

- Machine shop virtual manufacturing environment.

Customers and Collaborators:

- Volvo
- Chalmers University
- In Control
- Unigraphics
- Simul8.
- Wright-Patterson Air Force Base
- Doyle Center, Pittsburgh, PA
- Dartmouth College
- University of Arizona
- Office of Naval Research
- George Washington University
- Brooks Automation (Autosimulations Division)
- Promodel Corporation
- TDI
- San Francisco MapLab
- Comcare Consortium
- San Jose Water Department

ACI (American Competitiveness Initiative) Activities

The Manufacturing Systems Integration Division received additional funding through the American Competitiveness Initiative under two distinct programs: Supply Chain Integration and Bioimaging. The bioimaging work, performed essentially in a consulting role, was awarded to MEL because of our recognized expertise in semantic integration. The supply chain integration funds augmented our existing supply chain program documented above.

Bioimaging

Introduction

MEL participates in the "Standards and Software Validation" thrust of the NIST Bioimaging ACI. MEL is supporting ITL in achieving the goal of this thrust, which is to improve the quality of image acquisition, analysis, and storage through effective standardization, improved software, and rigorous testing. MEL's tasks in this project are:

- Development of standardized representation schemes and archival techniques for a web-based data storage system that will permit semantic annotation, content-based search and retrieval, visual browsing, cross linking between pathological states and image features, all with appropriate levels of security
- Development of an ontology to represent the semantics of archived images that can be used as the basis for open standard implementations of archive systems.

Achievements

- A workshop was held at NIST in 2006 to determine the need to standardize imaging methods for data collection and data analysis in the context of drug or radiation therapy trials. The NIST meeting was a stakeholders meeting attended by 230+ scientists from academia, imaging and pharmaceutical companies, contract research and trade organizations, and representatives from imaging societies and agencies of the Federal Government.
- Worked on a project intended to support clinical decision making by using image analysis of diseased organs to highlight deviations from normal conditions and to suggest potential disease conditions. The intention is not to automate diagnosis. While providing general a framework for building clinical decision support systems through image analysis, the initial project focused on images captured through wireless endoscopy of the gastrointestinal (GI) system. A disease ontology for part of the system was developed and is currently being validated with experts.
- Cosponsored (with ITL, NIH, and Stanford University) a workshop on evaluating ontologies. This workshop report will develop a plan for addressing the following barriers for effective utilization of ontologies: lack of a systematic method for evaluating ontologies, inadequate techniques for verification and validation, lack of standard methods for comparing ontologies, and paucity of real world applications demonstrating effectiveness of ontologies.

Impacts

The bioimaging workshop report has generated considerable interest in the radiology community. The Radiological Society of North America is planning on implementing some of the recommendations of the workshop. The image analysis work has elicited interest in applying the methodology to large databases of medical images such as the NIH's RIDER (Reference Image Database to Evaluate Response) project.

Supply Chain Integration

Introduction

ACI funding to Supply Chain Integration allowed us to undertake additional supporting research on fundamental issues associated with automatic testing of information content that is exchanged between systems. This research supports the semantic integration projects described above. It is being done in collaboration with the Information Technology Laboratory at NIST, Stanford University, and, the University of Maryland. We conducted two major research activities: (1) development of testing methods, metrics, and conformance criteria for integrating supply chain standards, and (2) development of methods and tools for the automatic generation of conformance tests. Traditional systems testing focuses on the syntax of the data for exchange. Focusing on the semantics and information in the exchange will increase supply chain efficiencies by reducing miscommunication, misinterpretation, and inaccuracies.

Achievements for Activity (1)

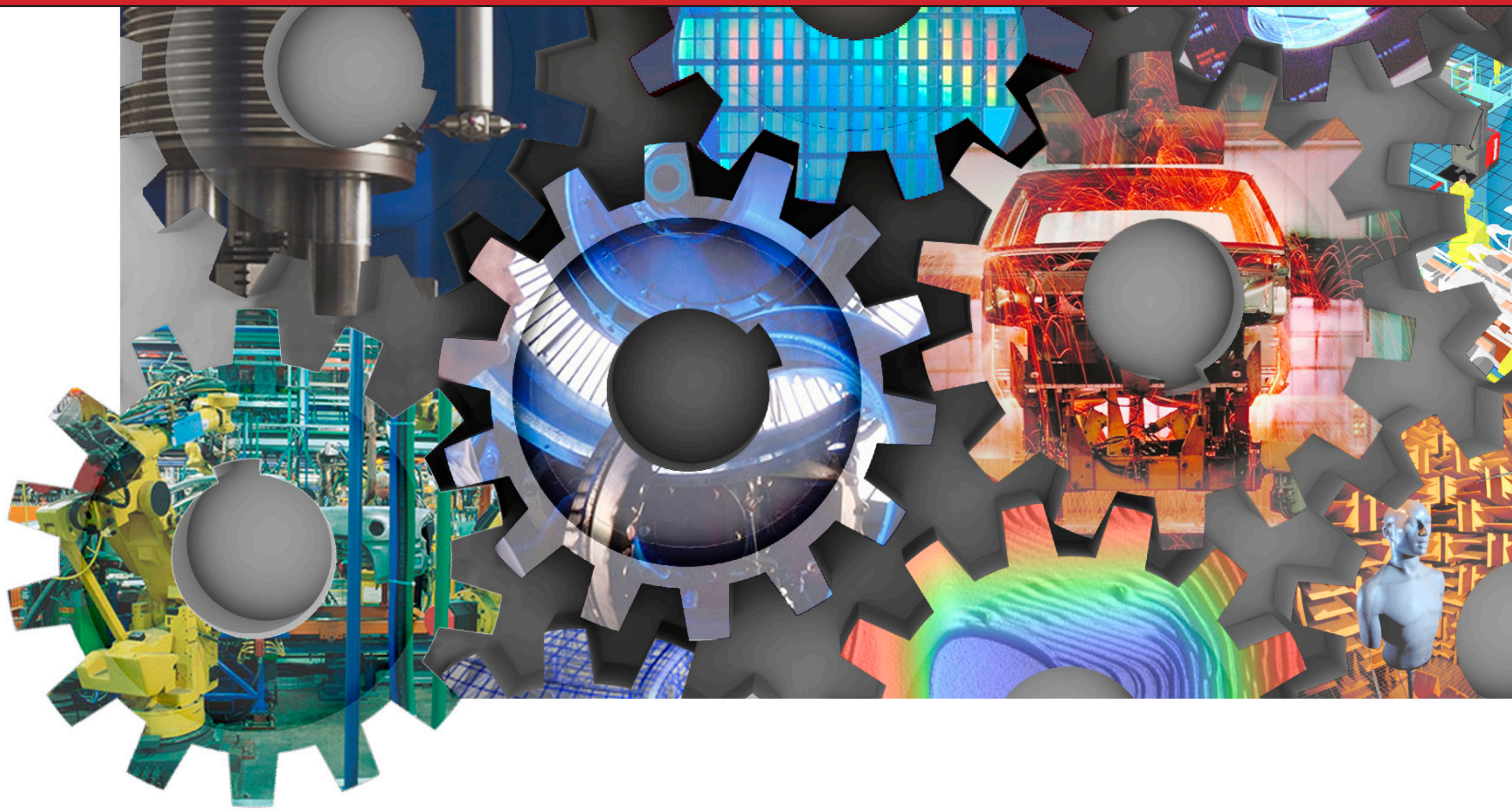
- Developed and demonstrated an initial suite of content-level tests for the exchange of e-Kanban messages for the IV&I/ATHENA project, showing that the principal idea of a semantic and web services mediation tool can be put into practice.
- Developed a Naming and Design Rule (NDR) Authoring and Testing environment and demonstrated its capabilities for a number of OAG standard supply-chain messages. NDRs are key to interoperable XML schemas used by government and industry. Since each application sector has particular terminologies and practices, single NDR relates to all applications. A neutral authoring and testing system promotes a consistent exchange environment that supports all rule sets.
- Established a working relationship with the OASIS working group responsible for developing Test Assertion Guidelines. OASIS is a standards development consortium, which will drive worldwide adoption and deployment of our guidelines.
- Collaborated with the Korean B2B Interoperability Testbed (KORBIT) to conduct a proof-of-concept demonstration of Web Services conformance testing associated with the IV&I/ATHENA project. Partnering with KORBIT leverages our ACI funds as both KORBIT and NIST share the development of tools for global e-business testing and demonstrate results collaboratively.
- Worked with Stanford University and the University of Maryland to develop metrics for comparing the semantic content of two information objects. These applied metrics will assist supply chain partners in establishing a baseline common understanding between systems, a first step in effective information exchange and interoperability.

Achievements for Activity (2)

- Developed a tool to automatically translate between Resource Description Framework (RDF) Schema and eXtensible Markup Language (XML) Schema, and between RDF and XML data in support of the IV&I/ATHENA project. RDF Schema is a vocabulary for describing properties and classes of RDF resources, which provide simple semantics. XML Schema is a language for restricting the structure of XML syntax and resulting XML documents. Both RDF and XML Schemas are in use in the global supply chain. NIST's tool automatically translates between the two standards, allowing manufacturing enterprises to retain interoperability while negotiating with a broader spectrum of providers.Developed new algorithms to generate covering arrays as part of the Automated Combinatorial Testing for Software (ACTS) projects[18]. New algorithms and faster processors make large-scale testing practical; thus reducing testing cost, improving cost-benefit ratio for software assurance

18 This work was performed in the Information Technology Laboratory using part of the MEL ACI funding allocation.

- Collaborated with KORBIT to develop a universal framework for testing conformance to OAGi supply chain standards. This framework was used and demonstrated in the IV&I/ATHENA projects. Having a universal framework for consistent conformance testing increases the probability that products will be portable and interoperable.
- Initiated development of an expanded information mapping test to support the Materials Off-Shore Supply Chains project. The work advances information exchange between different information models and proof-of-concept tools, in collaboration with the automotive industry and other partners, and provides better data management across ocean freight supply chains.



Appendix

Staff Recognition

Precision Engineering

Board Memberships

Staff	Board Membership
Estler, Tyler	• BIPM Director's Advisory Group on Uncertainty, Sevres, France
Phillips, Steven	• Association of Coordinate Metrology, Canada
Postek, Michael	• SPIE Advanced Lithography Advisory Board • SCANNING Editorial and Advisory Boards • Nanotechnology Briefs Board of Directors
Potzick, James	• SEMI Standards Microlithography Committee
Silver, Richard	• SPIE Advanced Lithography Executive Committee, 2005 • North American Regional Standards Committee, SEMI Standards • Advanced Metrology Advisory Group, SEMATECH • Editorial Board, Nanotechnology E-Bulletin • NIST Patent Review Committee, 2006-2007

Leadership

Staff	Leadership Demonstrated
Dagata, John A.	• Organizing committee, NSF-sponsored workshop on Grand Challenges for Bio-Nano Integrated Manufacturing, Arlington VA April 14-16, 2008. • Organizing committee and keynote speaker, 2008 International Workshop on Tip-based Nanofabrication, National Taiwan University of Science and Technology, Taipei, Taiwan, October 19-21, 2008.
Dixson, Ronald	• Conference Chair: 2nd Annual Tri-National Workshop on Standards for Nanotechnology NIST, Feb. 2008 • Co-chaired session with Michael Postek, NIST: EIPBN 2005, Alignment and Metrology session • Lead the "Critical Dimension Standards: Past, Present, and Future," NIST-SPIE sponsored workshop in conjunction with SPIE Advanced Lithography Conference, March 1, 2007 • Chair of ISO/TC201/SC9/SG3

Staff	Leadership Demonstrated
Estler, Tyler	• Conference Chair: ASPE Summer Topical Meeting on Precision Interferometric Metrology. July 20-22, 2005, Middletown, CT • Developed and lead a tutorial on: *Self-Calibration: Reversal, Redundancy, Error Separation, and "Absolute Testing"* – American Society for Precision Engineering Annual Meeting, Norfolk, VA October 2005 • Developed and lead a tutorial on: *Concepts and Applications of Measurement Uncertainty* – American Society for Precision Engineering Annual Meeting, Dallas, TX October 2007 • Chairman, ASME B89.7.4 Committee on Measurement Risk Analysis • Chairman, JCGM WG1 S/C 3 committee on Conformity Assessment • Chairman, Scientific and Technical Committee P (Precision Engineering and Metrology), CIRP – the International Academy for Production Engineering
Orji, George	• Session Chair: Instrumentation, Metrology and Standards for Nanomanufacturing. SPIE 2008, San Diego CA. • Session Chair: Instrumentation, Metrology and Standards for Nanomanufacturing. SPIE 2007, San Diego CA. • Taught the Invited short course: "Introductory Metrology" International SEMATECH Manufacturing Initiative Symposium on Manufacturing Effectiveness. Austin TX, October 22-25, 2007 • Moderated the SPIE Panel discussion on Reference Metrology (with Ronald Dixson). SPIE Advanced Lithography Conference. San Jose CA. February 28th 2008
Phillips, Steven	• Developed and lead a tutorial on: *Concepts and Applications of Measurement Uncertainty* – American Society for Precision Engineering Annual Meeting, Dallas, TX October 2007 • Taught a short course on "Laser Trackers, Standards, and Measurement Uncertainty, Coordinate Metrology Systems Conference, 2005 • Chairman, ASME B89.7.3 committee on Measurement Decision Rules • Chairman, ASME B89.7.5 committee on Metrological Traceability • Chairman, ASME B89.4 committee on Coordinate Metrology Division • Subject Matter Expert #1, ISO TC213 WG10 on Coordinate Metrology • Subject Matter Expert #1, ISO TC213 WG4 on Measurement Uncertainty • Task force chair, ASTM E57 committee on Short range laser scanning

Staff	Leadership Demonstrated
Postek, Michael	• Conference Chair: Instrumentation, Metrology and Standards for Nanomanufacturing. SPIE 2008, San Diego CA. • Conference Chair: Metrology for Nano-EHS September 2007 NIST Gaithersburg, MD. • Conference Chair: Instrumentation, Metrology and Standards for Nanomanufacturing. SPIE 2007, San Diego CA. • Conference Chair: Electron/Instrument Interaction Modeling in the Scanning Electron Microscope XII. A NIST Sponsored Workshop, 2007 SCANNING, April, 2007. • Conference Chair: Interagency Working Group – Instrumentation Metrology and Standards for Nanomanufacturing Workshop, Gaithersburg, MD October 17-19, 2006 • Conference Chair: Electron/Instrument Interaction Modeling in the Scanning Electron Microscope XII. A NIST Sponsored Workshop, 2007 SCANNING, • Conference Chair: Workshop on Instrumentation, Metrology and Standards for Nanomanufacturing Processes NIST Gaithersburg (October, 2006). • Conference Chair: Electron/Instrument Interaction Modeling in the Scanning Electron Microscope XI. A NIST Sponsored Workshop, 2006 SCANNING, May, 2006. • Conference Chair: Manufacturing Metrology Issues for Carbon Nanotubes A NIST Sponsored Workshop, November 1-3, 2005. • Conference Chair: Variable Pressure SEM Roadmap 3. A NIST Sponsored Workshop November 3-6 2005. • Conference Chair: Electron/Instrument Interaction Modeling in the Scanning Electron Microscope X. A NIST Sponsored Workshop (2005 SCANNING meeting). • Session Chair: Frontiers of Characterization and Metrology for Nanoelectronics 2007 - Microscopy for Nanoelectronics • Session Chair: SME WESTEC Advanced Productivity Exposition in Los Angeles, California. 2006 • Session Chair: EIPBN 2005. Alignment and Metrology session • Co-lead a workshop on “Scanning Microscopy in Forensic Science” with Frank Platek, USDA and David Ward, FBI at the Scanning 2008 Conference in Gaithersburg, MD.

Staff	Leadership Demonstrated
Postek, Michael continued	• Co-lead a workshop on "CD Metrology and Image Formation in the Scanning Electron Microscope" with Dr. Oliver Wells at the SPIE Microlithography Meeting, Santa Clara California, March, 2008. • Co-lead a workshop on "Metrology, Nanocharacterization, and Instrumentation for Emerging Nanotechnology and Nanoelectronics" with David Seiler, NIST within the IEDM 2007 Short Course on "Emerging Nanotechnology and Nanoelectronics," December 9, 2007 IEDM meeting 2007, Washington DC • Co-lead a workshop on "Scanning Microscopy in Forensic Science" with Frank Platek, USDA and David Ward, FBI at the Scanning 2007 Conference, Monterey CA. • Co-lead a workshop on "CD Metrology and Image Formation in the Scanning Electron Microscope" with Dr. Oliver Wells at the SPIE Microlithography Meeting, Santa Clara California, March, 2007. • Co-lead a workshop on "Scanning Microscopy in Forensic Science" with Frank Platek, USDA and David Ward, FBI at the Scanning 2006 Conference, Washington D. C. May 2006. • Co-lead a workshop on "CD Metrology and Image Formation in the Scanning Electron Microscope" with Dr. Oliver Wells at the SPIE Microlithography Meeting, Santa Clara California, March, 2006. • Co-lead a workshop on "Scanning Microscopy in Forensic Science" with Frank Platek, USDA and David Ward, FBI at the Scanning 2005 conference, Monterey, CA. April 2005. • Co-lead a workshop on "CD Metrology and Image Formation in the Scanning Electron Microscope" with Dr. Oliver Wells at the SPIE Microlithography Meeting, Santa Clara California, March, 2005. • Assistant to the NIST Director For Nanotechnology (2005-2006) • Chair, NIST Nanotechnology Strategic Working Group (2005-2006) • National Nanotechnology Initiative (NNI) National Science and Technology Council, Committee on Technology. Subcommittee on Nanoscale Science, Engineering and Technology (NSET) • NNI Nanomanufacturing Sub-committee • NNI National Environmental and Health Implications Sub-committee • NNI Research Directions II Sub-committee • President's Export Council Subcommittee on Export Administration (PECSEA) Nanotechnology Working Group Member. • National Science Foundation – Nanoscale Science and Engineering Center (NSEC) Nanomanufacturing – Reverse site visit reviewer, 2005

Staff	Leadership Demonstrated
Potzick, James	• Created and presented the short course “Nanoscale metrology--theory and practice” (with Brian Grenon, Grenon Consulting, Inc.) at BACUS 2007 and 2008. • Convener and leader, SEMI Standards Task Force Terminology for Micro-lithography Metrology • Leader Nano1 international comparison of linewidth measurements for BIPM.
Renegar, Brian	• Task force chair, ASME B46 committee on Surface Texture revision
Sawyer, Daniel	• Lead the Laser Tracker Performance Evaluation Workshop (with Steve Phillips), CMSC 2005 Austin, Texas • Lead the Workshop on “Introduction to the B89.4.19 Standard for Laser Tracker Performance Evaluation” at the 2005 Large Volume Metrology Conference, Brought, UK • Chairman, ASME B89.1. committee on Oil and Survey Tapes • Chairman, ASME B89.4.19 committee on Laser Trackers
Silver, Richard	• Conference Chair: Metrology, Inspection, and Process Control, SPIE Advanced Lithography, 2005 • Conference Chair: Modeling Aspects in Optical Metrology, SPIE International Conference, 2007 • Co-Chair of Nanotechnology Working Group, 2005-2008, SPIE sponsored sessions. • Co-Chair of SEMI Standards Microlithography Committee, 2004-2008 • Session Chair: SPIE Advanced Lithography on metrology, 2004-2008 • Program Committee: Instrumentation, Metrology and Standards for Nano-manufacturing, • Session Chair: Instrumentation, Metrology and Standards for Nanomanufacturing, 2007-2008 • Session Chair: Modeling Aspects in optical Metrology 2007. • Session Chair: Microlithography Panel organizer, SPIE Microlithography, 2004-5 • SPIE Advanced Lithography, Organizing committee, 2001-2008 • Program Committee, Instrumentation, Metrology and Standards for Nano-manufacturing • Organizing Committee, Instrumentation, Metrology and Standards for Nano-manufacturing, 2007-2008 • Organizing Committee, Modeling Aspects in optical Metrology, 2007 • Microlithography Panel organizer, SPIE Microlithography, 2004-5 • SEMI Microlithography Committee Chair • SEMI Standards two-dimensional grids task force leader • SEMI Standards overlay metrology task force leader • Overlay Metrology Advisory Group, Sematech • Defect Metrology Advisory Group, Sematech

Staff	Leadership Demonstrated
Song, John	• Session Chair: Advanced surface evaluations for the Eighth International Symposium on Measurement Technology and Intelligent Instruments (ISMTII 2007), Sendai, Japan, September 24th to 27th, 2007. • Lead the Second NIST Standard Bullet Workshop, August 16, 2006, Largo, FL • Lead the NIST workshop for SRM 2461 standard casings was hold in Largo, FL, January 8, 2008. • Post-Doc Research Adviser of NRC/NAS for Dr. Al Hilton's research project entitled "Ballistics Identification using Topography Measurements and Correlations" (2007-present). • Official Observer for the CIPM (BIPM) Consultative Committee for Mass and Related Quantities - Working Group on Hardness (CCM-WGH); • Council Member for the ICMI (International Committee on Measurements and Instrumentation); • Committee Member for International Measurement Confederation (IMEKO) TC 5 (Hardness Measurement); • International Committee Member for the ISMTII (International Symposium on Measurement Technology and Intelligent Instruments); • International Committee Member for the ISIST (International Symposium on Instrumentation Science and Technology); • International Committee Member for the ISPMM (International Symposium on Precision Mechanical Measurements)
Stanfield, Eric	• Chairman, ASME B89.1.19 on Master Balls
Vorburger, Ted	• Subject Matter Expert #1, ISO TC213 WG16 on Areal and profile surface texture

Excellence

Staff	Excellence Recognized
Blackburn, Chris	• 2007 NIST J.D. French Award for Measurement Service Excellence for significant improvements in accuracy and extensions of range in the calibration of long length standards. Their efforts resulted in a reduction in uncertainty by more than 600% over prior capability.
Borchardt, Bruce	• 2007 NIST J.D. French Award for Measurement Service Excellence for significant improvements in accuracy and extensions of range in the calibration of long length standards. Their efforts resulted in a reduction in uncertainty by more than 600% over prior capability.
Dagata, John A.	• Invited author. Dagata, J. A., Fundamental science and lithographic applications of scanning probe microscope oxidation, in S. Kalinin and A. Gruverman, Scanning probe microscopy: Electrical and electromechanical phenomena at the nanoscale, (Springer, NY 2006) p. 858.
Dixson, Ronald	• 2006 Department of Commerce Bronze Medal Award for the development of the Reference Measurement System, a state of the art calibrated probe microscopy at SEMATECH, the semiconductor industry research consortium, used for pitch, height, and linewidth calibrations for the semiconductor industry.
Dixson, Ronald	• Invited presentation: "Traceable Calibration of Critical Dimension Atomic Force Microscope Tip Width with One Nanometer Uncertainty," Veeco CD-AFM Workshop, SEMICON West, July 12, 2005. • Invited presentation: "Single Crystal Critical Dimension Reference Materials (SCCDRM): Candidate NIST Standard Reference Material (SRMs) for Atomic Force Microscopy," NIST/SEMATECH CD Standards Workshop, July 11, 2006. • Invited presentation: "Calibration Standards for Scatterometry/OCD: Approaches to Accuracy and Traceability and the Role of CD-AFM Reference Metrology," NIST/SEMATECH Workshop on OCD Standards, July 18, 2007.
Doiron, Ted	• 2006 Best Paper Award, Measurement Science Conference
Estler, Tyler	• 2007 NIST J.D. French Award for Measurement Service Excellence for significant improvements in accuracy and extensions of range in the calibration of long length standards. Their efforts resulted in a reduction in uncertainty by more than 600% over prior capability. • Elected Fellow of CIRP – The International Academy for Production Engineering, 2005 • Invited presentation: Fundamentals of Traceability and Uncertainty" Large-scale Metrology Workshop, PTB Braunschweig, Germany November 2006 • Invited presentation: ASME B89 Standards on Measurement Uncertainty and Traceability," Association for Coordinate Metrology Canada, Rochester, NY June 2007
Kramar, John	• Invited presentation: Nanomanufacturing at NIST. ASME International Conference on Manufacturing Science and Engineering, October 2006, Ypsilanti, MI

Staff	Excellence Recognized
Orji, George	• 2006 Department of Commerce Bronze Medal Award for the development of the Reference Measurement System, a state of the art calibrated probe microscopy at SEMATECH, the semiconductor industry research consortium, used for pitch, height, and linewidth calibrations for the semiconductor industry. • Invited Presentation: "Tip Effects and Accuracy in CD-AFM Reference Metrology" Veeco Metrology Technical Forum. San Francisco July 12th 2005. • Invited Presentation: "CD-AFM Reference Measurement System" SEMATECH Metrology Program Advisory Group. Austin TX 2005 • Invited Presentation: "Reference Measurement Systems: An Example." International Technology Roadmap for Semiconductors (ITRS) Metrology Technical Working Group meeting. San Francisco, CA. July 11th 2006 • Invited Presentation: "Reference Measurement System: Projects and Status" SEMATECH Metrology Program Advisory Group. Monterey CA February 22nd 2008
Phillips, Steven	• 2007 NIST J.D. French Award for Measurement Service Excellence for significant improvements in accuracy and extensions of range in the calibration of long length standards. Their efforts resulted in a reduction in uncertainty by more than 600% over prior capability. • Invited presentation: Laser Tracker Testing at NIST Using the ASME B89.4.19 Standard, Coordinate Metrology Systems Conference, 2007 • Invited presentation: Testing Laser Tracker Systems, Association of Coordinate Metrology Canada, 2007 • Invited presentation: Laser Trackers: Testing and Standards, Manufacturing and Measuring Conference 2007 • Invited presentation: Recent Developments in the Standardization and Testing of Laser Trackers, Manufacturing and Measuring Conference 2006 • Invited presentation: Measurement Uncertainty, CMMs, and Standards: Today and the Future, Association of Coordinate Metrology Canada, 2005

Staff	Excellence Recognized
Postek, Michael	• 2007 Nano 50 Award - Nanotech Brief's Nano 50 Awards in the Innovator category "for pioneering achievements in scanning electron microscope imaging and performance improvements and in fostering accurate dimensional metrology and national standards for nanotechnology and nanomanufacturing." • 2005 Department of Commerce Silver Medal, with John Villarrubia and Andras Vladar for the NIST Model-based Metrology measurement technique and its application to industrial CD metrology. • 2005 Nano 50 Award - First annual Nanotech Brief's Nano 50 Awards in the Technology category for the NIST Model-based Metrology measurement technique recognizing the top 50 technologies, products and innovators that have "significantly impacted or expected to impact the state of the art in nanotechnology." • Keynote Speaker: "You Can't Make It if You Can't Measure It," SME 2008 Meeting, Boston, MA • Invited presentation: Helium Ion Microscopy: A New Potentially Disruptive Technology For Nanotechnology And Nanomanufacturing, National Nano Engineering Conference (NNEC), November, 2007, Boston, MA • Invited presentation: Nanometrology: A Key Element for Successful Nanomanufacturing 2007 AVS Meeting October 2007, Seattle, WA • Invited presentation: Helium Ion Microscopy: A New Tool for Nanomanufacturing. SPIE Instrumentation, Metrology and Standards for Nanomanufacturing. August 2007, San Diego, CA. • Invited presentation: Instrumentation, Metrology, and Standards: Key Elements for the Future of Nanomanufacturing. SPIE Instrumentation, Metrology and Standards for Nanomanufacturing, August 2007, San Diego, CA. • Invited presentation: New NIST Reference Material RM 8475: Carbon, Metal Catalyst and Carbon Nanotubes. NSTI Conference, Santa Clara, CA. • Invited presentation: Documentary and Artifact Standards Activities for Nanotechnology – ASME B-89 Meeting, Charlotte, NC, 2007 • Invited presentation: "Helium Ion Microscopy: a New Technique for Semiconductor Metrology and Nanotechnology," Frontiers of Characterization and Metrology for Nanoelectronics Conference, Gaithersburg, MD, February 2007. • Invited presentation: Accurate Measurements for Nanotechnology and Nanomanufacturing: Are they Possible?, Hitachi High Technologies America (HHTA)'s National Nanotechnology Seminar Series, Moffett Field, CA, November, 2006 • Invited presentation: "Introduction and Review of the Research Needs Identified in the 2004 Instrumentation and Metrology Workshop," Instrumentation, Metrology, and Standards for Nanomanufacturing Workshop, National Science and Technology Council (NSTC) Interagency Working Group (IWG) on Manufacturing Research and Development (R&D), October 2006.

Staff	Excellence Recognized

Postek, Michael
Continued
	• Invited presentation: Nanometrology and Nanomanufacturing at the National Institute of Standards and Technology
	  • The 2006 Micro Nano Breakthrough Conference "Building a Micro/Nano Tech Economy" hosted by ONAMI, Vancouver WA, July 2006.
	  • Boeing Company Seattle, WA, July 2006.
	  • Oregon State University, Eugene, Oregon, July 2006.
	  • Albany Nanotech, Albany NY, March 2006.
	  • National Research Council of Canada Institute for National Measurement Standards (NRC-INMS), Ottawa Canada, March 2006.
	• Invited presentation: NIST Nanotechnology, Nanotechnology and Advanced Materials session, US Department of Commerce and Japan's Ministry of Economy, Trade and Industry (METI) National Science Foundation, Arlington, VA, May 2006.
	• Invited presentation: Nanotechnology at the National Institute of Standards and Technology
	• INC2 2006 meeting (Second International Nanotechnology Conference on Communication and Cooperation), Crystal City, VA, May 2006.
	• NSET Subcommittee of the NNI, May 2006.
	• Invited presentation: NIST: The Nanometrology Resource for Nanotechnology (and Nanomanufacturing)
	• SEMI NanoForum 2006 meeting, San Jose, California, November, 2006
	• Drexel University, Philadelphia, PA, December 2005.
	• Microsystems and Nano Economic Summit, OhioMEMS Association, Cleveland, Ohio, September 2005.
	• Invited presentation: Advanced Scanning Electron Microscopy Needs for Nanotechnology and Nanomanufacturing, Nano 2005 Conference, Boston, MA, November 2005.
	• Invited presentation: Unique Nanometrology Research Capabilities at NIST, Maryland Department of Business and Economic Development (DBED)/Univ. of Maryland and IMEC Event, College Park, MD 2005.
	• Invited presentation: Nanotechnology R&D at the National Institute of Standards and Technology
	• Future Manufacturing Forum, Mont Royal Centre, Montreal, Canada, September 2005.
	• Workshop on Nanotechnology Applications to Chemical and Biological Defense and Homeland Security, Reston VA, September 2005.
	• DOE/NIBIB Workshop on Biomedical Applications of Nanotechnology in Bethesda, MD March 2005.

Staff	Excellence Recognized
Postek, Michael Continued	• Invited presentation: NIST: Nanometrology Resource for Biomedical Applications of Nanotechnology 2005 US Measurement System Workshop on Nanobiotechnology, American Chemical Society, Washington D.C., August 2005. • Invited presentation: Metrology Research in the NIST Advanced Measurement Laboratory. NCSL Workshop Gaithersburg, MS August 2005. • Invited presentation: Variable Pressure/Environmental SEM a Powerful Tool for Nanotechnology and Nanomanufacturing, Microscopy Society of America, Hawaii 2005. • Invited presentation: Metrology for a New Science: Advanced Metrology Needs for Nanotechnology and Nanomanufacturing, Micro Nano Breakthrough Conference, Portland OR, July 2005. • Invited presentation: Variable Pressure/Environmental Scanning Electron Microscopy: Application to Photomask Dimensional, Metrology Micro Nano Breakthrough Conference, Portland OR July 2005. • Invited presentation: Advanced Metrology Needs for Nanotechnology and Nanomanufacturing, Electron, Ion and Photon Beam Technology and Nanofabrication Meeting, Orlando Florida, June 2005 • Invited presentation: Metrology: Fundamental for Realizing Products at the Nanoscale, The Society of Manufacturing Engineers Minneapolis, MN, April 2005. • Invited presentation: NNI Grand Challenge Instrumentation and Metrology Workshop Nanotechnology, SPIE Microlithography meeting, San Jose, CA, March 2005.
Potzick, James	• 2006 Department of Commerce Silver Medal Award for the development and certification of photmask linewidth standard reference materials and for the critical assessment and application of new optical modeling methods for the accurate determination of the true linewidth. • Invited presentation: "Limits of optical dimensional metrology at the nano-scale," 2nd Tri-National Workshop on Standards for Nanotechnology, Gaithersburg, Md. USA (Feb. 6, 2008) • Invited presentation: "Linewidth Standards and CD Metrology," Workshop:Critical Dimension Standards: The Past, Present, and Future, SPIE Symposium on Advanced Lithography (2007) • Invited book chapter: "Photomask feature metrology," Ch. 21 of A Handbook on Mask Making Technology, Syed A. Rizvi, Ed., Marcel Dekker Inc. New York (2005)
Sawyer, Dan	• 2007 NIST J.D. French Award for Measurement Service Excellence for For significant improvements in accuracy and extensions of range in the calibration of long length standards. Their efforts resulted in a reduction in uncertainty by more than 600% over prior capability. • Keynote Address: Recent Developments in the Standardization and Testing of Laser Trackers at NIST, Manufacturing and Measuring Conference, Nashville, TN 2006, Large Volume Metrology Conference, Broughton, UK • Invited Presentation: Recent Developments in the Standardization and Testing of Laser Trackers at NIST, International Workshop on Accelerator Alignment, Stanford, University, 2006

Staff	Excellence Recognized
Silver, Richard	• Nano 50 Award for Scatterfield Optical Microscopy, 2007 • Semiconductor Equipment Manufacturers International Certificate of Appreciation, Co-Chair duties Microlithography Committee, 2006,2007 • Special Membership to the Faculty, University of MD Graduate School, Dept. of Physics, 2000-6 • Invited Presentation, "Scatterfield Microscopy: Extending the Limits of Optical Microscopy", Nano 50 Awards, Nov. 2007. • Sematech AMAG, two invited presentations on OCD limits and advanced optical overlay metrology, Sept. 2007. • Microlithography Panel Participant, SPIE Microlithography, 2006-7 • Invited Paper, "Model-based Analysis of the Limits of Optical Metrology with Experimental Comparisons", SPIE Germany, 2007. • Invited Paper, "Fundamental Limits Optical Critical Dimension Metrology: A Simulation Study", SPIE Advanced Lithography, 2007. • Tutorial, Nanometer Scale Metrology. A 3 day workshop as invited keynote speaker, Singapore, March 2007. • Invited Metrology colloquium speaker, PTB Germany, 2007. • Presentation to the SEMI Microlithography standards committee, 2-dimensional grid standards and overlay metrology, March and July 2007. • Sematech AMAG, two invited presentations on OCD limits and advanced optical overlay metrology, March 2007. • Sematech DMAG, invited presentation on Advanced Optical Defect Metrology, March 2007. • Invited presentation to the ITRS Roadmap committee on challenges and directions for advanced optical semiconductor metrology, Feb. 2006. • Invited paper, "The Limits of Image-based Optical Metrology", SPIE Microlithography, 2006. • Sematech AMAG, invited presentations on OCD limits and advanced optical overlay metrology, March 2007. • Invited presentation to the SEMI Microlithography standards committee, 2-dimensional grid standards and overlay metrology, March and July 2006.

Staff	Excellence Recognized
Song, John	• Invited presentation: "NIST Standard Bullets and Casings Project", Imperial College London, UK, August 31, 2005. • Invited presentation: "NIST Standard Bullets and Casings Project", the National Metrology Institute of Japan, November 20, 2007. • Invited presentation: "Design, Manufacturing and Tests for NIST SRM 2460 Standard Bullets", the Second NIST Standard Bullet Workshop, August 16, 2006, Largo, FL • Invited presentation: "Establish the Golden Images of NIST SRM 2460/2461 Standard Bullets and Casings for Ballistics Measurement Traceability", The 2008 National Integrated Ballistics Information Network (NIBIN) Users Congress, January 8, 2008 Largo, FL. • Invited presentation: "Progress in developing NIST SRM 2461 standard casings", The 2007 National Integrated Ballistics Information Network (NIBIN) Users Congress, Dublin, CA, May 24, 2007. • Invited publication: "Verifying measurement uncertainty using a control chart with dynamic control limits," MEASURE (Journal of NCSL-International), NCSL-International, September 2007, pp76-80.
Stanfield, Eric	• 2005 NIST J.D. French Award for Measurement Service Excellence
Stone, Jack	• 2007 Department of Commerce Silver Medal Award for development of a unique high-accuracy optical probe for the measurement of sub-millimeter features and deep holes allowing NIST to open a new, unprecedented, realm of dimensional measurements 100 times smaller than previously available.

Staff	Excellence Recognized
Villarrubia, John	• Nanotech Briefs Nano 50 award for the Model-Based Library method. • 2005 Department of Commerce Silver Medal, with Michael Postek and Andras Vladar for the NIST Model-based Metrology measurement technique and its application to industrial CD metrology. • Dianna Nyyssonen Metrology Best Paper for “Unbiased Estimation of Line-Edge and Line-Width Roughness,” awarded at the Feb. 2006 SPIE Advanced Lithography meeting. • Expert panelist, “Metrology and Processing for Advanced Metallization panel,” at the Advanced Metallization Conference in San Diego, CA, October 16, 2006. • 1990s papers on AFM image simulation (dilation), surface reconstruction (erosion), and tip estimation (blind reconstruction) remain among the most widely cited papers in AFM metrology, with over 100 citations each. • Invited presentation: “Issues and Approaches in CD Metrology with AFM and SEM,” Micro and Nano Technology Measurement Club, London, England, 9/20/2006 • Invited: “Issues in Line Edge and Linewidth Roughness Metrology,” J. S. Villarrubia, 2005 International Conference on Characterization and Metrology for ULSI Technology, Richardson, TX March 15-18, 2005. • Invited: “Scanning electron microscope dimensional metrology using a model-based library,” J. S. Villarrubia, A. E. Vlad‡r, and M. T. Postek, Surface and Interface Analysis. • Invited: “Metrology Issues in LER and LWR,” Hitachi Technical Forum, San Jose, CA • Invited colloquium speaker: “Modeling for Dimensional Metrology using Secondary Electron Scanning Electron Microscopy,” Colloquium at SUNY Albany’s College of Nanoscale Science and Engineering, Dec. 8, 2006. • Invited presentation: “Monte Carlo modeling of secondary electron imaging in three dimensions,” SPIE Microlithography meeting, San Jose, CA, Feb. 28, 2007. • Invited presentation: “Informatics Issues in Library-Based Dimensional Metrology,” at Nanoinformatics Strategies, a NSF National Nanomanufacturing Network workshop, Arlington, VA, June 13, 2007.
Vladar, Andras	• 2005 Department of Commerce Silver Medal, with John Villarrubia and Andras Vladar for the NIST Model-based Metrology measurement technique and its application to industrial CD metrology. • 2005 Nano 50 Award - First annual Nanotech Brief’s Nano 50 Awards in the Technology category for the NIST Model-based Metrology measurement technique recognizing the top 50 technologies, products and innovators that have “significantly impacted or expected to impact the state of the art in nanotechnology.”

Manufacturing Metrology

Board Memberships

Staff	Board Membership
Harper, Kari	• Member, NIST Assessment Review Board (ARB); responsible for conducting and approving quality system reviews for the measurement services of each NIST division [2005-2008]
Lee, Kang	• Invited Panel Member, Department of Energy (DOE) Review Panel for the Industrial Technology Program (ITP) on Wireless Sensors [June 2005]
Nedzelnitsky, Victor	• Member, NIST Institutional Review Board (IRB); appointed by the NIST Director
Rhorer, Richard	• Member, American Society for Precision Engineering (ASPE) Board of Directors; Chair of Nominations Committee; Chair of the Scholarship Committee • Invited Panel Member, Department of Energy (DOE) Review Panel for the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL) [July 2006] • Chair, NIST Museum Committee; responsible for the display and preservation of NIST artifacts and instruments that have historical importance

Leadership

Staff	Leadership
Bartel, Tom	• Chair of Force Metrology technical session, International Measurement Confederation (IMEKO) 20th Conference on Measurement of Force, Mass, and Torque, November 28, 2007, Merida, Mexico
Damazo, Brad	• Participant in the one-year NIST New Leaders Program training for leadership and management skills [2008]
Donmez, Alkan	• Secretariat of the ISO TC39/SC2 Standards Committee "Test Conditions for Machine Tools" • Co-Chair of the Mechanical Micromachining Science and Technology Symposium at the American Society of Mechanical Engineers (ASME) International Mechanical Engineering Conference and Exposition (IMECE), November 5-11, 2005, Orlando, FL • Co-chair of the 2007 International Conference on Smart Machining Systems (ICSMS), March 13-15, 2007, NIST, Gaithersburg, MD • Completed the one-year NIST Organizational Leaders Program training for leadership and management skills [2006]

Staff	Leadership
Evans, Dave	• Chair of U.S. Delegation for the ISO TC108 Standards Committee "Mechanical Vibration and Shock" • Chair of U.S. Delegation for the ISO TC108/SC3 Standards Committee "Use and Calibration of Vibration and Shock Instrumentation" • Vice-Chair of the ANSI/ASA S2 Standards Committee "Mechanical Vibration and Shock" • Chair of the ANSI/ASA S2/WG2 Standards Committee "Terminology" • Chair of the ANSI/ASA S2/WG5 Standards Committee "Calibration and Use of Instruments"
Fick, Steve	• Chair of the ISO TC135/SC3 Standards Committee "Acoustic Methods"
Griesmann, Ulf	• General Chair of the 2006 Topical Meeting on Optical Fabrication and Testing, Optical Society of America (OSA), October 9-11, 2006, Rochester, NY • Member, Optics and Electro-Optics Standards Council, consisting of technical experts that provide guidance on behalf of the U.S. for national and international standards in the areas of optics and optical measurements
Ivester, Rob	• NIST Program Analyst, NIST Director's Office, 1-year assignment [February 2008] • Participant in the one-year NIST New Leaders Program training for leadership and management skills [2008]
Jabbour, Zeina	• Chair of Mass Metrology technical session, International Measurement Confederation (IMEKO) 20th Conference on Measurement of Force, Mass, and Torque, November 29, 2007, Merida, Mexico • Invited Member, CIPM Consultative Committee on Mass and Related Quantities (CCM) ad hoc working group on redefinition of the SI units • Completed the one-year NIST New Leaders Program training for leadership and management skills [2005]
Jurrens, Kevin	• Completed the one-year NIST Organizational Leaders Program training for leadership and management skills [2006]

Staff	Leadership
Lee, Kang	• Chair of the IEEE Instrumentation and Measurement Society TC9 Sensor Technology Committee • Chair of Machine Condition Monitoring technical session, Instrumentation and Measurement Technology Conference (IMTC) 2005, May 17-19, Ottawa, Canada • Chair of IEEE 1451 and Sensor Web technical sessions, Sensors Expo and Conference, June 7-8, 2005, Chicago, IL • Co-Chair of 3rd Annual Conference on IEEE 1588 - Precision Clock Synchronization, October 10-12, 2005, Winterthur, Switzerland • Chair of Sensor Network Interoperability technical session, SensorsGov Conference and Expo, December 6-8, 2005, Hampton, VA • Chair of Sensors, Transducers, and Smart Sensors technical session, Instrumentation and Measurement Technology Conference (IMTC) 2006, April 24-27, Sorrento, Italy • Chair of Sensor Standards Harmonization and Wireless Sensor Standards technical sessions, Sensors Expo and Conference, June 6-8, 2006, Rosemont, IL • Co-chair of the Fourth Annual Conference on the IEEE 1588 Standard for Precision Clock Synchronization, October 2-4, 2006, NIST, Gaithersburg, MD • Co-chair of the IEEE Sensors Application Symposium, February 5-8, 2007, San Diego, CA • Chair of Distributed Measurement Systems technical session, 2007 International Instrumentation and Measurement Technology Conference, May 1-3, 2007, Warsaw, Poland • Co-chair of Technical Program for 2007 IEEE International Symposium on Precision Clock Synchronization for Measurement, Control, and Communication, October 1-3, 2007, Vienna, Austria
Lee, Vincent	• Participant in the NIST one-year leadership development program Building the Next Generation [2008]
Moylan, Shawn	• Chair of Micro-Machining technical session, MicroManufacturing Conference 2007, March 14-15, 2007, Society for Manufacturing Engineering (SME), Hoffman Estates, IL
Nedzelnitsky, Victor	• Chair of U.S. Delegation for the IEC TC29 Standards Committee "Electroacoustics" • Chair of the ANSI/ASA S1/WG1 Standards Committee "Standard Microphones and their Calibration"
Rhorer, Richard	• Chair of Dynamic Behavior of Materials technical session, Society of Experimental Mechanics (SEM) Conference, June 7-10, 2005, Portland, OR
Seifarth, Rick	• Chair of Industry Workshop on Torque Metrology, September 12, 2006, NIST, Gaithersburg, MD
Shaw, Gordon	• Chair of Small Force Metrology technical session, Society of Experimental Mechanics (SEM) Conference, June 5-7, 2006, St. Louis, MO

Staff	Leadership
Soons, Johannes	• Chair of the ANSI/ASME B5/TC56 Standards Committee "Information Technology for Machine Tools" • Completed the one-year NIST New Leaders Program training for leadership and management skills [2006]
Wagner, Randy	• Vice-Chair of the SAE Emergency Vehicle Siren Task Force

Excellence

Staff	Excellence Recognized
Chesnutwood, Kevin	• Participant in upcoming 2008 BIPM Metrology Summer Program [June 2008]
Damazo, Brad	• Invited Speaker, "Review of Micro Manufacturing Techniques," Micro-Manufacturing Conference 2005, Society for Manufacturing Engineering (SME), May 3, 2005, Minneapolis, MN
Donmez, Alkan	• Recipient, 2006 Department of Commerce Silver Medal Award for Exceptional Federal Service for outstanding leadership and achievements leading to the first-ever harmonization of national and international standards for machine tool performance • Invited Speaker, "Smart Machining Systems," International Machine Tool Engineers Conference, August 28-29, 2006, Taichung, Taiwan • Invited Speaker, "NIST Advancements for the Metrology of Micro/Meso-Scale Machine Tools," First International Conference of Micromanufacturing, September 13-14, 2006, Urbana-Champaign, IL • Invited Speaker, "Metrology for Meso-Scale Machine Tools," National Tooling and Machining Association (NTMA) Annual Conference, October, 2006, St. Louis, MO • Invited Speaker, "Smart Machining Systems," National Nuclear Security Administration (NNSA) Future Technologies Conference, October 11-13, 2006, Washington, D.C. • Invited Speaker, "Application of Axis of Rotation Standard for Machine Rotary Tables," International Machine Tool Engineers Conference, October 29-30, 2007, Taichung, Taiwan • Invited Speaker, "A Novel Cooling System to Reduce Thermally-Induced Errors of Machine Tools," Special CIRP Seminar at the Swiss Federal Institute of Technology (ETH), January 22, 2008, Zurich, Switzerland
Evans, Dave	• Recipient, 2007 NIST Edward Bennett Rosa Award for outstanding achievements in development of standards and measurement practices to assure the quality and performance of acoustical devices and measuring instruments used by the public and laboratories worldwide • Recognized by the Acoustical Society of America (ASA) for outstanding contributions to standards activities, including service as Chair of the ANSI-accredited standards committee S2 on Mechanical Vibration and Shock from 1993-2000 and as Vice-Chair from 2000-2006

Staff	Excellence Recognized
Harper, Kari	• Recipient, 2007 NIST Bronze Medal Award for Superior Federal Service; for contributions to the first-ever assessment of the U.S. measurement system's ability to sustain innovation at a world-leading pace
Ivester, Rob	• Invited Speaker, "Comparison of Measurements and Simulations for Machining of 7075-T651 Aluminum," Thirdwave Systems International Users' Conference, May 4-5, Dearborn, MI • Invited Speaker, "Cycle-Time Reduction in Turning by Simulation-Based Optimization," Thirdwave Systems International Users' Conference, April 5, 2006, Chicago, IL • Invited Speaker, "Manufacturing Process Modeling," Workshop on Models for Safety, Quality, and Competitiveness of the Food Processing Section, Institute of Food Technologists, June 23, 2006, Orlando, FL
Jabbour, Zeina	• Invited Speaker, "Redefinition of the Kilogram: Status and Impact on Mass Metrology," National Conference of Standards Laboratories International (NCSLI), Plenary Session, August 2007, Minneapolis, MN • Invited Speaker, "Redefinition of the Kilogram: Status and Impact on Mass Metrology," Measurement Science Conference, March 13-14, 2008, Anaheim, CA
Kang Lee	• Recipient, 2006 NIST Equal Employment Opportunity / Diversity Award for 25 years (e.g., 1,500 Saturdays) of dedication to education and inspiration of middle and early high school students through hands-on science with the "Adventures in Science" program • Recipient, 2006 Society Award from the IEEE Instrumentation and Measurement Society for his dedicated contribution and services as Chair of the Technical Committee on Sensor Technology. Under Kang's leadership, this committee developed the IEEE 1451 smart transducer interface standards and IEEE 1588 standard for precision clock synchronization. • Profiled in a special issue of the EE Times publication on "Great Minds, Great Ideas" about people and technologies that change marketplaces and open new opportunities. The issue profiled 29 innovators in the world who make a difference in their field, transform markets, and change the way people work, live, and play. Kang was recognized as an innovator in an article titled "Paving the Road to Ubiquitous Computing." • Selected by IEEE Instrumentation and Measurement Society as an IEEE Distinguished Lecturer on the topics of smart sensors and distributed measurement and control systems • Invited Speaker, "Smart Sensor Networking and Standards," Emerging Technology Summit: Advancing the Sensor Web, April 14-15, 2005, Washington, DC

Staff	Excellence Recognized
Lee, Kang	• Invited Speaker, "IEEE 1451 Smart and Wireless Sensor Standards," International Society of Weighing and Measurement, June 28, 2005, Rockville, MD • Invited Speaker, "Integration of RFID with Smart and Wireless Sensor Networks," Networked Radio Frequency Identification Workshop, February 14-15, 2006, Geneva, Switzerland • Invited Speaker, "Integration and Applications of IEEE 1451 and RFID," RFID Academic Convocation, China International RFID Technology Development Conference and Exposition, October 26-28, 2006, Shanghai, China • Invited Speaker, "Historical Review and Future Prospects of IEEE 1451 Standards," Workshop on IEEE 1451 Smart Transducer Interfaces for Sensors and Actuators, October 29-November 4, 2006, Industrial Technology Research Institute, Center for Measurement Standards, Hsinchu, Taiwan • Invited Speaker, "Sensor-Integrated RFID Standards," RFID as an Enabler for the Next Generation Enterprise Mobility, 17th International Conference on Flexible Automation and Intelligent Manufacturing, June 20, 2007, Valley Forge, PA • Invited Speaker, "Smart Sensor Networks and RFID," Chinese Academy of Sciences Institute of Automation (CASIA), August 13, 2007, Beijing, China, • Keynote Speaker, "IEEE 1451 Smart Transducer Standards," 8th International Conference on Electronic Measurement and Instruments, August 16, 2007, Xian, China • Invited Speaker, "IEEE 1451.7 Sensor-integrated RFID Standard and Beyond," International Cooperation Forum, 2007 International RFID Technology Development Conference, November 10, 2007, Shanghai, China • Recognized in the preface of a book written by Dr. John Eidson of Agilent Technologies about the IEEE 1588 standard for precision clock synchronization. Kang chairs the IEEE Committee on Sensor Technology that was responsible for developing this standard. According to Dr. Eidson, "Everyone using IEEE 1588, including myself, owes special thanks to Kang Lee of NIST not only for his work as the IEEE sponsor of the standard, but also for his tireless efforts in its promotion."
McGlauflin, Michael	• Recipient, 2007 NIST Bronze Medal Award for Superior Federal Service for sustained achievements and excellence in providing outstanding technical support for machine tool metrology and performance standards
Nedzelnitsky, Victor	• Recipient, 2007 NIST Edward Bennett Rosa Award for outstanding achievements in development of standards and measurement practices to assure the quality and performance of acoustical devices and measuring instruments used by the public and laboratories worldwide

Staff	Excellence Recognized
Pratt, Jon	• Recipient, 2006 *Measurement Science and Technology* Outstanding Paper Award in the Precision Measurement category for his article "Prototype Cantilevers for SI-traceable Nanonewton Force Calibration" • Invited Speaker, "Advances in Small Force Metrology," Tri-National Workshop on Standards for Nanotechnology, February 7-8, 2007, National Research Council, Canada
Seifarth, Rick	• Participant in upcoming 2008 BIPM Metrology Summer Program [June 2008]
Shaw, Gordon	• Invited Speaker, "Electrochemical Joining of Nano-Components," Tri-National Workshop on Standards for Nanotechnology, February 7-8, 2007, National Research Council, Canada
Soons, Johannes	• Recipient, 2006 Department of Commerce Silver Medal Award for Exceptional Federal Service for outstanding leadership and achievements leading to the first-ever harmonization of national and international standards for machine tool performance • Recipient, Certificate of Appreciation from ASME Council on Codes and Standards for major contributions to the work of the ASME B5/TC52 Standards Committee on machine tool performance evaluation
Wagner, Randy	• Recipient, 2007 NIST Edward Bennett Rosa Award for outstanding achievements in development of standards and measurement practices to assure the quality and performance of acoustical devices and measuring instruments used by the public and laboratories worldwide

Intelligent Systems

Board Memberships

Staff	Board Membership
John Horst	• Advisory Board, Quality Expo • Advisory Board, 3D Collaboration and Interoperability Conference • Board of Directors, Dimensional Metrology Standards Consortium Board of Directors
James Albus	• Editorial board for Autonomous Robots, Robotics and Autonomous Systems, Journal of Robotic Systems, Intelligent Automation and Soft Computing
Jim Gilsinn	• Director, Instrumentation, Systems, and Automation (ISA) society's Standards & Practices (S&P) Board
Roger Bostelman	• Board member on the ANSI/ITSDF B56.5 Sub-Committee for "Safety Standard for Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles."
Elena Messina	• Advisory Board, Texas A&M Engineering Extension Service (TEEX)
Raj Madhavan	• Editorial Board of the International Journal of Tomography & Statistics (IJTS) • IEEE Robotics and Automation Society (RAS) Conference Editorial Board (CEB)

Leadership

Staff	Leadership
Steve Balakirsky	• Chair, RoboCup Rescue Virtual Competition, 2006-present • Local Arrangements Chair, 2007 RoboCup Rescue International Competition • Technical Committee, RoboCup Rescue Simulation League
Nicholas Dagalakis	• Co-organizer, 4th International Conference on Safety of Industrial Automation Systems SIAS-2005 • Organized a RIA-R15.05 standards committee meeting on Robot Performance at NIST, with the collaboration of RIA. • Co organized a workshop on Metrology Needs for Micro Nano Systems Technologies. • Hosted 5 invited talks by distinguished researchers.
Jim Gilsinn	• Editor, ISA SP99 Committee on Security for Industrial Automation & Controls Systems, Working Group 2 • Coordinator, Open DeviceNet Vendor Association (ODVA) EtherNet/IP Implementors Workshop • Leader, ODVA EtherNet/IP Performance Workgroup • Leadership Committee, ISA 99 • Chair, ISA Expo 2007 & 2008 Technical Conference, Security Exchange
John Horst	• Chair, Dimensional Metrology Standards Consortium High-Level Measurements Process Planning (HIPP) Subcommittee • Executive Committee member, AIAG Metrology Interoperability Project Team

Staff	Leadership
Hui-Min Huang	• Chair, Society of Automotive Engineers (SAE) AS4D Unmanned Systems, Committee on Performance Measures • Chair, Autonomy Levels for Unmanned Systems ad hoc government working group • Leader, Terminology Working Group within ASTM E54.08.01 Homeland Security Applications, Operational Equipment, Urban Search & Rescue Robot Performance Standards Task Group
Adam Jacoff	• Execute Committee, RoboCup Rescue Robot League, 2006-2009 • U. S. RoboCup Committeee • Chair, RoboCup Rescue Competitions 2005-current • Chair, IEEE International Workshop on Safety, Security and Rescue Robotics (SSRR) 2006 • Chair, RoboCup Rescue Robot League, which has grown under his leadership to be one of the premier international competitions stimulating advancements in mobile robot autonomy and mobility
Raj Madhavan	• Founded the Washington DC section of the IEEE Robotics and Automation Chapter • Chair of IEEE Robotics and Automation Society Washington Chapter
Elena Messina and Adam Jacoff	• Chairs, Workshop on Performance Measures for USAR Systems at the 2006 ANS Joint topical – Emergency Preparednessa dn Robotics for Hazardous Environments.
Elena Messina	• Chair, ASTM Homeland Security Applications, Operational Equipment, Urban Search & Rescue Robots • General Chair, Performance Metrics for Intelligent Systems 2006, 2007, 2008 • Workshop Chair, American Nuclear Society 2008 Joint Topical Conference Emergency Preparedness and Robotics for Hazardous Environments. • Session Chair, Metrics and Standards, SPIE Unmanned Systems Conference 2006-2008 • Co-organizer, Workshop on Evaluation of Cognitive Systems, 2006
Elena Messina, Raj Madhavan, and Adam Jacoff	• Chairs, Workshop on “Robots for Emergency Response” at the 2008 ANS Joint Topical – Emergency Preparedness and Robotics for Hazardous Environments.
Raj Madhavan	• Program Chair, Performance Metrics for Intelligent Systems 2006, 2007, 2008
Raj Madhavan, Elena Messina	• Co-chairs (along with Angel del Pobil) of Workshop on Performance Evaluation and Benchmarking for Intelligent Robots and Systems at IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), San Diego, U.S.A., Nov. 2007.
Raj Madhavan, Steve Balakirsky	• Founders and Chairs, IEEE Robotics and Automation Systems New Initiatives Competition “Advancing Robotic Research through an Open Source High-Fidelity Simulation Framework and Competition” (2007).
John Michaloski	• Chair, Open Modular Architecture Controller Human-Machine Interface
Fred Proctor	• Executive Committee of the Computers and Information in Engineering (CIE) Division of the American Society of Mechanical Engineers.

Staff	Leadership
Craig Schlenoff	• Chair of the NIST Research Advisory Committee 2007
Craig Schlenoff and Steve Balakirsky	• Chairs, Workshop on Knowledge Representation for Autonomous Systems at the 2005 ACM Conference on Information and Knowledge Management.
Keith Stouffer	• Coordinator, 2nd Federal Industrial Control System Security Workshop, NIST, March 2007 • Chair, NIST Process Control Security Requirements Forum (PCSRF) • Leadership Committee, ISA 99

Excellence

Staff	Excellence Recognized
James S. Albus Charles H. Giauque Adam S. Jacoff Frederick Proctor William Shackleford Ann Marie Virts Brian A. Weiss	• Jacob Rabinow Award (2006) For outstanding technical achievement in the application of parallel kinematic robotics research to large aircraft maintenance operations, resulting in the first industrial production of cable-suspended, robotic platforms and tripod manipulators developed by NIST's Intelligent Systems Division.
James Albus	• Keynote presentation to International Conference on Smart Machining Systems, 2007 • Invited presentation to U.S. Military Academy – Army Research Institute Workshop on Network Science in Full Spectrum Operations, at West Point, 2007 • Distinguished Lecture at University of Texas, Arlington on Toward A Computational Theory of Mind, 2007
James Albus, Tony Barbera, Craig Schlenoff, Steve Balakirsky	• Invited workshop on robot control architectures at the IDGA Military Robotics conference in Washington DC on April 18, 2005.
Stephen Balakirsky	• Invited to showcase manufacturing robotics competition based on PerfSim project at this year's International Conference on Robotics and Automation (ICRA). • Invited to give a tutorial (one of only 2) on ISD robot simulation system at this year's Simulation, Modeling, and Programming for Autonomous Robots (SIMPAR) conference. • Presented a full-day tutorial at the IEEE International Conference on Robotics and Automation (ICRA) 2006 describing ISD-developed simulation tools • Presented a full-day tutorial at the AAAI 2006 describing ISD-developed control system performance and simulation tools

Staff	Excellence Recognized
Roger Bostelman	• Invited talk on HLPR Chair to the Interagency Committee on Disability Research, Wash, DC, Sept. 2007 • Invited talk: "Reviewing Unmanned Military Systems in Unstructured Environments: Advances in Perception" at the Unmanned Military Systems Conference, Wash. D.C., Jan. 8-10, 2008. • Invited talk: "Advanced Autonomous Intelligent Vehicle Technology" Intelligent Vehicle Technology Transfer Workshop, Gaithersburg, MD Feb. 13-14, 2008. • DMC 2007 award for Best Presentation at the December 07 "Gee Whiz Technologies"
Nicholas Dagalakis	• Invited Talk by OSHA Expert on Safety, from the OSHA's Hazardous Energy Enforcement Policy & Inspection Procedures Office. • Invited talk VT-WFU Center for Injury Biomechanics, Winston-Salem, NC. • Invited talk at the 2nd workshop of the Next Generation Robot (NGR), organized by the Robotic Industries Association at the campus of the Oakland University, Rochester, MI. • Technical review and vote for the "RIA TR R15.106-20xx, Technical Report on "Teaching Multiple Robots". • Technical review and vote for the "RIA-R15 Standards Development and Approval Procedures". • Session Chair, Human-Machine Interaction, PerMIS '0 • Nick Dagalakis of ISD gave an invited presentation on May 5th, at the NIST Nano/Bio/Health Outreach Workshop, organized by Dr. Ann Plant of the Biotechnology Division. The title of the talk was "Advanced Control Systems and Positioning for Nanoscale Measurements and Standards." • Member of the NIST Scientific Computing Steering Group committee. • Member of the NIST Nanofab Users Advisors committee. • Invited presentation at a conference organized by the Maryland Technology Development Corporation (TEDCO), the Tech Council of Maryland (TCM) and the NIST Technology Services Office. • Technical Advisor, ANSI US TAG for ISO TC 184, SC 02, Robots and Robotic Devices
Joseph A. Falco Frederick Proctor Keith A. Stouffer Albert J. Wavering	• Department of Commerce Gold Medal for Distinguished Service (2005): For technical leadership of the NIST Process Control Security Requirements Forum culminating in the development of a common set of information security requirements for SCADA and industrial control systems used throughout the nation's critical infrastructure.

Staff	Excellence Recognized
Joseph A. Falco John A. Horst Hui-Min Huang Willlam G. Rippey Keith A. Stouffer	• Department of Commerce Bronze Medal Award for Superior Federal Service (2006): For technical leadership and engineering achievement demonstrating outstanding initiative, commitment, and technical competence in developing critically-needed software testing tools for the I++ Dimensional Measurement Equipment and Dimensional Markup Language data exchange standards.
Jason Gorman	• Invited seminar at the Massachusetts Institute of Technology, Cambridge, MA. • Invited seminar for the NIST Center for Nano-Scale Science and Technology seminar series.
Jim Gilsinn	• Invited Speaker, University of Michigan "Workshop on Metrics for Evaluating Network System Performance", April 19, 2006 • Senior Member, ISA society • 2006 ISA Standards & Practices Department Award
John Horst	• Invited speaker, Quality Expo 2008 Detroit, MI • Invited speaker, Quality Measurement Conference, April 2008, Tampa FL • Invited speaker, SME CAD Interoperability Conference, 2007, Detroit, MI. • Invited speaker, NCSLI 2007 conference, 2007, Minneapolis, MN • Invited speaker, Quality Expo 2007 Rosemont, IL • Invited speaker, AIAG AutoTech 2007 • Invited speaker, Control 2005, Sinsheim, Germany • Invited speaker, IA.CMM I++ DME conference, Heigenbreucken, Germany 2006 • Invited speaker, Metromeet 2008 • Automotive Industry Action Group (AIAG) Outstanding Achievement Award for efforts to enable metrology systems interface standards in the automotive industry. (2005)
Hui-Min Huang	• Distinguished Service Award from E54 Homeland Security Applications Committee of ASTM International. • Invited plenary on architectural perspective for a robotics standards technical framework at the OMG Robotics Domain Special Interest Group meeting
Adam Jacoff, James Albus	• Federal Laboratory Consortium Mid-Atlantic Regional Excellence in Technology Transfer Honorable Mention for "Innovative Robotic Crane improves Large Aircraft Maintenance Operations."
Adam Jacoff, Raj Madhavan, Elena Messina	• Guest Editors, Special Issue on Quantitative Performance Evaluation of Robotic and Intelligent Systems, Journal of Field Robotics, John Wiley & Sons, Inc., 2007, Volume 24, Issue 8-9 (August - September 2007).
Raj Madhavan, Elena Messina, James Albus	• Editors, Intelligent Vehicle Systems: A 4D/RCS Approach, Nova Science Publishers, Inc., ISBN:1-60021-260-3, Dec. 2006.

Staff	Excellence Recognized
Elena Messina	• Guest Editor, *Integrated Computer-Aided Engineering*, Volume 12, Issue 3, 2005, Special Issue on Performance Metrics for Intelligent Systems. • Invited speaker, ANSI Homeland Security Standards Panel Plenary Meeting (2005), • Invited speaker, Unmanned Systems Capabilities Conference (2005 & 2006), • Invited speaker, the Grace Hopper Conference (2006), • Invited speaker, Catastrophe Management Conference (2006) • Invited speaker, NIST Research Advisory Committee Summer Colloquium Series (2007) • Invited speaker, 2007 Robotics and Unmanned Ground & Sea Systems. • ADVANCE Distinguished Lecturer, Case Western Reserve University (2008) • Distinguished Service Award from E54 Homeland Security Applications Committee of ASTM International.(2008)
John Michaloski	• ISA On-line Webinar, "Integrating CNC and ERP - A Real World Success," in June 2006
Frederick Proctor, et al.	• Guest Editorial, "STEP-Compliant Process Planning and Manufacturing," International Journal of Computer Integrated Manufacturing special issue on STEP-NC, Vol. 19, No. 6, September 2006.
Bill Rippey	• Invited technical coordinator for trade show interoperability demonstrations sponsored by International Association of CMM Manufacturers (iacmm), 2004-2008. The yearly demonstrations at Control involve integration of 8-14 vendor's products.
Craig Schlenoff	• Colleague's Choice Award: For exemplary leadership and championship of the NIST mission in the management of independent evaluation for the DARPA Advanced Solider Sensor Information System and Technology (ASSIST) and Spoken Language Communication and Translation System for Tactical Use (TransTac) programs. (2007) • Invited plenary presentation at the 2005 AAAI Spring Symposium on autonomous systems • Invited chair of the "DOT Applications" session at the NDIA 6th Annual Intelligent Vehicle Systems Symposium. (2006) • Invited talk to the 2007 DHS Transportation Research and Development working group on the DHS ontology and its application toward the information requirements process for other related projects
Keith Stouffer	• Invited speaker, Water Environment Research Foundation Security Workshop, Washington, D.C., April 2005 • Invited speaker, Information Security and Privacy Advisory Board (ISPAB), June 2005 • Invited speaker, Honeywell Users Group Symposium, Phoenix, AZ, June 2005 • Invited speaker, KEMA 5th Annual Cyber Security Conference: Technology Solutions for Critical Infrastructure, Albuquerque, NM, August 2005 • Invited speaker, EPRI Program 86 Advisory Meeting and Workshop, Charlotte, NC, September 2005

Staff	Excellence Recognized
Keith Stouffer Continued	• Invited speaker, ISA EXPO 2005, Chicago, IL, 2005 • DHS Control System Federal Stakeholder meeting, Arlington, VA, January 2006 • Invited speaker, CIP Networks Conference & 11th Annual Meeting, Phoenix, AZ, February 2006Coordinator, NIST Federal Industrial Control System Security Workshop, NIST, April 2006 • Invited speaker, DHS S&T Technical Exchange meeting, Arlington, VA, May 2006 • Invited speaker, Process Control Systems Forum, La Jolla, CA, June 2006 • Invited speaker, KEMA 6th Annual Cyber Security Conference: Technology Solutions for Critical Infrastructure, Portland, OR, August 2006 • Invited speaker, 2006 International Control Systems Security and Standards Coordination Workshop, Portland, OR, August 2006 • Invited speaker, ISA EXPO 2006, Houston, TX, October 2006 • Invited speaker, Security Seminar for Critical Infrastructures, Tokyo, Japan, February 2007 • Invited speaker, Government Accountability Office (GAO) briefing, NIST, March 2007 • Invited speaker, ISA SP99 WG4 briefing, March 2007 • Coordinator, 2nd Federal Industrial Control System Security Workshop, NIST, March 2007 • Invited speaker, International SCADA Cyber Security Advanced Training and Workshop, Idaho Falls, ID, May 2007 • Invited speaker, Platts 5th Annual Cyber Security for Utilities Conference, Houston, TX, May 2007 • Invited speaker, ISA SP99 WG4 meeting, Phoenix, June 2007 • Invited speaker, Applied Control Solutions Conference, Knoxville, TN, August 2007 • Invited speaker, ISA EXPO 2007, Houston, TX, October 2007 • Invited speaker, Wisconsin Joint Utilities Meeting, La Crosse, WI, January 2008 • Invited speaker, ARC Advisory Group Winning Strategies and Best Practices for Global Manufacturers Forum 2008, Orlando, FL, February 2008 • Invited speaker, World Cyber Security Summit 2008, Kuala Lumpur, Malaysia, May 2008 • Invited speaker, Platts 6th Annual Cyber Security for Utilities Conference, Austin, TX, May 2008 • Technical Advisor, CIGRE B5 committee • Technical Advisor, DHS Control System Security Program
Ann Virts	• Colleague's Choice Award: For dedicated contributions which supported NIST's mission, promoted effective external interactions, and enhanced division vitality..

Manufacturing Systems Integration

Board Memberships

Staff	Board Membership
Fenves, Steven	• Advisory Board, Faculty of Civil Engineering, Technion, the Israel Institute of Technology. • Advisory Board, Construction Engineering Research Laboratory, US Army Corps of Engineers. • Editorial Board, Journal of Engineering with Computers (Founding Editor). • Editorial Board, Journal of Artificial Intelligence for Engineering Design, Analysis, and Manufacturing. • Editorial Board, International Journal of Computer Applications in Technology.
Frechette, Simon	• System Integration Board, PDES, Inc.
Jain, Sanjay	• Editorial Board, International Journal of Industrial Engineering
Johansson, Bjorn	• Board member, Swedish Manufacturing Simulation Network • Board member, Special Interest Group Product Models • Chairman of the Board, Special Interest Group -Product Models, Sweden 2007
Jones, Al	• Advisory Board for the Engineering Department at Loyola College, Baltimore, MD • Advisory Board for the Industrial Engineering Department at Morgan State University.
Leong, Swee	• SRC (Semiconductor Research Council) TAB (Technical Advisory Board) • Executive Committee of the Simulation Interoperability Standards Organization
Lyons, Kevin	• Alternate, Interagency Working Group on Manufacturing R&D while at the National Science Foundation (NSF)
McLean, Chuck	• Editorial Advisory Board of the International Journal of Production Planning & Control • Executive Board - Winter Simulation Conference • Editorial Board – Journal of Simulation • Editorial Board – Journal of Digital Enterprise Technology
Ray, Steve	• Accreditation Board for Engineering and Technology • University of Maryland Institute for System Research Strategic Advisory Board • PDES, Inc. Executive Board • USPRO Executive Board • European Union INTEROP Network of Excellence Advisory Committee • Intelligent Manufacturing Systems U.S. Delegation
Shakarji, Craig	• Member of the NIST Journal of Research Editorial Board
Sriram, Ram	• Advisory Board of the Journal of Concurrent Engineering: Research and Applications • Editorial Journal Review Board for "Research for Engineering Design," Springer Verlag • Advisory Board, several international conferences • Scientific Officer, National Center for Biomedical Ontologies

Staff	Board Membership
Subrahmanian, Eswaran	• Editorial Board, International Journal of Product Life Cycle Management, 2004-to present. • Editorial Board, Journal of Design Research, 2002-to present. • Industry Innovation Board (Science Team, Dutch Paper and Board), Netherlands, 2005.

Leadership

Staff	Leadership
Barkmeyer, Edward	• Voting representative for NIST in the Technical Committees of the Object Management Group (OMG) • Chair of two OMG Revision Task Forces, charged with maintenance and revision of the Product Data Management Enablers interface standard • Chair of two OMG Working Groups in the Manufacturing Domain Task Force, Enterprise Resource Planning and Manufacturing Business Objects • Co-Chair of two OMG independent Working Groups, Web services, and Business Rules, which became formal standards development bodies within the OMG
Barnard Feeney, Allison	• NIST voting member on the US TAG to ISO TC 184/SC4, Industrial Automation
Bock, Conrad	• Working Group Lead for activity and action models at the Object Management Group • Working Group Lead for functional modeling in the Systems Engineering Modeling Language Submission Team at the Object Management Group • Lead for semantics of the Business Process Definition Metamodel at the Object Management Group • Lead for formal semantics of the Unified Modeling Language
Denno, Peter	• Leader of the System Engineering Tool Interoperability Plugfest. The work is recognized in the plans of INCOSE, OMG and ISO TC 184/SC4 • Activity Lead of the Systems Engineering Tool Interoperability effort of INCOSE's Model Based Systems Engineering (MBSE) Initiative, which is a major initiative within INCOSE • Leader of the MOSS validation effort collaborative with the Automotive Industry Action Group and other partners
Fenves, Steven	• Chair, Editorial Task Committee for the Committee on Specifications, American Institute of Steel Construction, Inc.
Frechette, Simon	• Co-Chair of the Software Development Productivity Working Group, National Coordination Office for Information Technology Research and Development
Gruninger, Michael (2005-2006)	• Project Leader of ISO TC 184/SC4/JWG8 Process Specification Language standardization (18629) • Editor of ISO/IEC JTC1 Information Technology / SC32 Data Management and Interchange

Staff	Leadership
Ivezic, Nenad	• Team Co-Leader of the AIAG Inventory Visibility and Interoperability Proof of Concept Team • NIST Lead on the AIAG-led validation pilot of the EU-funded ATHENA project. Project Manager of the associated world-wide distributed team comprised of AIAG, Ford, GM, NIST, Korean B2B Testbed (KorBIT), University of Belgrade; and the EU-funded collaborators: SAP, Italian Research Council (CNR), Gruppo Formula, Fraunhoffer Institute, and TXT Company
Jain, Sanjay	• Associate Editor, International Journal of Simulation and Process Modeling
Johansson, Bjorn	• Program Committee Secretary, Swedish Production Symposium, Gothenburg, Sweden 2007 • International Program Committee member for European Conference on Modeling and Simulation • International Program Committee member for Industrial Simulation Conference • International Program Committee member for European Simulation and Modelling Conference • International Program Committee member for Swedish Production symposium • International Program Committee member for International Middle Eastern Multiconference on Simulation and Modelling • International Program Committee member for International Conference on Flexible Automation and Intelligent Manufacturing
Kulvatunyou, Boonserm (2005-2007)	• Voting member of ebXML Interoperability, Implementation & Conformance. • Team Co-Leader of AIAG Inventory Visibility and Interoperability Proof of Concept Team. • Senior Member of Chapter 48 Secretary of Society of Manufacturing Engineering
Lee, Tina	• Secretary, Product Development Group/Simulation Interoperability Standards Organization
Leong, Swee	• Chair, Product Development Group/Simulation Interoperability Standards Organization. • Manager, Simulation Standards Consortium. • Co-Chair, Plenary Session Organizing Committee with theme entitled, "Modeling & Simulation in Manufacturing" at the Simulation Interoperability Standards Organization Fall Simulation Interoperability Workshop • Chair, Modeling & Simulation Standards in Manufacturing Panel discussion at the Simulation Interoperability Standards Organization Fall Simulation Interoperability Workshop

Staff	Leadership
Lyons, Kevin	• Served on a two-year detail at the National Science Foundation as Program Manager. Under his direction, the Nanomanufacturing Program exhibited sustained growth and added an additional Center focused on Nanomanufacturing • Co-Chair and Co-Editor for Interagency Working Group (IWG) workshop and report on Instrumentation, Metrology, and Standards for Nanomanufacturing, October 2006 • Sponsored and participated in a World Technology Evaluation Center (WTEC) study on Carbon Nanotube Production R&D at NSF. The study was initiated with a US baseline workshop and concluded with travel to Japan, Korea, and China with public briefing in November 2006 • Lead NIST advisor volunteer for the FIRST (For Inspiration and Recognition of Science and Technology) robotics student group at Magruder High School. The regional competition was held in Annapolis, MD March, 2007 • Invited by the Advanced Technology Program (ATP) Office to assist them during the proposal review cycle (June 2007 for 2 months).
McLean, Chuck	• Secretary, Simulation Interoperability Standards Organization Crisis Management and Societal Security (CMSS) Forum • Standards Program Manager SimSummit Consortium
Morris, KC	• Chartered and led the Working Group on XML Schema Interoperability for the Federal CIO Council's Data Architecture Subcommittee
Ray, Steve	• Co-Organizer of the Ontolog Forum, Ontology Summit (2006, 2007, 2008) • Committee Chair, National Center for Ontology Research (NCOR) Ontology Evaluation • Chair, IMS Vision Forum study group on "Key Technology for Manufacturing Innovation and Environmental Sustainability", 2006
Riddick, Frank	• Vice-Chair, Product Development Group/Simulation Interoperability Standards Organization
Shao, Guodong	• Conference Committee and Track Chair of the Virtual Reality and Graphical Simulation for the Industrial Simulation Conference 2006 • Invited talk at Brooks Automations 13th Annual Worldwide Symposium on Simulation Prototype for Incident Management Training • Conference Program Committee and Track Chair of the Virtual Reality and Graphical Simulation for the Industrial Simulation Conference 2007
Shakarji, Craig	• Chair of ASME B89.4.10 on CMM software evaluation US Representative on ISO 213 WG 10 (Coordinate Measuring Machines) • Editor of: • ISO 15530-4 (CMM Uncertainty by Simulation) • ISO 10360-5 (CMM Probing Test) • ISO 23165-5 (CMM Probing Test Uncertainty)
Sriram, Ram	• Technical Co-Chair of the Imaging as a Biomarker workshop (Sept. 14-15, 2006) • Guest Co-Editor of a special issue of the ASME Journal of Computing and Information Science in Engineering, 2006 • Chair, NIST Library Advisory Board

Staff	Leadership
Sudarsan, Rachuri	• Regional Editor for the USA for the International Journal of Product Development • Associate Editor for the new International Journal of Product Lifecycle Management (IJPLM) published by the Inderscience Publishers • Conference Co-Chair for Open Standards for Manufacturing and Healthcare Informatics • Special Issue Co-Editor for ASME Journal of Computing and Information Science in Engineering on Engineering Informatics • Invited talk on "The role of standards in PLM domain" in Intellegent Manufacturing Systems Network of Excellence (IMS-NoE) SIG 1 (Special Interest Group on PLM) workshop in Lyon • Workshop Co-Chair for French-US Workshop, "ICT and Standards for Supply Chains and PLM" • Member, Scientific Committee for the 16th International Conference on Engineering Design ICED 07 held in Paris France, on 28-31 August 2007 • Program Committee for the International conference on Software Knowledge Information Management and Applications (SKIMA) 2006 and 2008. • Invited lecture at PLM Summit, North America 2007 on the topic of quality issues in PLM.
Subrahmanian, Eswaran	• Program Committee Member, ACM Conference on ICT for Development, Bangalore, India, Dec. 2007 • Program Committee Member, Special Track on ICT for Development, W3C Conference, 2007 • Program Committee Member, ACM Conference on ICT for Development, Berkeley California, May 2006 • Co-chairman, Open ICT Ecosystems: Open standards for Manufacturing and health care Informatics, National Institute for Standards and technology, March 2006 • Co-Chairman, Indo-US Workshop on Design Engineering, 5-7, Jan, 2006 • Program Committee, PLM06 – Product Life Cycle Management Conference, Bangalore India, 2006 • Program Committee, IEEE-ACM Conference on ICT and Sustainable Development, Berkley, March 2006 • Nominating member, Japan Science Prize. 1999-to date • Founding member, Center for Science Technology and Policy, Bangalore, India, 2005 • Visiting Professor (Summer) 2007 in the Faculty of Technology Policy and Management at TU Delft Netherlands • Visiting Professor, University of Lumiere-Lyon2, Lyon, June 14- July 14, 2005 • Co-Editor, Special Issue on "Annotation and Engineering Design," Research In Engineering Design, Expected fall of 2008 • Co-Editor, Special Issue on "Engineering Informatics", JCISE. Issue to appear in March 2008

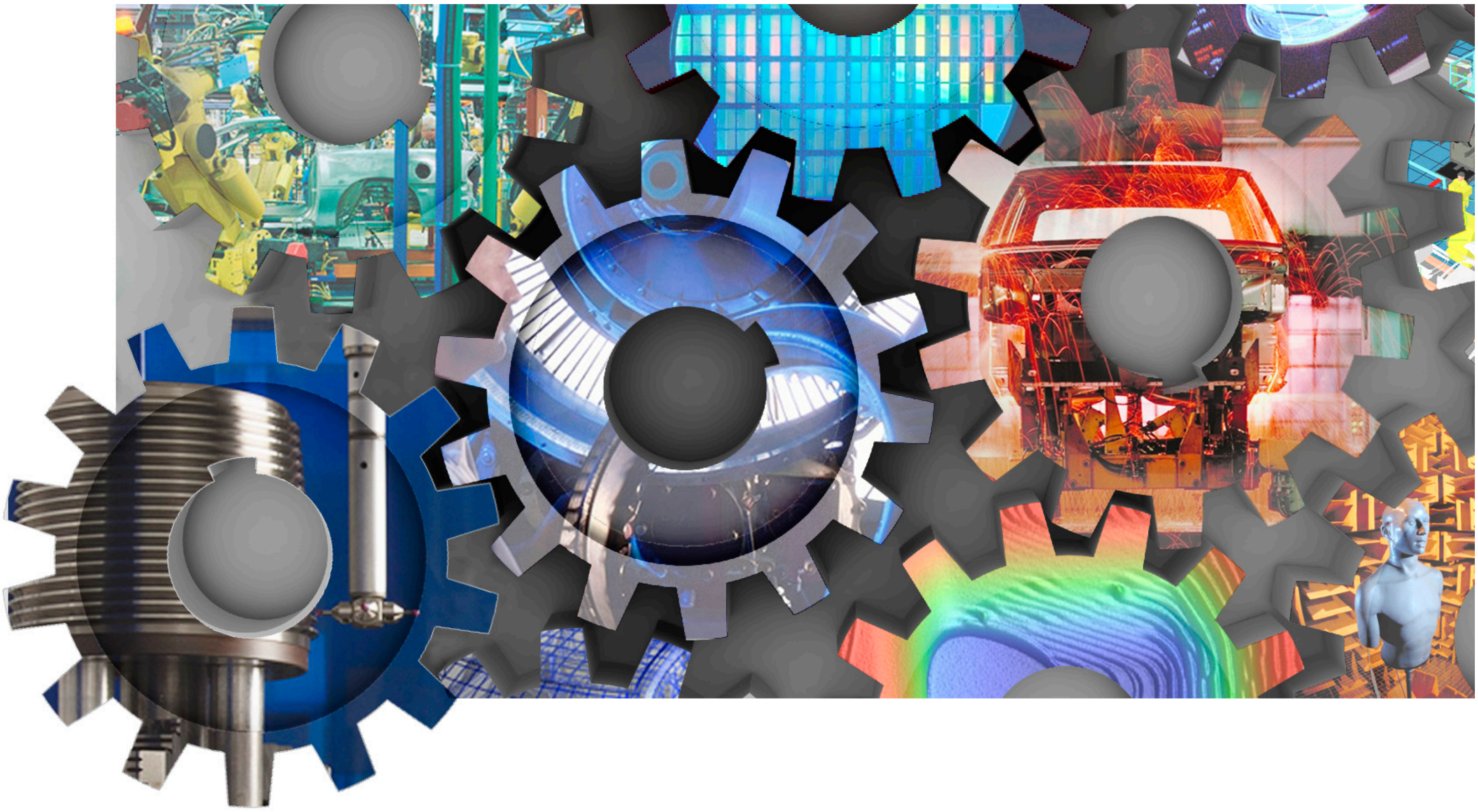
Staff	Leadership
Wallace, Evan	• Co-Chair of the Ontology Platform Special Interest Group of the OMG • Co-Chair of the Ontology Definition Metamodel Finalization Task Force of the OMG • Representative for NIST in the OWL Working Group of the World Wide Web Consortium (W3C) • Formerly represented NIST in the W3C Semantic Web Best Practices and Deployment Working Group (now closed)

Excellence

Staff	Excellence
Barnard-Feeney, Allison	• ISO TC184-SC4 Award for Leadership in the Development of SC4 Standards, October 2006 • PDES, Inc. Bryan K. Martin Technical Excellence Award, March 2006
Bock, Conrad	• Published article, "UML 2 Activity and Action Models," translated to German by a major German consulting firm for the magazine OBJEKTspektrum. • International Council on Systems Engineering Outstanding Service Award for contribution to the development of the Systems Modeling Language. • Department of Commerce Bronze Medal for outstanding technical leadership incorporating process modeling in the Unified Modeling Language and the Systems Modeling Language
Feng, Shaw	• Invited editor for a special issue on Modeling and Optimization of Supplier-based Manufacturing and Management using Software Agents, International Journal of Manufacturing Technology and Management magazine
Fenves, Steven	• Awarded Lifetime Achievement Award from the American Institute of Steel Construction for outstanding service to the structural steel design, construction, and academic community • Honored with a special session at the 17th Analysis and Computation Specialty Conference of ASCE in Pittsburgh, Pennsylvania
Frechette, Simon Barnard-Feeney, Allison Lubell, Josh	• Awarded the 2005 Silver Medal Award for Exceptional Service for sustained leadership in the development and deployment of the STEP Application Protocol AP203 Edition 2, a new standard for computer-aided design interoperability
Goyal, Puja Lubell, Josh Morris, KC	• Awarded the 2005 Bronze Medal Award for Superior Federal Service for building XML schemas and creating a collection of software tools and test case data sets to support multi-party collaboration work process for the life cycle of facilities equipment
Ivezic, Nenad	• Recipient of the 2006 Automotive Industry Action Group (AIAG) Individual Achievement Award for outstanding contributions to the automotive industry • Recipient of the 2007 Automotive Industry Action Group (AIAG) Individual Achievement Award for outstanding contributions to the automotive industry

Staff	Excellence
Jain, Sanjay	• Invited Guest Editor for a special issue on supply chain simulation and modeling of the International Journal of Simulation and Process Modeling • Invited Coordinator for Simulation Interoperability track in 2007, and Homeland Security and Emergency Response track in 2006 and 2005 Winter Simulation Conference
Johansson, Bjorn	• Invited Coordinator for Simulation based scheduling track in 2007 and Manufacturing track in 2008 Winter Simulation Conference • Invited Chair for a session on Sustainable Food Manufacturing at FOODSIM2008, Dublin, Ireland 2008
Leong, Swee	• Invited seminar at Beijing University Aeronautics & Astronautics entitled, "Modeling and Simulation in Manufacturing" in November 2007
Lyons, Kevin	• Presented at a public briefing of World Technology Evaluation Center (WTEC) study on Carbon Nanotubes held at the National Science Foundation on November 2-3, 2006 • Presented at 2006 NSF Grantees Conference (Dec 2006) "NIST: The U.S. Nanometrology Resource for Nanotechnology and Nanomanufacturing" • Requested by the ManTech Electronics sub-panel to present and update on Nanomanufacturing technologies, specifically those critical to the DoD, at their Winter meeting (Jan 2007) in Orlando • Principal author and editor (1 of 5) of "Manufacturing at the Nanoscale" report sponsored by the National Science and Technology Council Committee on Technology, Subcommittee on Nanoscale Science, Engineering, and Technology and the National Science Foundation • Invited panelist for 'Challenges in Micro and Nanomanufacturing' Panel Discussion held at the ASME Manufacturing Science and Engineering Conference at Georgia Institute of Technology in October 15-18 2007 • Invited Guest Editor for special nanomanufacturing issue of Journal of Nanoparticle Research to be published in Spring/Summer 2008
McLean, Chuck & Jain, Sanjay	• More than 100,000 downloads of co-authored workshop report on "Modeling and Simulation for Emergency Response- Workshop Report, Standards, and Tools"
McLean, Chuck	• Invited Keynote Speaker – Simulation Interoperability Standards Consortium Fall Simulation Interoperability Workshop September 2007
Ray, Steve	• Invited Keynote presentation entitled "Standards, Interdependence and Complexity - Developments and Trends in Standards from the Enterprise to the Shop Floor," at the International Conference on Smart Machining Systems (ICSMS), March 13-15, 2007 • Invited Keynote at Product Lifecycle Management '06 in Bangalore, India, July 2006, entitled "The Next Generation of Standards – A Science-Based Discipline of Information Management for Manufactured Products" • Invited "Viewpoint" interview, "International Journal of Product Lifecycle Management," Volume 2, No 3, 2007.

Staff	Excellence
Sriram, Ram	• Key Note Speaker, Concurrent Engineering 2005, July 29th, 2005. • Invited Panel Chair, PLM 2005, Lyon France, July 11-15th, 2005. • Founder's Guest Editorial, 20th Anniversary Issue, AI in Engineering Journal. • Keynote Speaker, Korean Society of CAD/CAM Engineers Annual Meeting, January 2007 • Elected as the Fellow of the American Society of Mechanical Engineers (December 2006) • Keynote Speaker, TMCE, Turkey, April 2008
Subrahmanian, Eswaran	• Steven J. Fenves Award for Systems Engineering, Carnegie Mellon University, 2005 • Best Paper Award ASME Design Theory and Methodology Conference, September 2007 • Invitational workshop on Design Problem formulation, Concept Selection and design education, IIT Bombay, India, Jan 8, 2007. (with Yoram Reich, Tel Aviv Univ.)
Sudarsan, Rachuri	• Gave invitational seminars at Indian Institute of Science (IISc) and Indian Institute of Management (IIM), and Indian Institute of Technology, India • Invited to invitational-only Product Lifecycle Management workshop held at Georgia Institute of Technology • Received a certificate of appreciation by ASME for contribution as panel member for the special session on Product Lifecycle Management held at ASME Congress



Publications

Precision Engineering Division

List of Publications

For

FY2004 to FY2008

(September 30, 2004 to March 20, 2008)

March 20, 2008

FY2008 Publications:

(R) R. Attota, R. M. Silver, R. G. Dixson, "*Line Width Measurement Technique Using Through-Focus Optical Images*", Applied Optics, Vol. 47, pp. 495-503, (01-Jan-2008)

R. G. Dixson, N. G. Orji, J. E. Potzick, J. N. Fu, M. W. Cresswell, R. A. Allen, S. J. Smith, A. J. Walton, "*Photomask Applications of Traceable Atomic Force Microscope Dimensional Metrology at NIST*", Proceedings of SPIE, Photomask Technology 2007, Monterey, CA, USA, 09/18/2007 to 09/18/2007, Vol. 6730, (01-Oct-2007)

T. V. Vorburger, R. G. Dixson, J. N. Fu, N. G. Orji, S. C. Feng, M. W. Cresswell, R. A. Allen, W. F. Guthrie, W. Chu, "*Nano- and Atomic-Scale Length Metrology*", Proc. 5th Int. Conf. on Precision, Meso, Micro, and Nano Engineering (COPEN 2007) (Allied Publishers Pvt. Ltd, Chennai, 2007), 5th Int. Conf. on Precision, Meso, Micro, and Nano Engineering (COPEN 2007), Trivandrum, India, 12/14/2007 to 12/14/2007, pp. 13-18, (14-Dec-2007)

FY2006 Publications:

B. M. Barnes, L. P. Howard, P. Lipscomb, R. M. Silver, "*Zero-Order Imaging of Device-Sized Overlay Targets Using Scatterfield Microscopy*", Proceedings of SPIE, Metrology, Inspection, and Process Control for Microlithography XXI, San Jose, CA, USA, 02/26/2007 to 02/26/2007, Vol. 6518, 10 pp., (01-Mar-2007)

(R) S. H. Bui, T. V. Vorburger, "*Surface Metrology Algorithm Testing System*", Precision Engineering, Vol. 31, pp. 218-225, (01-Jan-2007)

(R) W. Chu, J. N. Fu, R. G. Dixson, T. V. Vorburger, "*3D Image Correction of Tilted Sample Through Coordinate Transformation*", Scanning, The Journal of Scanning Microscopies, (01-Jan-2007)

W. Chu, J. N. Fu, R. G. Dixson, T. V. Vorburger, "*Linewidth Measurement Based on Automatically Matched and Stitched Images*", Proceedings of the International Conference on Frontiers of Characterization and Metrology for Nanoelectronics: 2007, International Conference on Frontiers of Characterization and Metrology for Nanoelectronics: 2007, Harbin, China, 03/27/2007 to 03/29/2007, Vol. 931, pp. 407-412, (01-Jan-2007)

R. G. Dixson, N. G. Orji, "*Comparison and Uncertainties of Standards for CD-AFM Microscope Tip Width Calibration*", Proceedings of SPIE, Metrology, Inspection, and Process Control for Microlithography XXI, San Jose, CA, USA, 02/26/2007 to 02/26/2007, Vol. 6517, 11 pp., (05-Apr-2007)

R. G. Dixson, W. F. Guthrie, M. W. Cresswell, R. A. Allen, N. G. Orji, "*Single Crystal Critical Dimension Reference Materials (SCCDRM): Process Optimization for the Next Generation of Standards*", Proceedings of SPIE, Metrology, Inspection, and Process Control for Microlithography XXI, San Jose, CA, USA, 02/26/2007 to 02/26/2007, Vol. 6518, 11 pp., (05-Apr-2007)

(R) T. D. Doiron, "*20 Degrees Celsius--A Short History of the Standard Reference Temperature for Industrial Dimensional Measurements*", Journal of Research (NIST JRES), Vol. 112, No. 1, pp. 1-23, (01-Jan-2007)

E. Marx, "*Images of Strips On and Trenches In Substrates*", Appl. Opt., Vol. 46, pp. 5571-5587, (01-Jan-2007)

Legend:
R - Refereed
I - Invited

March 20, 2008

B. Muralikrishnan, C. J. Blackburn, D. S. Sawyer, B. R. Borchardt, W. T. Estler, S. D. Phillips, "*Laser Tracker Testing at NIST Using the ASME B89.4.19 Standard*", The Journal of the CMSC, Vol. 2, No. 2, pp. 11-15, (01-Jan-2007)

B. Muralikrishnan, J. A. Stone Jr, J. R. Stoup, "*Roundness Measurements Using the NIST Fiber Probe*", Proceedings of the Annual Meeting of the American Society for Precision Engineering 2007, Annual Meeting of the American Society for Precision Engineering 2007, Dallas, TX, USA, 10/14/2007 to 10/19/2007, (01-Jan-2007)

N. G. Orji, A. Martinez, B. Bunday, J. A. Allgair, T. V. Vorburger, "*Progress on Implementation of a Reference Measurement System based on a Critical-dimension Atomic Force Microscope*", J. Micro/Nanolith, Vol. 6, No. 2, (01-Apr-2007)

N. G. Orji, R. G. Dixson, B. Bunday, M. R. Bishop, M. W. Cresswell, J. A. Allgair, "*TEM Calibration Methods for Critical Dimension Standards*", Proceedings of SPIE, Metrology, Inspection, and Process Control for Microlithography XXI, San Jose, CA, USA, 02/26/2007 to 02/26/2007, Vol. 6518, 10 pp., (05-Apr-2007)

(R) N. G. Orji, R. G. Dixson, "*Higher Order Tip Effects in CD-AFM Linewidth Measurements*", Measurement Science and Technology, Vol. 18, pp. 448-455, (01-Jan-2007)

B. C. Park, J. Choi, S. J. Ahn, D. H. Kim, L. Joon, R. G. Dixson, N. G. Orji, J. N. Fu, T. V. Vorburger, "*Use of Carbon Nanotube Probes in a Critical Dimension Atomic Force Microscope*", Proceedings of SPIE, Metrology, Inspection, and Process Control for Microlithography XXI, San Jose, CA, USA, 02/26/2007 to 02/26/2007, Vol. 6518, (01-Mar-2007)

S. D. Phillips, "*Laser Trackers: Testing and Standards*", Proceedings of Manufacturing & Measurement Conference & Workshop, Manufacturing & Measurement Conference & Workshop, Clearwater Beach, FL, USA, 04/23/2007 to 04/26/2007, (01-Jan-2007)

M. T. Postek, K. W. Lyons, "*Instrumentation, Metrology, and Standards: Key Elements for the Future of Nanomanufacturing*", Proceedings of SPIE, Instrumentation, Metrology, and Standards for Nanomanufacturing, Michael T. Postek, John A. Allgair, Editors, San Diego, CA, USA, 08/29/2007 to 08/29/2007, Vol. 6648, 7 pp., (01-Sep-2007)

M. T. Postek, A. E. Vladar, J. A. Kramar, L. A. Stern, J. Notte, S. McVey, "*Instrumentation, Metrology, and Standards for Nanomanufacturing*", Proceedings of SPIE, Instrumentation, Metrology, and Standards for Nanomanufacturing, Michael T. Postek, John A. Allgair, Editors, San Diego, CA, USA, 08/29/2007 to 08/29/2007, Vol. 6648, 6 pp., (10-Sep-2007)

M. T. Postek, A. E. Vladar, J. A. Kramar, L. A. Stern, J. Notte, S. McVey, "*Helium Ion Microscopy: A New Technique for Semiconductor Metrology and Nanotechnology*", In: Frontiers of Characterization and Metrology for Nanoelectronics, American Institute of Physics Press, 2 Huntington Quadrangle, Suite 1NO1, Melville, NY, 11747, USA, pp. 161-167, (01-Jan-2007)

M. T. Postek, A. E. Vladar, J. A. Kramar, L. A. Stern, J. Notte, S. McVey, "*The Helium Ion Microscope: A New Tool for Nanotechnology and Nanomanufacturing*", Proceedings of SPIE, Instrumentation, Metrology, and Standards for Nanomanufacturing, San Diego, CA, USA, 08/29/2007 to 08/29/2007, (01-Sep-2007)

J. E. Potzick, E. Marx, M. P. Davidson, "*Accuracy in Optical Image Modeling*", Proceedings of SPIE, Metrology, Inspection,

Legend:
R - Refereed
I - Invited

March 20, 2008

and Process Control Conference for Microlithography XXI, San Jose, CA, USA, 02/26/2007 to 02/26/2007, Vol. 6518, 11 pp., (26-Feb-2007)

(R) X. Qian, J. S. Villarrubia, "*General Three-Dimensional Image Simulation and Surface Reconstruction in Scanning Probe Microscopy Using a Dexel Representation*", Ultramicroscopy, Vol. 108, pp. 29-42, (01-Jan-2007)

J. Roberts, W. Banke, R. G. Dixson, "*Leveraging LER to Minimize Linewidth Measurement Uncertainty in a Calibration Exercise*", Proceedings of SPIE, Metrology, Inspection, and Process Control for Microlithography XXI, San Jose, CA, USA, 02/26/2007 to 02/26/2007, Vol. 6518, 15 pp., (05-Apr-2007)

(R) R. M. Silver, B. M. Barnes, R. Attota, J. S. Jun, M. T. Stocker, E. Marx, H. J. Patrick, "*Extending the Limits of Image-Based Optical Metrology*", Applied Optics, Vol. 46, pp. 4248-4257, (01-Jan-2007)

R. M. Silver, R. Attota, E. Marx, "*Model-Based Analysis of the Limits of Optical Metrology With Experimental Comparisons*", Proceedings of SPIE, Modeling Aspects in Optical Metrology, Munich, Germany, 01/01/2007 to 01/01/2007, Vol. 6617, 13 pp., (18-Jun-2007)

R. M. Silver, T. A. Germer, R. Attota, B. M. Barnes, B. Bunday, J. A. Allgair, E. Marx, J. S. Jun, "*Fundamental Limits of Optical Critical Dimension Metrology: A Simulation Study*", Proceedings of SPIE, Metrology, Inspection, and Process Control for Microlithography XXI, San Jose, CA, USA, 02/01/2007 to 02/01/2007, Vol. 6518, pp. 6518-6518, (01-Jan-2007)

J. Song, T. V. Vorburger, "*Verifying Measurement Uncertainty Using a Control Chart With Dynamic Control Limits*", Measure, Vol. 2, (01-Jan-2007)

J. Song, S. R. Low III, L. Ma, "*Tolerancing Form Deviations for NIST Standard Reference Material (SRM) 2809 Rockwell Diamond Indenters*", Recent Advancement of Theory and Practice in Hardness Measurement | 2007 | | HARDMEKO 2007, Recent Advancement of Theory and Practice in Hardness Measurement, Tsukuba, Japan, 11/19/2007 to 11/21/2007, (01-Jan-2007)

J. Song, P. Rubert, A. Zheng, T. V. Vorburger, "*Topography Measurements for Determining the Decay Factors in Surface Replication*", Proceedings of the 8th International Symposium of Measurement Technology and Intelligent Instruments (ISMTII), 8th International Symposium of Measurement Technology and Intelligent Instruments (ISMTII), Sendai, Japan, 09/25/2007 to 09/27/2007, (01-Jan-2007)

J. Song, T. V. Vorburger, S. M. Ballou, T. B. Renegar, L. Ma, E. P. Whitenton, D. R. Kelley, R. A. Clary, A. Zheng, M. Ols, "*NIST Standard Bullets and Casings Project*", Proceedings of 2007 ASPE, 2007 ASPE, Dallas, TX, USA, 10/14/2007 to 10/19/2007, (01-Jan-2007)

J. Song, T. V. Vorburger, "*A Novel Parameter Proposed for 2D and 3D Topography Measurements and Comparisons*", Proceedings of SPIE, Advanced Characterization Techniques for Optics, Semiconductors, and Nanotechnologies III, San Diego, CA, USA, 08/26/2007 to 08/30/2007, Vol. 6672, 8 pp., (01-Sep-2007)

J. Song, T. V. Vorburger, "*Verifying Measurement Uncertainty Using a Control Chart With Dynamic Control Limits*",

Legend:
R - Refereed
I - Invited

March 20, 2008

Proceedings of 2007 Measurement Science Conference, 2007 Measurement Science Conference, Long Beach, CA, USA, 01/22/2007 to 01/26/2007, (01-Sep-2007)

M. T. Stocker, R. M. Silver, R. Attota, J. S. Jun, "*Calibrated Overlay Wafer Standard*", Special Publication (NIST SP) 260-165, (01-Jan-2007)

J. A. Stone Jr, L. Lu, P. Egan, "*Calibrating Laser Vacuum Wavelength With a GPS-Based Optical Frequency Comb*", Proceedings of NCSL Workshop and Symposium 2007, NCSL Workshop and Symposium 2007, St. Paul, MN, USA, 07/29/2007 to 08/02/2007, Vol. 2, No. 4, pp. 28-38, (15-May-2007)

T. V. Vorburger, J. H. Yen, B. Bachrach, T. B. Renegar, L. Ma, H. Rhee, X. A. Zheng, J. Song, C. D. Foreman, "*Surface Topography Analysis for a Feasibility Assessment of a National Ballistics Imaging Database*", NIST Interagency/Internal Report (NISTIR) 7362, 173 pp., (01-May-2007)

T. V. Vorburger, H. G. Rhee, T. B. Renegar, J. Song, X. A. Zheng, "*Comparison of Optical and Stylus Methods for Measurement of Rough Surfaces*", Int. J. Adv. Manuf. Technol., Vol. 33, pp. 110-118, (01-Jan-2007)

(R) H. Zhou, J. N. Fu, R. M. Silver, "*A Time-Resolved Kinetic Monte-Carlo Simulation Study On Si (111) Etching*", Journal of Physical Chemistry, Vol. 111, pp. 3566-3574, (01-Jan-2007)

FY2006 Publications:

R. Attota, R. M. Silver, M. R. Bishop, R. G. Dixson, "*Optical Critical Dimension Measurement and Illumination Analysis using the Through-focus Focus Metric*", Proceedings of SPIE, Metrology, Inspection, and Process Control for Microlithography XX, San Diego, CA, USA, 02/20/2006 to 02/20/2006, Vol. 6152, 11 pp., (24-Mar-2006)

A. Balijepalli, T. W. LeBrun, S. K. Gupta, "*A Flexible System Framework for a Nanoassembly Cell Using Optical Tweezers*", Proceedings of ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, ASME International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, Unknown, USA, 09/10/2006 to 09/13/2006, (01-Jan-2006)

B. M. Barnes, L. P. Howard, R. M. Silver, "*Illumination Optimization for Optical Semiconductor Metrology*", Proceedings of SPIE, Novel Optical Systems Design and Optimization IX, San Diego, CA, USA, 08/16/2006 to 08/17/2006, Vol. 6289, 11 pp., (01-Sep-2006)

R. G. Dixson, N. G. Orji, J. N. Fu, M. W. Cresswell, R. A. Allen, W. F. Guthrie, "*Traceable Atomic Force Microscope Dimensional Metrology at NIST*", Proceedings of SPIE, Metrology, Inspection, and Process Control for Microlithography XX, San Jose, CA, USA, 02/20/2006 to 02/20/2006, Vol. 6152, (01-Mar-2006)

(R) K. Doytchinov, F. Kornblit, C. C. Castellanos, J. C. Oliveira, T. B. Renegar, T. V. Vorburger, "*International Comparison of Surface Roughness and Step Height (Depth) Standards, SIM 4.8*", Metrologia, Vol. 43, No. 04002, (01-Jan-2006)

W. T. Estler, D. S. Sawyer, B. R. Borchardt, S. D. Phillips, "*Large-Scale Metrology Instrument Performance Evaluations at*

Legend:
R - Refereed
I - Invited

March 20, 2008

NIST", The Journal of the CMSC, Vol. 1, No. 2, pp. 27-32, (01-Jan-2006)

B. H. Kang, J. T. Wen, N. G. Dagalakis, J. J. Gorman, "*Analysis and Design of Parallel Mechanisms with Flexure Joints*", Proceedings of IEEE Transactions, Robotics, USA, 12/01/2005 to 12/01/2005, Vol. 21, pp. 1179-1185, (01-Dec-2005)

R. Katz, C. D. Chase, R. Kris, R. Peltinov, J. S. Villarrubia, B. Bunday, "*Bias Reduction in Roughness Measurement through SEM Noise Removal*", Proceedings of SPIE, Metrology, Inspection, and Process Control for Microlithography XX, San Jose, CA, USA, 02/20/2006 to 02/20/2006, Vol. 6152, 12 pp., (24-Mar-2006)

T. W. LeBrun, T. W. Hwang, I. Y. Park, J. Song, Y. Lee, N. G. Dagalakis, C. Gagnon, A. Balijepalli, "*Three-dimensional Scanning Optical Tweezers*", Proceedings of SPIE, International Symposium on Optomechatronic Technologies, Optomechatronic Actuators and Manipulation, Kee S. Moon, Editor, December 2005, Sapporo, Japan, 12/05/2005 to 12/05/2005, Vol. 6048, 12 pp., (05-Dec-2005)

C. Londono, J. R. Lawall, M. T. Postek, J. A. Stone Jr, J. R. Stoup, "*The NIST Advanced Measurement Laboratory: at the Leading Edge of Measurement Science and Technology*", Proceedings of SPIE, Interferometry XIII: Techniques and Analysis, Katherine Creath, Joanna Schmit, Editors, San Diego, CA, USA, 08/14/2006 to 08/14/2006, (01-Aug-2006)

B. Muralikrishnan, J. A. Stone Jr, J. R. Stoup, "*Enhanced Capabilities of the NIST Fiber Probe for Microfeature Metrology*", Proceedings of the Annual Meeting of the American Society for Precision Engineering 2006, Annual Meeting of the American Society for Precision Engineering 2006, Monterey, CA, USA, 10/01/2006 to 10/01/2006, (01-Jan-2006)

B. Muralikrishnan, J. A. Stone Jr, J. R. Stoup, "*Fiber Deflection Probe for Small Hole Metrology*", J. International Societies for Precision Engineering and Nanotechnology, Vol. 30, No. 2, pp. 154-164, (01-Jan-2006)

B. Muralikrishnan, J. A. Stone Jr, J. R. Stoup, "*Fiber Deflection Probe Uncertainty Analysis for Micro Holes*", NCSL International Measure: The Journal of Measurement Science 2006, (01-Jan-2006)

N. G. Orji, A. Martinez, R. G. Dixson, J. A. Allgair, "*Progress on Implementation of a CD-AFM Based Reference Measurement System*", Proceedings of SPIE, Metrology, Inspection, and Process Control for Microlithography XX, San Jose, CA, USA, 02/19/2006 to 02/24/2006, Vol. 6152, 12 pp., (01-Mar-2006)

M. T. Postek, J. S. Villarrubia, A. E. Vladar, "*Advanced Metrology Needs for Nanotechnology and Nanomanufacturing*", Journal of Vacuum Science and Technology B, Vol. 23, No. 6, pp. 3015-3022, (01-Nov-2005)

(R) M. T. Postek, R. R. Cavanagh, C. M. Allocca, D. T. Smith, R. D. Shull, D. A. Wollman, D. G. Seiler, S. Knight, A. Diebold, R. M. Silver, C. W. Clark, K. W. Lyons, J. R. Whetstone, R. F. Boisvert, "*National Nanotechnology Initiative Interagency Workshop on Instrumentation and Metrology for Nanotechnology Grand Challenge Report*", National Nanotechnology Initiative Interagency Workshop on Instrumentation and Metrology for Nanotechnology Grand Challenge Report, National Nanotechnology Initiative Interagency Workshop on Instrumentation and Metrology for Nanotechnology, Gaithersburg, MD, USA, 01/27/2004 to 01/29/2004, (01-Aug-2006)

M. T. Postek, J. J. Kopanski, D. A. Wollman, "*NIST Accomplishments in Nanotechnology*", Special Publication (NIST SP)

Legend:
R - Refereed
I - Invited

March 20, 2008

1052, 186 pp., (01-Jan-2006)

J. E. Potzick, "*A Benefit/Cost Model for Metrology in Manufacturing*", Proceedings of 2nd ISMI Symposium, Manufacturing Effectiveness, Austin, TX, USA, 10/24/2005 to 10/26/2005, (24-Oct-2005)

J. E. Potzick, E. Marx, M. P. Davidson, "*Parametric Uncertainty in Optical Image Modeling*", Proceedings of SPIE, Photomask Technology (BACUS) 2006, Monterey, CA, USA, 09/18/2006 to 09/18/2006, Vol. 6349, 10 pp., (18-Sep-2006)

(R) H. Rhee, T. V. Vorburger, J. W. Lee, J. N. Fu, "*Discrepancies Between Roughness Measurements Obtained With Phase Shifting and White-Light Interferometry*", Applied Optics, Vol. 44, No. 28, pp. 5919-5927, (01-Oct-2005)

D. S. Sawyer, S. D. Phillips, B. R. Borchardt, W. T. Estler, "*Recent Developments in the Standardization and Testing of Laser Trackers*", Proceedings Manufacturing and Measuring Conference 2006, Manufacturing and Measuring Conference, Knoxville, TN, USA, 04/24/2006 to 04/28/2006, (01-Jan-2006)

R. M. Silver, B. M. Barnes, R. Attota, J. S. Jun, J. J. Filliben, J. Soto, M. T. Stocker, P. Lipscomb, E. Marx, H. J. Patrick, R. G. Dixson, R. D. Larrabee, "*The Limits of Image-Based Optical Metrology*", Proceedings of SPIE, Metrology, Inspection, and Process Control for Microlithography XX, San Jose, CA, USA, 02/19/2006 to 02/24/2006, Vol. 6152, 15 pp., (01-Mar-2006)

Y. Sohn, B. M. Barnes, L. P. Howard, R. M. Silver, R. Attota, M. T. Stocker, "*Koehler Illumination for High-Resolution Optical Metrology*", Proceedings of SPIE, Metrology, Inspection, and Process Control for Microlithography XX, Santa Clara, CA, USA, 02/19/2006 to 02/24/2006, Vol. 6152, 9 pp., (01-Mar-2006)

J. Song, T. V. Vorburger, L. Ma, J. M. Libert, S. M. Ballou, "*A Metric for the Comparison of Surface Topographies of Standard Reference Material (SRM) Bullets and Casings*", Proceedings of American Society of Precision Engineers, ASPE--American Society for Precision Engineering, Unknown, VA, USA, 01/01/2005 to 01/01/2005, (01-Oct-2005)

J. Song, S. R. Low III, A. Zheng, "*Calibration Reproductibility Test for NIST's No. 3581 Standard Rockwell Diamond Indenter*", Proceedings of XVIII IMEKO World Congress, IMEKO World Congress, Rio de Janeiro, Brazil, 09/17/2006 to 09/22/2006, (01-Jan-2006)

J. Song, L. Ma, T. V. Vorburger, "*The Effect of Gaussian Filter Long Wavelength Cutoff in Topography Comparisons and Measurements*", Proceedings of 2006 American Society of Precision Engineering, 2006 American Society of Precision Engineering, Monterey, CA, USA, 10/17/2006 to 10/19/2006, (01-Jan-2006)

J. Song, T. V. Vorburger, T. B. Renegar, H. Rhee, A. Zheng, L. Ma, J. M. Libert, S. M. Ballou, B. Bachrach, K. Bogart, "*Correlation of Topography Measurements of NIST SRM 2460 Standard Bullets by Four Techniques*", Proceedings of the 2005 International Symposium on Measurement Technology and Intelligent Instrumentation, International Symposium on Measurement Technology and Intelligent Instrumentation, Huddersfield, United Kingdom, 09/05/2005 to 09/09/2005, Vol. 17, (01-Jan-2006)

J. Song, T. V. Vorburger, "*Topography Measurements and Applications*", Proceedings of the 2006 International Symposium on Precision Mechanical Measurements (ISPMM), 2006 International Symposium on Precision Mechanical Measurements

Legend:
R - Refereed
I - Invited

March 20, 2008

(ISPMM), Urumqi, China, 08/03/2006 to 08/06/2006, (01-Jan-2006)

J. Song, T. V. Vorburger, T. B. Renegar, X. A. Zheng, H. Rhee, J. M. Libert, L. Ma, K. Bogart, S. M. Ballou, B. Bachrach, *"Correlation of Topography Measurements of NIST SRM 2460 Standard Bullets by Four Techniques"*, Measurement Science and Technology, Vol. 17, pp. 500-503, (01-Jan-2006)

J. R. Stoup, B. S. Faust, T. D. Doiron, *"Early Results From the NIST M48 CMM in the New AML Facility"*, Measurement Science Conference 2006 (Presentation), Measurement Science Conference, Anaheim, CA, USA, 03/02/2006 to 03/03/2006, (03-Mar-2006)

J. S. Villarrubia, A. E. Vladar, M. T. Postek, *"Scanning electron microscope dimensional metrology using a model-based library"*, Surface and Interface Analysis, Vol. 37(11), pp. 951-958, (01-Nov-2005)

(R) A. E. Vladar, Z. Radi, M. T. Postek, D. C. Joy, *"Nano-Tip Electron Gun for the Scanning Electron Microscope"*, Scanning, Vol. 28, pp. 133-141, (01-Jan-2006)

T. V. Vorburger, R. G. Dixson, J. N. Fu, N. G. Orji, S. C. Feng, M. W. Cresswell, R. A. Allen, W. F. Guthrie, W. Chu, *"Nano- and Atomic-Scale Length Metrology"*, Proceedings of International Symposium on Instrumentation Science and Technology, International Symposium on Instrumentation Science and Technology, Harbin, China, 08/08/2006 to 08/12/2006, (01-Jan-2006)

FY2005 Publications:

A. Balijepalli, T. W. LeBrun, C. Gagnon, Y. Lee, N. G. Dagalakis, *"A Modular System Architecture for Agile Assembly of Nanocomponents using Optical Tweezers"*, Proceedings of SPIE, Optics and Photonics Conference, San Diego, CA, USA, 09/10/2005 to 09/10/2005, Vol. 5908, 10 pp., (10-Sep-2005)

A. Balijepalli, T. W. LeBrun, E. al, *"A Modular System Architecture for Agile Assembly of Nano-Components using Optical Tweezers"*, Proceedings of SPIE, Optical Information Systems III, Bahram Javidi, Demetri Psaltis, Editors, September 2005, San Diego, CA, USA, 08/03/2005 to 08/03/2005, Vol. 5908, 10 pp., (01-Sep-2005)

S. H. Bui, T. V. Vorburger, T. B. Renegar, *"Virtual Surface Calibration and Computational Uncertainty"*, American Society for Precision Engineering Annual Meeting | 19th | Proceedings of the Annual Meeting of the American Society of Precision Engineering | ASPE, ASPE--American Society for Precision Engineering, 10/01/2004 to 10/01/2004, (01-Oct-2004)

F. S. Chien, W. F. Hsieh, S. Gwo, J. S. Jun, R. M. Silver, A. E. Vladar, J. A. Dagata, *"Characterization of Prototype Silicon Pitch Artifacts Fabricated by Scanning Probe Lithography and Anisotropic Wet Etching"*, Journal of Applied Physics, Vol. 23, No. No. 1, (01-Jan-2005)

R. G. Dixson, *"Reference Measurement System Using Critical Dimension Atomic Force Microscopy (CD-AFM): Final Report"*, , (01-Jan-2005)

(R) R. G. Dixson, R. A. Allen, W. F. Guthrie, M. W. Cresswell, *"Traceable Calibration of Critical-Dimension Atomic Force Microscope Linewidth Measurements with Nanometer Uncertainty"*, J. Vacuum Sci. Technol. B, Vol. 23, pp. 3028-3032, (01-

Legend:
R - Refereed

March 20, 2008

Jan-2005)

T. D. Doiron, E. S. Stanfield, B. S. Faust, J. R. Stoup, M. Abbott, "*New Capabilities At NIST In Dimensional Metrology*", Proceedings of the NCSL International Workshop and Symposium, NCSL International Workshop and Symposium, Unknown, USA, 08/01/2005 to 08/01/2005, (01-Jan-2005)

J. N. Fu, R. G. Dixson, N. G. Orji, T. V. Vorburger, C. V. Nguyen, "*Linewidth Measurement from a Stitched AFM Image*", CP 788 Characterization and Metrology for ULSI 2005, D.G. Seiler et al. eds. (Amer. Inst. Phys., Melville, NY, 2005), ULSI Technology, Richardson/Dallas, TX, USA, 03/15/2005 to 03/18/2005, pp. 421-426, (01-Jan-2005)

J. J. Gorman, T. W. LeBrun, E. al, "*Characterization of Optical Traps Using On-Line Estimation Methods*", Proceedings of SPIE, Optical Trapping and Optical Micromanipulation II, Kishan Dholakia, Gabriel C. Spalding, Editors, 593023 (Aug. 26, 2005), San Diego, CA, USA, 07/31/2005 to 07/31/2005, Vol. 5930, 12 pp., (26-Aug-2005)

J. A. Kramar, "*Nanometer Resolution Metrology with the NIST Molecular Measuring Machine*", Measurement Science and Technology, Vol. 16, pp. 2121-2128, (23-Sep-2005)

K. J. Lan, J. H. Yen, J. A. Kramar, "*Sliding Mode Control for Active Vibration Isolation of a Long Range Scanning Tunneling Microscope*", Review of Scientific Instruments, Vol. 75(11), pp. 4367-4373, (29-Oct-2004)

M. C. Malburg, J. Raja, S. H. Bui, T. B. Renegar, B. Brian, T. V. Vorburger, "*Internet-Based Surface Metrology Algorithm Testing System*", Modeling, Simulation and Prediction of Rockwell Hardness Indentation, (01-Jan-2005)

E. Marx, J. E. Potzick, "*Simulation of Optical Microscope Images for Photomask Feature Size Measurements*", Proceedings of 2005 Digest of the IEEE Antennas and Propagation Society International Symposium, 1998 Digest of the IEEE Antennas and Propagation Society International Symposium, Unknown, USA, 01/01/2005 to 01/01/2005, pp. 2116-2119, (01-Jan-2005)

(R) E. Marx, J. E. Potzick, "*Simulation of Optical Microscope Images for Photomask Feature Size Measurements*", 2005 Digest of IEEE Antennas and Propagation Society International Symposium, 2005 Digest of IEEE Antennas and Propagation Society International Symposium, Unknown, USA, 07/03/2005 to 07/08/2005, Vol. 3B, pp. 2116-2119, (03-Jul-2005)

T. Mcwaid, J. Schneir, R. G. Dixson, V. W. Tsai, "*Dimensional Metrology with AFM*", Program of 2nd Industrial Applications of Scanned Probe Microscopy; NIST, Gaithersburg, MD, USA, to , (01-Jan-2005)

B. Muralikrishnan, J. A. Stone Jr, J. R. Stoup, "*Micro-Feature Metrology*", Proceedings of MicroManufacturing Conference and Exhibits 2006 - Society of Manufacturing Engineers, MicroManufacturing Conference and Exhibits 2006 - Society of Manufacturing Engineers, Los Angeles, CA, USA, 03/22/2006 to 03/22/2006, (01-May-2005)

B. Muralikrishnan, J. A. Stone Jr, J. R. Stoup, "*Measuring Internal Geometry of Fiber Ferrules*", Proceedings of MicroManufacturing Conference 2005, Society for Manufacturing Engineers, MicroManufacturing Conference 2005, Society for Manufacturing Engineers, Minneapolis , MN, USA, 01/01/2005 to 01/01/2005, (01-May-2005)

B. Muralikrishnan, J. A. Stone Jr, J. R. Stoup, S. C. Vemuri, C. Sahay, A. Potluri, "*Fiber Deflection Probe for Small Hole*

Legend:
R - Refereed
I - Invited

March 20, 2008

Measurements", American Society for Precision Engineering Annual Meeting | 19th | Proceedings of the Annual Meeting of the American Society of Precision Engineering | ASPE, ASPE--American Society for Precision Engineering, 10/01/2004 to 10/01/2004, (01-Oct-2004)

D. B. Newell, J. A. Kramar, J. R. Pratt, D. T. Smith, *"Review of SI Traceable Force Metrology for Instrumented Indentation and Atomic Force Microscopy",* Measurement Science and Technology, Vol. 16, pp. 2129-2137, (23-Sep-2005)

(R) N. G. Orji, T. V. Vorburger, J. N. Fu, R. G. Dixson, C. V. Nguyen, J. Raja, *"Line Edge Roughness Metrology Using Atomic Force Microscopes",* Measurement Science and Technology, Vol. 16, pp. 2147-2154, (01-Jan-2005)

N. G. Orji, R. G. Dixson, J. N. Fu, T. V. Vorburger, *"Traceable Pico-Meter Level Step Height Metrology",* Metrology and Properties of Engineering Surfaces, 9th International Conference on Metrology and Properties of Engineering Surfaces, USA, to , Vol. 257, pp. 1264-1269, (01-Dec-2004)

S. D. Phillips, *"Measurement Uncertainty, CMMs, and Standards: Today and the Future",* Proceedings of 2005 International Dimensional Workshop, 2005 International Dimensional Workshop, Nashville, TN, USA, 05/09/2005 to 05/13/2005, (01-Jan-2005)

(R) M. T. Postek, A. E. Vladar, *"Variable Pressure/Environmental SEM a Powerful Tool for Nanotechnology and Nanomanufacturing",* Microscopy And Microanalysis, Vol. 11, No. Suppl 2, pp. 388-389, (01-Jan-2005)

(R) M. T. Postek, J. J. Pellegrino, *"NNI Workshop Instrumentation and Metrology for Nanotechnology",* NIST Interagency/Internal Report (NISTIR), (01-Nov-2004)

(I) J. E. Potzick, *"Photomask Feature Metrology",* Chapter 21 of Handbook of Photomask Manufacturing Technology, CRC Press, Unknown, New York, NY, Unknown, USA, pp. 413-432, (07-Apr-2005)

R. M. Seugling, D. B. Newell, J. A. Kramar, J. R. Pratt, *"Realizing and Disseminating the SI Micronewton With the Next Generation NIST Electrostatic Force Balance",* Proceedings of the American Society for Precision Engineering, Orlando, FL, USA, 10/29/2004 to 10/29/2004, (01-Oct-2004)

R. M. Silver, A. E. Vladar, *"Photomask Metrology, Photomask Fabrication Technology",* Photomask Metrology, Chapter in Photomask Fabrication Technology, McGraw-Hill Professional, Two Penn Plaza, 11th Floor, New York, NY, 10121, USA, pp. 281-342, (01-Jan-2005)

R. M. Silver, R. Attota, M. T. Stocker, M. R. Bishop, L. P. Howard, T. A. Germer, E. Marx, M. P. Davidson, R. D. Larrabee, *"High-resolution Optical Metrology",* Proceedings of SPIE, Metrology, Inspection, and Process Control for Microlithography XIX, Richard M. Silver, Editor, May 2005, Contributors to Overlay, Causes Registration Errors, San Jose, CA, USA, 03/03/2005 to 03/03/2005, Vol. 5752, pp. 67-79, (01-May-2005)

J. Song, T. V. Vorburger, *"Standard Deviation or Standard Deviation of the Mean - How to Report Statistical Variation in Surface Calibrations?",* Proceedings of American Society for Precision Engineering, Proceedings of the American Society for Precision Engineering, FL, USA, 10/26/2004 to 10/26/2004, (01-Oct-2004)

Legend:
R - Refereed
I - Invited

March 20, 2008

J. Song, L. Ma, E. P. Whitenton, T. V. Vorburger, "*2D and 3D Surface Texture Comparisons Using Autocorrelation Functions*", Proceedings of the 6th Instrumentation and Measurement Technology Conference, Instrumentation and Measurement Technology Conference, Hong Kong, Hong Kong, 11/27/2003 to 11/30/2003, Vol. 437, pp. 295-296, (01-Jan-2005)

J. A. Stone Jr, B. Muralikrishnan, J. R. Stoup, "*A Fiber Probe for CMM Measurements of Small Features*", Proceedings of SPIE, Recent Developments in Traceable Dimensional Measurements III, San Diego, CA, USA, 07/31/2005 to 07/31/2005, Vol. 5879, 11 pp., (01-Aug-2005)

J. A. Stone Jr, A. Stejskal, "*Refractometry Using a Helium Standard*", NCSLI Newsletter, Vol. 45, No. 2, pp. 13-16, (01-Apr-2005)

J. A. Stone Jr, "*Methods for Evaluating the Reference Value in Laboratory Intercomparisons of Dimensional Measurements*", Proceedings of SPIE, Recent Developments in Traceable Dimensional Measurements III, San Diego, CA, USA, 07/31/2005 to 07/31/2005, (01-Aug-2005)

W. Tan, R. Allen, M. W. Cresswell, C. E. Murabito, B. C. Park, R. G. Dixson, W. F. Guthrie, "*Comparison of SEM and HRTEM CD-Measurements Extracted From Monocrystalline Tes-Structures Having Feature Linewidths From 40 nm to 240 nm*", International Conference on Microelectronic Test Structures, Leuven, Belgium, 04/04/2005 to 04/07/2005, (04-Apr-2005)

M. Tanaka, J. S. Villarrubia, A. E. Vladar, "*Influence of Focus Variation on Linewidth Measurements*", Proceedings of SPIE, Metrology, Inspection, and Process Control for Microlithography XIX, San Jose, CA, USA, 02/27/2005 to 03/03/2005, Vol. 5752, pp. 144-155, (03-Mar-2005)

V. W. Tsai, T. V. Vorburger, R. G. Dixson, J. N. Fu, R. Koning, R. M. Silver, E. R. Williams, "*The Study of Silicon Stepped Surfaces as Atomic Force Microscope Calib Standards With a Calibrated AFM at NIST*", Chapter in: Characterization and Metrology for ULSI Technology 2005 ; D.G. Seiler et. al., Editors, American Institute of Physics Press, New York, NY, USA, (29-Sep-2005)

J. S. Villarrubia, B. Bunday, "*Unbiased Estimation of Linewidth Roughness*", Proceedings of SPIE, Metrology, Inspection, and Process Control for Microlithography XIX, Richard M. Silver, Editor, May 2005, San Jose, CA, USA, 02/27/2005 to 03/04/2005, Vol. 5752, pp. 480-488, (01-May-2005)

J. S. Villarrubia, "*Issues in Line Edge and Linewidth Roughness Metrology*", In: Characterization and Metrology for ULSI Technology: 2005, AIP Conference Proceedings, AIP Press, New York, NY, USA, Vol. 788, pp. 386-393, (01-Jan-2005)

J. S. Villarrubia, A. E. Vladar, M. T. Postek, "*Scanning Electron Microscope Dimensional Metrology Using a Model-Based Library*", Surface and Interface Analysis, Vol. 37, pp. 951-958, (01-Apr-2005)

J. S. Villarrubia, A. E. Vladar, M. T. Postek, "*Scanning Electron Microscope Dimensional Metrology using a Model-based Library*", Surface and Interface Analysis, Vol. 37, pp. 951-958, (01-Jan-2005)

Legend:
R - Refereed
I - Invited

March 20, 2008

J. S. Villarrubia, "*Issues in Line Edge and Linewidth Roughness Metrology*", Proceedings of American Institute of Physics International Conference on Characterization and Metrology for ULSI Technology 2005, American Institute of Physics International Conference on Characterization and Metrology for ULSI Technology 2005, Richardson, TX, USA, 09/09/2005 to 09/09/2005, Vol. 788, pp. 386-393, (09-Sep-2005)

J. S. Villarrubia, A. E. Vladar, M. T. Postek, "*A Simulation Study of Repeatability and Bias in the CD-SEM*", Journal of Microlithography Microfabrication, Vol. 4, No. 3, pp. 1-10, (01-Jul-2005)

J. Y. Yen, K. J. Lan, J. A. Kramar, "*Active Vibration Isolation of a Large Stroke Scanning Probe Microscope by Using Discrete Sliding Mode Control*", Sensors and Actuators, Vol. 121, No. No. 1, pp. 243-250, (31-May-2005)

(R) H. Zhou, J. N. Fu, R. M. Silver, "*The Influence of Defects on the Morphology of Si (111) Etched in NHF*", Journal of Physical Chemistry, Vol. 109, pp. 23386-23394, (01-Jan-2005)

Legend:
R - Refereed
I - Invited

Manufacturing Metrology Division

List of Publications

For

FY2005 to FY2008

(September 30, 2004 to March 20, 2008)

March 20, 2008

FY2008 Publications:

(R) T. W. Bartel, "*Statistical Analysis of 4 MN Force Range Key Comparison*", Proceedings of the IMEKO 20th TC3, 3rd TC16, and 1st TC22 International Conference, IMEKO 20th TC3, 3rd TC16 & 1st TC22 International Conference Force, Mass, Torque, Density, Pressure, Vacuum and Vibrations, Merida, Mexico, 11/27/2007 to 12/01/2007 823017, (27-Nov-2007)

(I) R. Gao, R. Yan, L. Zhang, K. B. Lee, "*Condition Monitoring of Operating Spindle Based on Stochastic Subspace Identification*", 2007 ASME International Mechanical Engineering Congress and Exposition, 2007 ASME International Mechanical Engineering Congress and Exposition, Seattle, WA, USA, 11/11/2007 to 11/15/2007, pp. 1-7, (11-Nov-2007)

(I) R. W. Ivester, "*Productivity Improvement through Modeling: An Overview of Manufacturing Experience for the Food Industry*", Comprehensive Reviews in Food Science and Food Safety, Vol. 7, No. 1, pp. 182-191, (03-Mar-2008)

Z. J. Jabbour, P. J. Abbott, E. R. Williams, R. Liu, V. J. Lee, "*Magnetic Levitation System for the Dissemination of a Non-Artifact Based Kilogram*", IMEKO International Conference, IMEKO International Conference, Merida, Mexico, 11/27/2007 to 12/01/2007, 11 pp., (27-Nov-2007)

K. B. Lee, Y. Song, "*Object-oriented Model for IEEE 1588 Standard*", 2007 International IEEE Symposium on Precision Clock Synchronization, International Conference on Electronic Measurement and Instruments (ICEMI), Vienna, Austria, Austria, 10/01/2007 to 10/03/2007, pp. 7-12, (01-Oct-2007)

K. B. Lee, "*Sensor Standards Harmonization--Path to Achieving Sensor Interoperability*", Autotestcon Conference | 2007 |, Autotestcon Conference 2007, Baltimore, MD, USA, 09/18/2007 to 09/20/2007, pp. 381-388, (01-Oct-2007)

K. B. Lee, J. T. Cain, "*Integrating Sensors and Actuators into RFID Tags*", RFID Technology and Applications, Cambridge Press, Boston, MA, USA, (01-Jan-2008)

(R) K. Lee, M. A. Donmez, "*Repeatability Analysis on the Tool Point Dynamics for Investigations on Uncertainty in Milling Stability*", 2007 ASME International Mechanical Engineering Congress & Exposition (IMECE2007), 2007 ASME International Mechanical Engineering Congress & Exposition (IMECE2007), Seattle, WA, USA, 11/11/2007 to 11/15/2007 823028, (11-Nov-2007)

Y. Song, K. B. Lee, "*An Implementation of Smart Transducer Web Services for IEEE 1451-based Sensor Systems*", SAS 2007 - IEEE Sensors and Applications Symposium, SAS 2007 - IEEE Sensors and Applications Symposium, San Diego, CA, USA, 02/06/2007 to 02/08/2007, pp. 1-6, (06-Feb-2008)

(R) E. P. Whitenton, R. W. Ivester, J. C. Heigel, "*A Novel Peak Detection Algorithm for Use in the Study of Machining Chip Segmentation*", ISCA Proceedings of the 20th International Conference on Computers and Their Applications in Industry and Engineering (CAINE-2007), November 7-9, 2007, San Francisco, CA, ISCA 20th International Conference on Computers and Their Applications in Industry and Engineering, San Francisco, CA, USA, 11/07/2007 to 11/09/2007 823018, (07-Nov-2007)

FY2007 Publications:

(R) T. J. Burns, S. P. Mates, R. L. Rhorer, E. P. Whitenton, D. Basak, "*Recent Results from the NIST Pulse-Heated Kolsky Bar*",

Legend:
R - Refereed
I - Invited

March 20, 2008

Proceedings of the 2007 SEM Annual Conference and Exposition on Experimental and Applied Mechanics, Springfield, MA, USA, 06/04/2007 to 06/06/2007, (04-Jun-2007)

K. L. Chesnutwood, S. L. Ho, "*Automation and upgrade of the 27.1 kN dead weight machine at the National Institute of Standards and Technology*", NCSL International Measure, Vol. 2 (1), (01-Mar-2007)

K. Chung, G. A. Shaw III, J. R. Pratt, "*Direct Electrostatic Calibration of Hybrid Sensors for Small Force Measurement*", Proceedings of the Society of Experimental Mechanics Annual Conference, Springfield, MA, USA, 06/04/2007 to 06/06/2007, (04-Jun-2007)

M. A. Donmez, M. Hahn, J. A. Soons, "*A Novel Cooling System to Reduce Thermally-Induced Errors of Machine Tools*", CIRP Annals, Elsevier B. V., Amsterdam, Netherlands, Vol. 56 , No. (1), pp. 521-524, (14-Jun-2007)

(R) S. E. Fick, E. Steven, D. Ruggless, "*In-situ Attenuation Corrections for Radiation Force Measurements of High Frequency Ultrasound with a Conical Target*", Journal of Research (NIST JRES), Vol. 111, pp. 435-442, (01-Nov-2006)

U. Griesmann, Q. Wang, M. Tricard, P. Dumas, C. Hill, "*Manufacture and Metrology of 300 mm Silicon Wafers with Ultra-Low Thickness Variations*", Characterization and Metrology for Nanoelectronics: 2007 International conference on Frontiers of Characterization and Metrology, 2007 International Conference of Characterization and Metrology, Washington, DC, USA, 03/27/2007 to 03/29/2007 823030, Vol. 931, 6 pp., (02-Jan-2007)

(R) U. Griesmann, Q. Wang, J. A. Soons, "*Three-Flat Test Solutions Including Mounting-Induced Deformations*", Optical Engineering, Vol. 46, No. 9, pp. 5856-5865, (01-Sep-2007)

J. C. Heigel, R. W. Ivester, "*Process Monitoring of Turning and Model Adaptation for Smart Machining Systems*", Proceedings of the International Conference on Smart Machining Systems, International Conference on Smart Machining Systems, Gaithersburg, MD, USA, 03/13/2007 to 03/15/2007, (01-Mar-2007)

(I) R. W. Ivester, E. P. Whitenton, J. C. Heigel, T. Marusich, C. Arthur, "*Measuring Chip Segmentation by High-Speed Microvideography and Comparison to Finite-Element Modeling Simulations*", 10th CIRP International Workshop on Modeling of Machining Operations, 10th CIRP International Workshop on Modeling of Machining Operations, Reggio Calabria, Italy, 08/27/2007 to 08/28/2007 823027, (27-Aug-2007)

R. W. Ivester, J. C. Heigel, "*Smart Machining Systems: Robust Optimization and Adaptive Control Optimization for Turning Operations*", Transactions of the North American Research Institute (NAMRI)/SME, Vol. Vol. 35, pp. 505-511, (22-May-2007)

(R) E. D. Langlois, G. A. Shaw III, J. A. Kramar, J. R. Pratt, D. C. Hurley, "*Spring constant calibration of AFM cantilevers with a piezosensor transfer standard*", Review Of Scientific Instruments, (24-Sep-2007)

K. B. Lee, R. Gao, R. Yan, L. Zhang, "*Open Architecture Software Design for Online Spindle Health Monitoring*", Instrumentation and Measurement Technology Conference | 2007 | IMTC, Instrumentation and Measurement Technology Conference, Warsaw, Poland, 05/01/2007 to 05/03/2007, pp. 1-6, (01-May-2007)

Legend:
R - Refereed
I - Invited

March 20, 2008

J. R. Pratt, J. A. Kramar, G. A. Shaw III, D. T. Smith, J. M. Moreland, "*A Piezoresistive Cantilever Force Sensor for Direct AFM Force Calibration*", 2007 Materials Research Society Spring Meeting, San Francisco, CA, USA, 04/10/2007 to 04/12/2007, (08-Apr-2007)

R. L. Rhorer, J. Chin, A. L. Forster, W. W. Chen, B. Song, X. Nie, "*Aging Effects on the Dynamic Tensile Response of Zylon Fibers*", Proceedings of Society for Experimental Mechanics, Society of Experimental Mechanics Annual Meeting, Springfield, MA, USA, 06/04/2007 to 06/06/2007 823037, (04-Jun-2007)

(I) G. A. Shaw III, K. Chung, B. Ming, A. E. Vladar, "*Focused Ion Beam Manufacturing Methods for Nickel-Titanium Shape-Memory Alloy Thin Films*", Proceedings of the 2007 SEM Annual Conference and Exposition on Experimental and Applied Mechanics, Springfield, MA, USA, 06/04/2007 to 06/06/2007, (04-Jun-2007)

(R) D. T. Smith, G. A. Shaw III, R. M. Seugling, D. Xiang, J. R. Pratt, "*Traceable Micro-Force Sensor for Instrumented Indentation Calibration*", 2007 Materials Research Society Spring Meeting, San Francisco, CA, USA, 04/10/2007 to 04/12/2007, (10-Apr-2007)

Y. Song, K. B. Lee, "*Smart Transducer Web Services Based on the IEEE 1451.0 Standard*", Instrumentation and Measurement Technology Conference | 2007 | IMTC, Instrumentation and Measurement Technology Conference, Warsaw, Poland, 05/01/2007 to 05/03/2007, pp. 1-6, (01-May-2007)

J. Vigouroux, L. Deshayes, S. Foufou, L. A. Welsch, "*An approach for Optimization of Machining Parameters Under Uncertainties Using Intervals and Evolutionary Algorithms*", Proceedings of the First International Conference on Smart Machining Systems, First International Conference on Smart Machining Systems, Gaithersburg, MD, USA, 03/13/2007 to 03/15/2007, (01-May-2007)

J. Vigouroux, S. Foufou, L. Deshayes, J. J. Filliben, L. A. Welsch, M. A. Donmez, "*On tuning the design of an evolutionary algorithm for machining optimization problem*", Proceedings of the fourth International Conference on Informatics in Control, Angers, France, 05/09/2007 to 05/12/2007 823038, (09-May-2007)

(R) R. P. Wagner, V. Nedzelnitsky, "*Effect of Power Line Interference on Microphone Calibration Measurements made at or near Harmonics of the Power Line Frequency*", Journal Of Research Of The National Institute Of Standards And Technology, Vol. 112, No. No. 2, pp. 107-114, (01-Mar-2007)

(R) L. Zhang, R. Yan, R. Gao, K. B. Lee, "*Design of a Real-time Spindle Health Monitoring and Diagnosis System Based on Open Systems Architecture*", International Conference on Smart Machining Systems, International Conference on Smart Machining Systems, Gaithersburg, MD, USA, 03/13/2007 to 03/13/2007, pp. 1-4, (13-Mar-2007)

FY2006 Publications:

T. W. Bartel, "*Uncertainty in NIST Force Measurements*", Journal of Research of the National Institute of Standards and Technology, Vol. 110 (6), pp. 589-603, (01-Dec-2005)

Legend:
R - Refereed
I - Invited

March 20, 2008

K. L. Chesnutwood, S. L. Ho, "*Automation and Upgrade of the 27.1 kN Dead Weight Machine at the National Institute of Standards and Technology*", NIST Interagency/Internal Report (NISTIR) 7309, 11 pp., (24-Apr-2006)

S. B. Chikkamaranahalli, R. R. Vallance, B. Damazo, R. M. Silver, "*Damping mechanisms for precision applications in UHV environment*", American Society for Precision Engineering 2006 Spring Topical Meeting: Challenges at the Intersection of Precision Engineering and Vacuum Technology, American Society for Precision Engineering 2006 Spring Topical Meeting: Challenges at the Intersection of Precision Engineering and Vacuum Technology, Pittsburgh, PA, USA, 05/01/2006 to 05/02/2006, (01-May-2006)

L. Deshayes, L. A. Welsch, A. Vacher, M. A. Donmez, "*Towards an Information Processing Representation for Dynamic Process Optimization in Smart Machining Systems*", Proceedings of the 6th International Conference on Integrated Design Manufacturing in Mechanical Engineering (IDMME) 2006, Grenoble, France, 05/17/2006 to 05/19/2006, (01-May-2006)

L. Deshayes, L. A. Welsch, R. W. Ivester, M. A. Donmez, "*Robust Optimization for Smart Machining System: An Enabler for Agile Manufacturing*", Proceedings of IMECE 2005: 2005 ASME International Engineering Congress & Exposition, 2005 ASME International Engineering Congress & Exposition, Orlando, FL, USA, 11/05/2005 to 11/11/2005, pp. 1-10, (01-Nov-2005)

A. Deshpande, V. Madhavan, V. Pednekar, A. H. Adibi-Sedeh, R. W. Ivester, "*Dependence of Metal Cutting Simulations on the Johnson-Cook Model Thermal Softening Parameter*", North American Manufacturing Research Conference (NAMRC), North American Manufacturing Research Conference (NAMRC), Milwaukee, WI, USA, 05/24/2006 to 05/26/2006, (01-Jan-2006)

R. S. Gates, J. R. Pratt, "*Prototype Cantilevers for SI Traceable NanoNewton Force Calibration*", Measurement Science and Technology, Vol. 17, pp. 2852-2860, (01-Jan-2006)

U. Griesmann, "*Three-Flat Test Solutions based on Simple Mirror Symmetry*", Applied Optics, Vol. 45 (23), pp. 5856-5865, (01-Aug-2006)

M. Hahn, M. A. Donmez, J. A. Soons, "*Evaluation of an Inexpensive Method of stabilize the Temperature of Machine Tool Components*", NIST Interagency/Internal Report (NISTIR) 7292, 16 pp., (01-Feb-2006)

R. W. Ivester, L. Deshayes, M. L. McGlauflin, Y. Marcon, "*Determination of Parametric Uncertainties for Regression-Based Modeling of Turning Operations*", 2006 Transactions of the North American Manufacturing Research Conference, Same, Boston, USA, 05/24/2006 to 05/26/2006, Vol. 34, pp. 1 - 8, (30-May-2006)

K. B. Lee, Y. Song, "*A Wireless Environmental Monitoring System Based on the IEEE 1451.1 Standard*", Technology Conference IMTC 2006, Technology Conference IMTC 2006, Sorrento, Italy, 04/24/2006 to 04/27/2006, (01-Apr-2006)

K. B. Lee, "*Smart Transducer Interface Standards for Condition Monitoring and Control of Machines*", Condition-Based Monitoring and Control Intelligent Manufacturing, Springer London, USA, pp. 347-372, (02-Aug-2006)

K. B. Lee, M. E. Reichardt, "*Open Standards for Homeland Security Sensor Networks*", IEEE Instrumentation Measurement

Legend:
R - Refereed
I - Invited

March 20, 2008

Magazine, IEEE Instrumentain and Measurement Society, New York, NY, USA, Vol. 8 No 5, (01-Dec-2005)

K. B. Lee, H. Weibel, D. Mohl, J. C. Eidson, "*2005 Conference on IEEE-1588 Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems*", Proceedings of the IEEE 1588 Conference, IEEE 1588 Conference, Winterhur, Switzerland, 10/10/2005 to 10/12/2005, (01-Jan-2006)

N. Machkour-Deshayes, J. R. Stoup, J. Lu, J. A. Soons, U. Griesmann, R. S. Polvani, "*Form-Profiling of Optics Using the Geometry Measuring Machine and NIST M-48 CMM*", Journal of Research National Institute of Standards and Technology, Vol. 111 (5), pp. 373-384, (01-Jan-2006)

G. A. Matei, E. J. Thoreson, J. R. Pratt, D. B. Newell, N. A. Burnham, "*Precision and Accuracy of Thermal Calibration of Atomic Force Microscopy Cantilevers*", Review of Scientific Instruments, Vol. 77, pp. 083703-1-083703-6, (01-Jan-2006)

S. P. Mates, R. L. Rhorer, S. Banovic, E. P. Whitenton, R. J. Fields, "*High Rate Tensile Strength Measurements of Frangible Bullets Using a Kolsky Bar*", Proceedings of the Society of Experimental Mechanics Annual Conference, St. Louis, MO, USA, 06/04/2006 to 06/07/2006, (01-Jan-2006)

S. P. Moylan, "*A Single Discharge Study of Micro-EDM*", Proceedings of the ASPE 21st Annual meeting, ASPE 21st Annual Meeting, Monterrey, CA, USA, 10/15/2006 to 10/20/2006, (01-Jan-2006)

B. F. Payne, "*Single Point Optical Calibration of Accelerometers at NIST*", Proceedings of SPIE 7th International Conference on Vibration Measurements by Laser Techniques, 7th International Conference on Vibration Measurements by Laser Techniques: Advances and Applications, Ancona, Italy, 06/19/2006 to 06/23/2006, Vol. 6345, 5 pp., (21-Jun-2006)

J. R. Pratt, J. A. Kramar, "*SI Realization of Small Forces Using an Electrostatic Force Balance*", Proceedings of IMEKO XVIII World Congress, IMEKO XVIII World Congress, Rio de Janeiro, Brazil, 09/17/2006 to 09/22/2006, (01-Jan-2006)

J. R. Pratt, J. A. Kramar, G. A. Shaw III, L. Kumanchik, "*Force Calibration Via Electrostatics*", Proceedings of the 2006 SEM Annual Conference & Exposition, 2006 SEM Annual Conference & Exposition, St. Louis, MO, USA, 06/04/2006 to 06/07/2006, pp. 35-45, (01-Jan-2006)

J. R. Pratt, J. A. Kramar, G. A. Shaw III, R. S. Gates, P. Rice, J. M. Moreland, "*New Reference Standards and Artifacts for Nanoscale Physical Property Characterization*", NSTI Nanotechnology Conference and Trade Show 2006, NSTI Nanotechnology Conference and Trade Show 2006, Boston, MA, USA, 05/07/2006 to 05/11/2006, (01-Jan-2006)

R. L. Rhorer, "*Optimizing Machining Processes for Precision: An Example using calculated cutting forces*", ASPE 21st Annual Meeting, ASPE 21st Annual Meeting, Monterey, CA, USA, 10/15/2006 to 10/20/2006, (01-Jan-2006)

G. A. Shaw III, J. R. Pratt, J. A. Kramar, "*Calibration of Microfabricated Cantilevers for SI-Traceable Small Force Measurement*", IMEKO XVIII World Congress, IMEKO XVIII World Congress, Rio Janeiro, Brazil, 09/17/2006 to 09/22/2006, (01-Jan-2006)

G. A. Shaw III, D. P. McDaniel, J. T. Elliott, A. Tona, A. L. Plant, "*Mechanical Stability of Collagen Fibril Networks*",

Legend:
R - Refereed
I - Invited

March 20, 2008

Material Research Society Symposium, Material Research Society Symposium, Boston, MA, USA, 11/28/2005 to 11/12/2005, (01-Nov-2005)

G. A. Shaw III, J. A. Kramar, J. R. Pratt, "*SI-Traceable Spring Constant Calibration of Microfabricated Cantilevers for Small Force Measurement*", Experimental Mechanics, Vol. 47 (1), pp. 143-151, (14-Sep-2006)

G. A. Shaw III, J. R. Pratt, R. S. Gates, M. Reitsma, "*Use of Transfer Artifacts for Small Force Measurement*", Proceedings of the Society for Experimental Mechanics Annual Meeting, Society for Experimental Mechanics Annual Meeting, St. Louis, MO, USA, 06/04/2006 to 06/08/2006, (01-Jan-2006)

Y. Song, K. B. Lee, "*An Implementation of the Proposed IEEE 1451.0 and 1451.5 Standards*", Sensors Applications Symposium Sensors Applications Symposium 2006, Sensors Applications Symposium Sensors Applications Symposium 2006, Houston, TX, USA, 02/07/2006 to 02/09/2006, (07-Feb-2006)

Q. Wang, U. Griesmann, "*Mini-Fizeau Interferometer for Curvature Sensing in the NIST Geometry Measuring Machine*", Technical Digest of the 2006 Optical Society of America Optical Fabrication and Testing Meeting, Technical Digest of the 2006 Optical Society of America Optical Fabrication and Testing Meeting, Rochester, NY, USA, 10/09/2006 to 10/11/2006, (01-Jan-2006)

L. Zhang, R. Gao, K. B. Lee, "*Optimization of Sensor Locations for Spindle Condition Monitoring*", Proceedings of North American Manufacturing Research (NAMRC) Conference, Milwaukee, WI, USA, 05/23/2006 to 05/26/2006, Vol. 34, pp. 55-62, (01-May-2006)

L. Zhang, R. Gao, K. B. Lee, "*Spindle Health Diagnosis Based on Analytic Wavelet Enveloping*", Instrumentation and Measurement, IEEE Instrumentation and Measurement Society, USA, Vol. 55 (5), pp. 1850-1858, (01-Sep-2006)

FY2005 Publications:

A. H. Adibi-Sedeh, M. Vaziri, V. Pednekar, V. Madhavan, R. W. Ivester, "*Investigation of the Effect of Using Different Material Models on Finiste Element Simulations of Machining*", 8th CIRP International Workshop on Modeling of Machining Operations, Chemnitz, Germany, 05/10/2005 to 05/11/2005, (01-Apr-2005)

K. L. Chesnutwood, "*Redesign of the 112.5 kN Dead Weight Machine Snubber System*", NIST Interagency/Internal Report (NISTIR) 7164, (01-Feb-2005)

S. B. Chikkamaranahalli, R. R. Vallance, B. Damazo, R. M. Silver, J. D. Gilsinn, "*Dynamic Modeling and Vibration Analysis of a UHV Scanning Tunneling*", ASME Annual Conference 2005, Proceedings of the American Society for Precision Engineering 2005 Annual conference, Norfolk, VA, USA, 10/09/2005 to 10/14/2005, (17-Aug-2005)

R. S. Davis, C. Aupetit, L. O. Becerra, W. Bich, N. Bignell, G. D. Chapman, J. W. Chung, J. Coarasa, S. Davidson, N. G. Domostroeva, K. M. Fen, M. Glaser, W. G. Lee, M. Lecollinet, Q. Li, R. Spurny, J. Verbeek, Z. J. Jabbour, A. Ooiwa, A. Torino, "*Final Report on CIPM Key Comparison of 1 kg Standards in Stainless Steel (CCM.M-K1)*", Metrologia, Vol. 41 (07002), (01-Oct-2004)

Legend:
R - Refereed
I - Invited

March 20, 2008

L. Deshayes, R. W. Ivester, T. Mabrouki, J. F. Rigal, "*Serrated Chip Morphology and Comparison with Finite Element Simulations*", ASME International Mechanical Engineering Congress & Exposition, ASME International Mechanical Engineering Congress & Exposition, Anaheim, CA, USA, 11/13/2004 to 11/19/2004, pp. 1-10, (01-Nov-2004)

U. Griesmann, N. Machkour-Deshayes, B. C. Kim, Q. Wang, L. Assoufid, "*Uncertainties in Aspheric Profile Measurements with the Geometry Measuring Machine at NIST*", SPIE - Optics and Photonics, SPIE, San Diego, CA, USA, 07/31/2005 to 08/04/2005, Vol. 5878, pp. 112-124, (31-Jul-2005)

U. Griesmann, Q. Wang, J. A. Soons, R. Carakos, "*A Simple Ball Averager for Reference Sphere Calibrations*", SPIE Optics and Photonics 2005 Conference, SPIE Optics and Photonics 2005 Conference, San Diego, CA, USA, 07/31/2005 to 08/04/2005, Vol. 5869, (01-Jan-2005)

U. Griesmann, Q. Wang, T. D. Raymond, "*Optical Flatness Metrology for 300 mm Silicon Wafers*", American Institute of Physics Proceedings of the 2005 Conference on Characterization and Metrology for ULSI Technology, American Institute of Physics Conference on Characterization and Metrology for ULSI Technology, Dallas, TX, USA, 03/15/2005 to 03/28/2005, Vol. 788, pp. 599-603, (01-Apr-2005)

R. W. Ivester, E. P. Whitenton, L. Deshayes, "*Comparison of Measurements and Simulations for Machining of Aluminum*", SME North American Manufacturing Research Conference, SME North American Manufacturing Research Conference, New York City, NY, USA, 05/24/2005 to 05/27/2005, Vol. 33, pp. 429-436, (01-May-2005)

K. B. Lee, J. C. Eidson, "*2004 Conference on IEEE 1588, Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems*", NIST Interagency/Internal Report (NISTIR) 7192, (01-Nov-2004)

K. B. Lee, M. E. Reichardt, "*Standardized Interfaces and WEB Enablement for Homeland and Security Sensor Networks*", Proceedings of Working Together: Research and Development Partnership in Homeland Security, Working Together: Research and Development Partnership in Homeland Security, Boston, MA, USA, 04/26/2005 to 04/27/2005, (01-Jan-2005)

N. Machkour-Deshayes, "*Magnetic Method to Characterize the Current Densities in a Breaker Arc*", 16th ANS Topical Meeting on the Technology of Fusion Energy, 16th ANS Topical Meeting on the Technology of Fusion Energy, Madison, WI, USA, 09/14/2004 to 09/16/2004, Vol. 47 (3), pp. 784-789, (01-Apr-2005)

N. Machkour-Deshayes, U. Griesmann, B. C. Kim, "*Modal Reconstruction of Aspheric Surfaces from Experimental Second Derivatives*", The Fourth International Conference on Operations Research (CIR0'5), The Fourth International Conference on Operations Research (CIR0'5), Marrakech, Morocco, USA, 05/23/2005 to 05/26/2005, 48 pp., (01-Jan-2005)

M. L. McGlauflin, J. A. Soons, M. A. Donmez, "*Comparison of Measurement Procedures for Evaluating Thermal Errors of Machine Tools due to Moving Linear Axes*", Laser Metrology and Machine Peformance VII, 7th International Conference on Laser Metrology, CMM and Machine Tool Performance, LANDAMAP 2005, Bedford, United Kingdom, 06/27/2005 to 06/30/2005, pp. 116-125, (01-Jun-2005)

R. S. Polvani, K. Medicus, "*X-Ray Topography Study of Surface Damage in Single-Crystal Sapphire*", International Journal of

Legend:
R - Refereed
I - Invited

March 20, 2008

Applied Ceramic Technology, Vol. 2, 336 pp., (01-Jul-2005)

J. R. Pratt, J. A. Kramar, D. B. Newell, D. T. Smith, "*Metrologies for Quantitative Nanomechanical Testing and Quality Control in Semiconductor Manufacturing*", Proceedings of the 30th SPIE International Symposium, Microlithography, 30th SPIE International Symposium, Microlithography, San Jose, CA, USA, 02/26/2005 to 03/04/2005, pp. 1457-1468, (01-Feb-2005)

J. R. Pratt, R. M. Seugling, "*Traceable Force Metrology for Micronewton Level Calibration*", Proceedings of the American Society for Precision Engineering 19th Annual Meeting, American Society for Precision Engineering 19th Annual Meeting, Orlando, FL, USA, 10/24/2004 to 10/29/2004, (01-Oct-2004)

G. A. Shaw III, J. R. Pratt, "*Development of Traceable Small Force Standards*", Society for Experimental Mechanics Annual Meeting, Society for Experimental Mechanics Annual Meeting, Portland, OR, USA, 06/07/2005 to 06/09/2005, Vol. 6, pp. 142-146, (01-Jun-2005)

Y. Song, K. B. Lee, "*Object-Oriented Application Framework for IEEE 1451.1 Standard*", Instrumentation and Measurement Technology Conference, Instrumentation and Measurement Technology Conference, Como, Italy, 05/18/2004 to 05/20/2004, Vol. 54, pp. 1527-1533, (01-Aug-2005)

J. A. Soons, "*Analysis of the Step-Diagonal Test*", Laser Metrology and Machine Peformance VII, 7th International Conference and Exhibition on Laser Metrology, Machine Tool, CMM & Robotic Performance, LAMDAMAP 2005, 7th International Conference and Exhibition on Laser Metrology, Machine Tool, CMM & Robotic Performance, LAMDAMAP 2005, Bedford, United Kingdom, 06/24/2005 to 07/01/2005, pp. 126-137, (01-Jun-2005)

(R) R. P. Wagner, "*Methods for hearing aid directivity index measurements under simulated real-ear conditions*", Journal of the Acoustical Society of America, Program: 150th Meeting of the Acoustical Society of America, Journal of the Acoustical Society of America, Program: 150th Meeting of the Acoustical Society of America, Minneapolis, MN, USA, 10/17/2005 to 10/21/2005, Vol. 118 , No. No. 3, Part 2 , (01-Sep-2005)

Q. Wang, U. Griesmann, R. S. Polvani, "*Interferometric Thickness Calibration of 300mm Silicon Wafers*", ASPE (American Society for Precision Engineering) 2005 Summer Topical Meeting - Precision Interferometric Metrology, ASPE (American Society for Precision Engineering) 2005 Summer Topical Meeting - Precision Interferometric Metrology, Middletown, CT, USA, 07/20/2005 to 07/22/2005, (20-Jul-2005)

E. P. Whitenton, "*The NIST Kolsky Bar Data Processing System*", SEM Annual Conference & Exposition 2005, SEM Annual Conference & Exposition 2005, Portland, OR, USA, 06/07/2005 to 06/09/2005, (07-Jun-2005)

E. P. Whitenton, R. W. Ivester, H. W. Yoon, "*Simultaneous Visible and Thermal Imaging of Metals During Machining*", Proceedings XXVII SPIE International Symposium on Defense Security, ThermoSense, XXVII SPIE International Symposium on Defense and Security, ThermoSense, Orlando, FL, USA, 03/28/2005 to 04/01/2005, Vol. 5782, pp. 71-82, (28-Mar-2005)

J. Wiczer, K. B. Lee, "*A unifying Standard for Interfacing Transducers to Networks - IEEE-1451.0*", ISA 2005

Legend:
R - Refereed
I - Invited

March 20, 2008

Expo/Conference - The Instrumentation, 2005 ISA - The Instrumentation, Systems, and Automation Society, Research Triangle, NC, USA, 01/01/2005 to 01/01/2005, (01-Jan-2005)

H. Yang, E. S. Buice, T. J. Fagan, S. J. Smith, R. Hocken, D. L. Trumper, R. M. Seugling, "*A Coarse/Fine Motion Control Stage; Preliminary Studies*", ASPE 19th Annual Meeting, ASPE 19th Annual Meeting, Orlando, FL, USA, 10/24/2004 to 10/29/2004, (01-Oct-2004)

L. Zhang, R. Gao, K. B. Lee, "*Wavelet-Based Enveloping for Spindle Health Diagnosis*", IMTC 2005 Conference, IMTC 2005 Conference, Ottawa, Canada, 05/17/2005 to 05/19/2005, pp. 1203-1208, (01-May-2005)

Legend:
R - Refereed
I - Invited

Intelligent Systems Division

List of Publications

For

FY2005 to FY2008

(September 30, 2004 to March 20, 2008)

March 20, 2008

FY2007 Publications:

S. B. Balakirsky, C. J. Scrapper Jr, S. Carpin, *"The Evolution of Performance Metrics in the RoboCup Rescue Virtual Robot Competition",* Proceedings of the Performance Metrics for Intelligent Systems Workshop | 2007 | PerMIS |, Performance Metrics for Intelligent Systems (PerMIS) 2007, Gaithersburg, MD, USA, 08/28/2007 to 08/30/2007, (28-Dec-2007)

R. V. Bostelman, J. S. Albus, *"Design of the HLPR ChairHome Lift Position and Rehabilitation Chair",* NIST Interagency/Internal Report (NISTIR) 7459, (09-Nov-2007)

N. G. Dagalakis, Y. Kim, D. S. Sawyer, C. M. Shakarji, *"Development of Tools for Measuring the Performance of Computer Assisted Orthopaedic Hip Surgery Systems",* Proceedings of the Performance Metrics for Intelligent Systems | 2007 | PerMIS |, Performance Metrics for Intelligent Systems Workshop (PerMIS) 2007, Gaithersburg, MD, USA, 08/29/2007 to 08/30/2007, (28-Dec-2007)

N. G. Dagalakis, J. B. Stiehl, Y. Kim, D. S. Sawyer, C. M. Shakarji, *"NIST Medical Phantom Device to Assist With the Calibration and Performance Testing of CAOS Systems",* , (09-Nov-2007)

H. Huang, *"Autonomy Levels for Unmanned Systems (ALFUS) Framework:Safety and Application Issues",* Performance Metrics for Intelligent Systems Workshop | 2007 | PerMIS |, Performance Metrics for Intelligent Systems (PerMIS) 2007, Gaithersburg, MD, USA, 08/28/2007 to 08/30/2007, (28-Dec-2007)

H. Huang, E. R. Messina, *"Autonomy Levels for Unmanned Systems (ALFUS) FrameworkVolume II: Framework Models Initial Version",* Special Publication (NIST SP) 1011-II-1.0, (28-Dec-2007)

Z. Kootbally, C. I. Schlenoff, R. Madhavan, *"A Brief History of PRIDE",* Proceedings of PerMIS | 2007 |, Performance Metrics for Intelligent Systems (PerMIS) 2007, Gaithersburg, MD, USA, 08/28/2007 to 08/30/2007, (28-Dec-2007)

T. R. Kramer, *"Evaluating Manufacturing Machine Control Language Standards: An Implementer s View",* Proceedings of PerMIS | 2007 |, PerMIS, 08/28/2007 to 08/30/2007, (28-Dec-2007)

R. Madhavan, E. R. Messina, *"Proceedings of the Performance Metrics for Intelligent Systems (PerMIS)2007 Workshop, August 28-30, 2007",* Special Publication (NIST SP), (28-Dec-2007)

R. Madhavan, M. Foedissch, T. Y. Chang, T. H. Hong, *"Grouping Sensory Primitives for Object Recognition and Tracking",* Applied Imagery Pattern Recognition (AIPR) 2005, Applied Imagery Pattern Recognition (AIPR) 2005, Washington, DC, USA, 10/19/2005 to 10/21/2005, (03-Dec-2007)

C. T. Pepper, S. B. Balakirsky, C. J. Scrapper Jr, *"Robot Simulation Physics Validation",* PerMIS Conference | 2007 |, Performance Metrics for Intelligent Systems (PerMIS) 2007, Gaithersburg, MD, USA, 08/28/2007 to 08/30/2007, (28-Dec-2007)

F. M. Proctor, W. G. Rippey, J. A. Horst, J. A. Falco, T. R. Kramer, *"Interoperability Testing for Shop Floor Measurement",* Proceedings of the Performance Metrics for Intelligent Systems Workshop | 2007 | PerMIS |, Performance Metrics for

Legend:
R - Refereed
I - Invited

March 20, 2008

Intelligent Systems (PerMIS) 2007, Gaithersburg, MD, USA, 08/28/2007 to 08/30/2007, (28-Dec-2007)

C. I. Schlenoff, Z. Kootbally, R. Madhavan, "*Driver Aggressivity Analysis Within the Prediction In Dynamic Environments (PRIDE) Framework*", Proceedings of SPIE | 2007 |, SPIE, 04/09/2007 to 04/13/2007, (19-Oct-2007)

C. J. Scrapper Jr, R. Madhavan, S. B. Balakirsky, "*Stable Navigation Solutions for Robots in Complex Environments*", IEEE International Workshop on Safety, Security, and Rescue Robotics (SSRR2007) , IEEE International Workshop on Safety, Security, and Rescue Robotics (SSRR2007) , Rome, Italy, 09/27/2007 to 09/29/2007, (15-Nov-2007)

(I) M. O. Shneier, R. V. Bostelman, J. S. Albus, W. P. Shackleford, T. Y. Chang, T. H. Hong, "*A Common Operator Control Unit Color Scheme for Mobile Robots*", Performance Metrics for Intelligent Systems Workshop | 2007 | PerMIS |, Performance Metrics for Intelligent Systems (PerMIS) 2007, Gaithersburg, MD, USA, 08/28/2007 to 08/30/2007, (28-Dec-2007)

B. K. Taylor, S. B. Balakirsky, E. R. Messina, R. D. Quinn, "*Design and Validation of a Whegs Robot in USARSim*", Proceedings of PerMIS | 2007 |, Performance Metrics for Intelligent Systems (PerMIS) 2007, Gaithersburg, MD, USA, 08/28/2007 to 08/30/2007, (31-Jan-2008)

S. Venkatesh, R. Morihara, J. L. Michaloski, F. M. Proctor, "*Closed Loop CNC Manufacturing -- Connecting the CNC to the Enterprise*", International Computers and Information in Engineering Conference | 2007 | ASME |, International Computers and Information in Engineering Conference, Las Vegas, NV, USA, 09/04/2007 to 09/07/2007, (26-Nov-2007)

S. Venkatesh, B. Sides, J. L. Michaloski, F. M. Proctor, "*Case Study in the Challenges of Integrating CNC Production and Enterprise Systems* ", 2007 ASME International Mechanical Engineering Congress and Exposition, 2007 ASME International Mechanical Engineering Congress and Exposition, Seattle, WA, USA, 11/11/2007 to 11/15/2007, (03-Dec-2007)

FY2007 Publications:

J. S. Albus, T. H. Hong, T. Y. Chang, "*Segmentation and Classification of Human Forms Using LADAR Data*", Proceedings of the Applied Image Patern Recognittion | 2006 | AIPR, AIPR Conference, 10/11/2006 to 10/13/2006, (14-Mar-2007)

R. V. Bostelman, J. S. Albus, "*Survey of Patient Mobility and Lift Technologies: Toward Advancements and Standards*", NIST Interagency/Internal Report (NISTIR) 7384, (06-Dec-2006)

R. V. Bostelman, P. Russo, J. S. Albus, T. H. Hong, R. Madhavan, "*Applications of a 3D Range Camera Towards Healthcare Mobility Aids*", IEEE, (03-Oct-2006)

N. G. Dagalakis, Y. Kim, D. S. Sawyer, C. M. Shakarji, "*Design and Fabrication of an Operating Room Computer Assisted Orthopaedic Hip Surgery Artifact*", Proceedings of the ASPE Annual Meeting | 22nd | 2007 |, ASPE Annual Meeting, 10/14/2007 to 10/19/2007, (17-Aug-2007)

J. J. Ference, S. Szabo, W. G. Najm, "*Performance Evaluation of Integrated Vehicle-Based Safety Systems*", Proceedings of the Performance Metrics for Intelligent Systems (PerMIS), Performance Metrics for Intelligent Systems, Gaithersburg, MD, USA, 08/21/2006 to 08/23/2006, (31-Jan-2007)

Legend:
R - Refereed
I - Invited

March 20, 2008

M. Foedisch, C. I. Schlenoff, R. Madhavan, "*Performance Analysis of Symbolic Road Recognition for On-Road Driving*", Performance Metrics for Intelligent Systems Workshop| 2006 | PerMIS, Performance Metrics for Intelligent Systems (PerMIS) Workshop 2006, Gaithersburg, MD, USA, 08/21/2006 to 08/23/2006, (31-Jan-2007)

J. J. Gorman, Y. Kim, A. E. Vladar, N. G. Dagalakis, "*Design of an On-Chip Micro-Scale Nanoassembly System*", Proceedings of the International Symposium on Nanomanufacturing | 2006| ISN, International Symposium on Nanomanufacturing, Cambridge, MA, USA, 11/03/2006 to 11/03/2006, pp. 160-165, (03-Nov-2006)

J. J. Gorman, Y. Kim, N. G. Dagalakis, "*Control of MEMS Nanopositioners With Nano-Scale Resolution*", Proceedings of the ASME International Mechanical Engineering Conference and Exhibition | 2006| ASME, ASME International Mechanical Engineering Conference and Exhibition, Chicago, IL, USA, 11/05/2006 to 11/10/2006, (10-Nov-2006)

J. A. Horst, S. McSpadden, "*A Roadmap For Metrology Interoperability*", NIST Interagency/Internal Report (NISTIR) 7381, (04-Dec-2006)

H. Huang, "*The Autonomy Levels for Unmanned Systems (ALFUS) Framework: Interim Results*", Proceedings of the Performance Metrics for Intelligent Systems (PerMIS) Workshop | | 2006|, Performance Metrics for Intelligent Systems (PerMIS) Workshop 2006, Gaithersburg, MD, USA, 08/21/2006 to 08/23/2006, (31-Jan-2007)

H. Huang, K. Pavek, M. Ragon, J. Jones, E. R. Messina, J. S. Albus, "*Characterizing Unmanned System Autonomy:Contextual Autonomous Capability and Level of Autonomy Analyses*", SPIE Defense and Security Conference | 2007 |, SPIE Defense and Security Conference, Orlando, FL, USA, 04/09/2007 to 04/13/2007, (15-May-2007)

A. S. Jacoff, E. R. Messina, "*DHS/NIST Response Robot Evaluation Exercises*", IEEE International Workshop on Safety, Security and Rescue Robotics (SSRR 2006) | | | NIST, IEEE International Workshop on Safety, Security and Rescue Robotics, 08/22/2006 to 08/24/2006, (08-Jan-2007)

A. S. Jacoff, E. R. Messina, "*Urban Search and Rescue Robot Performance Standards: Progress Update*", SPIE Defense and Security Conference, (15-Jun-2007)

R. Madhavan, E. R. Messina, "*Performance Metrics for Intelligent Systems (PerMIS) 2006 Workshop: Summary and Review*", Proceedings of the Applied Imagery Pattern Recognition Workshop |2006 | AIPR, Applied Imagery Pattern Recognition (AIPR), Washington, DC, USA, 10/11/2006 to 10/13/2006, (13-Oct-2006)

E. R. Messina, R. Madhavan, "*Proceedings of the Performance Metrics for Intelligent Systems (PerMIS) Workshop 2006*", Special Publication (NIST SP) 1062, (31-Jan-2007)

V. Molino, R. Madhavan, E. R. Messina, A. Downs, A. S. Jacoff, S. B. Balakirsky, "*Traversability Metrics for Urban Search and Rescue Robots on Rough Terrain*", PerMIS | | | NIST Intelligent Systems Division and DARPA, Performance Metrics for Intelligent Systems (PerMIS) Proceedings, 08/21/2006 to 08/23/2006, (31-Jan-2007)

R. J. Norcross, "*Towards Development of an ISO Container to Spreader Bar Sensor System*", NIST Interagency/Internal Report

Legend:
R - Refereed
I - Invited

March 20, 2008

(NISTIR) 7418, (12-Jun-2007)

M. Price, J. Kenney, R. D. Eastman, T. H. Hong, "*Training and Optimization of Operating Parameters for Flash LADAR Cameras*", NIST Interagency/Internal Report (NISTIR) 7405, (10-Apr-2007)

C. I. Schlenoff, E. R. Messina, A. M. Lytle, B. A. Weiss, A. M. Virts, "*Test Methods and Knowledge Representation for Urban Search and Rescue Robots*", Climbing and Walking Robots Book To be published in a chapter in the Climbing and Walking Robots Book, , (17-Aug-2007)

M. O. Shneier, W. P. Shackleford, T. H. Hong, T. Y. Chang, "*Performance Evaluation of a Terrain Traversability Learning Algorithm in The DARPA LAGR Program*", Proceedings of the Performance Metrics for Intelligent Systems Workshop| 2006 | PerMIS, Performance Metrics for Intelligent Systems (PerMIS) Workshop 2006, Gaithersburg, MD, USA, 08/21/2006 to 08/23/2006, (31-Jan-2007)

S. Szabo, R. J. Norcross, J. A. Falco, "*Objective Test and Performance Measurement of Automotive Crash Warning Systems*", SPIE Defense and Security Conference, (10-Apr-2007)

B. A. Weiss, C. I. Schlenoff, M. O. Shneier, A. M. Virts, "*Technology Evaluations and Performance Metrics for Soldier-Worn Sensors for ASSIST*", Proceedings of the Performance Metrics for Intelligent Systems (PerMIS) Workshop | | 2006|, Performance Metrics for Intelligent Systems (PerMIS) Workshop 2006, Gaithersburg, MD, USA, 08/21/2006 to 08/23/2006, (31-Jan-2007)

FY2006 Publications:

J. S. Albus, T. Barbera, "*Intelligent Control and Tactical Behavior Development: A Long Term NIST Partnership with the Army*", Proceedings of ICINCO 06 ? International Conference in Control, Nuclear Society, 9th Emerg. Preparedness & Response, 11th Robotics & Remote Sys for Hazardous Environ., Salt Lake City, UT, USA, 02/11/2006 to 02/16/2006, (26-Jun-2006)

J. S. Albus, R. V. Bostelman, T. Y. Chang, T. H. Hong, W. P. Shackleford, M. O. Shneier, " *Learning in a Hierarchical Control System: 4D/RCS in the DARPA LAGR Program*", Submitted to the Journal of Field Robotics., (26-Jun-2006)

J. S. Albus, A. J. Barbera, H. A. Scott, S. B. Balakirsky, "*Collaborative Tactical Behaviors for Autonomous Ground and Air Vehicles*", Proceedings of SPIE Vol. 5804, Unmanned Ground Vehicle Technology VII (Orlando), Orlando, FL, USA, 03/29/2005 to 03/31/2005, Vol. 5804, (28-Jun-2006)

J. S. Albus, R. V. Bostelman, T. H. Hong, W. P. Shackleford, M. O. Shneier, "*THE LAGR PROJECT - Integrating learning into the 4D/RCS Control Hierarchy*", International Conference on Informatics in Control, Automation and Robotics | 3rd | | Set bal Polytechnic Institute, International Conference in Control, Automation and Robotics (ICINCO 06), Setubal, Portugal, 08/01/2006 to 08/05/2006, (27-Jun-2006)

J. S. Albus, "*Intelligent Systems for Construction and Long Range Exploration on Planetary Surfaces*", Proceedings of the, American Institute of Aeronautics and Astronautics, Arlington , VA, USA, 09/26/2005 to 09/29/2005, (28-Jun-2006)

Legend:
R - Refereed
I - Invited

March 20, 2008

S. B. Balakirsky, C. J. Scrapper Jr, S. Carpin, M. L. Lewis, "*USARSim: Providing a Framework for Multi-Robot Performance Evaluation*", Performance Metrics for Intelligent Systems Workshop| 2006 | PerMIS, Performance Metrics for Intelligent Systems (PerMIS) Workshop 2006, Gaithersburg, MD, USA, 08/21/2006 to 08/23/2006, (31-Jan-2006)

S. Bergna, J. J. Gorman, N. G. Dagalakis, "*Design and Modeling of Thermally Actuated MEMS Nanopositioners*", Proceedings of ASME International Mechanical Engineering Congress and Exposition, Microelectromechanical Systems, MEMS-1 P MEMS Division Poster Session, Orlando, FL, USA, 11/05/2005 to 11/11/2005, Vol. IMECE2005-82158, (11-Nov-2005)

R. V. Bostelman, T. H. Hong, R. Madhavan, "*Obstacle Detection using a Time-of -Flight Range Camera for Automated Guided Vehicle Safety and Navigation*", Integrated Computer-Aided Engineering Journal, (28-Jun-2006)

R. V. Bostelman, T. H. Hong, R. Madhavan, T. Y. Chang, "*Safety Standard Advancement Toward Mobile Robot Use Near Humans*", RIA SIAS 2005 4th International Conference on Safety of Industrial Automated Systems, Chicago, IL, USA, 09/26/2005 to 09/28/2005, (26-Jun-2006)

R. V. Bostelman, T. H. Hong, R. Madhavan, "*Experiments toward Non-contact Safety Standards for Automated Industrial Vehicles*", Proceedings of the SPIE Defense and Security Symposium, SPIE Defense and Security Symposium, Kissimmee, FL, USA, 03/28/2005 to 04/01/2005, (28-Jun-2006)

R. V. Bostelman, J. S. Albus, "*HLPR Chair* A Service Robot for the Healthcare Industry*", International Workshop on Advances in Service Robotics | 3rd | | ASER, International Workshop on Advances in Service Robotics, Vienna, Austria, 07/07/2006 to 07/07/2006, (01-Sep-2006)

R. V. Bostelman, T. H. Hong, T. Y. Chang, W. P. Shackleford, M. O. Shneier, "*Unstructured Facility Navigation by Applying the NIST 4D/RCS Architecture*", International Conference on Cybernetics and Information Technologies, Systems and Application (CITSA 06) | 3rd | 4th International Conference on Computing, Communications and Control Technologies | IIIS, International Conference on Cybernetics and Information Technologies, Systems and Application, 07/20/2006 to 07/23/2006, (05-Sep-2006)

R. V. Bostelman, T. H. Hong, R. Madhavan, B. A. Weiss, "*3D Range Imaging for Urban Search and Rescue Robotics Research*", SSRR Workshop | | |, Safety, Security and Rescue Robotics (SSRR 2005), Kobe, Japan, 06/06/2005 to 06/09/2005, (26-Jun-2006)

R. V. Bostelman, T. H. Hong, R. Madhavan, T. Y. Chang, H. A. Scott, "*Performance Analysis of Unmanned Vehicle Positioning and Obstacle Mapping*", SPIE 06-International Society for Optical Engineering, Defense and Security Symposium, SPIE 06-International Society for Optical Engineering, Defense and Security Symposium, Orlando, FL, USA, 04/17/2006 to 04/21/2006, (27-Jun-2006)

R. V. Bostelman, T. H. Hong, R. Madhavan, "*Towards AGV Safety and Navigation Advancement ? Obstacle Detection using a TOF Range Camera*", 12th International Conference on Advanced Robotics (ICAR), Seattle, WA, USA, 07/18/2005 to 06/20/2005, (26-Jun-2006)

Legend:
R - Refereed
I - Invited

March 20, 2008

J. A. Falco, M. Lochner, D. Teumim, "*Guidance and Performance Impact Testing to Support the use of Antivirus Software on SCADA and Industrial Control Systems*", Proceedings of the, ISA Expo, Chicago , IL, USA, 10/25/2005 to 10/27/2005, (26-Jun-2006)

J. A. Falco, S. Hurd, D. Teumim, "*Using Host-based Anti-virus Software on Industrial Control Systems: Integration Guidance and a Test Methodology for Assessing Performance Impacts*", Special Publication (NIST SP) 1058, (29-Sep-2006)

M. Foedisch, M. Lochner, D. Teumim, "*Towards an Approach for Knowledge-based Road Detection*", 2005 CIKM Conference: Workshop on Research in Knowledge Representation for Autonomous Systems, Bremen, Germany, 10/31/2005 to 11/05/2005, (26-Jun-2006)

M. Foedisch, C. I. Schlenoff, M. O. Shneier, "*Towards an Approach for Knowledge-Based Road Detection*", CIKM Conference: Workshop on Research in Knowledge Representation for Autonomous Systems| | |, Research in Knowledge Representation for Autonomous Systems Workshop, Bremen, Germany, 10/31/2005 to 11/05/2005, (26-Jun-2006)

J. J. Gorman, N. G. Dagalakis, "*Probe-Based Micro-Scale Manipulation and Assembly Using Force Feedback*", Proceedings of the International Conference on Robotics and Remote Systems for Hazardous Environments, pp. 621-628, (26-Jun-2006)

J. A. Horst, "*Making Interoperability Happen*", Submitted to the AIAG ActionLine Magazine., (26-Jun-2006)

J. A. Horst, A. J. Barbera, C. I. Schlenoff, D. Aha, "*Identifying Sensory Processing Requirements for an On-Road Driving Application of 4D/RCS*", NIST Interagency/Internal Report (NISTIR) 7167, (04-Jan-2006)

J. A. Horst, A. J. Barbera, "*Trajectory Generation for an On-Road Autonomous Vehicle*", NIST Interagency/Internal Report (NISTIR) 7262, (26-Jun-2006)

H. Huang, K. Pavek, J. S. Albus, E. R. Messina, "*Autonomy Levels for Unmanned Systems (ALFUS) Framework: An Update*", 2005 SPIE Defense and Security Symposium, Orlando, FL, USA, 03/28/2005 to 04/01/2005, (28-Jun-2006)

H. Huang, J. S. Albus, E. R. Messina, H. A. Scott, M. Juberts, "*Entity Knowledge Model Supporting Intelligent Systems*", KIMAS, International Conference on Integration of Knowledge Intensive Multi-Agent Systems KIMAS 05: Modeling, EVOLUTION and Engineering, Waltham, MA, USA, 04/18/2005 to 04/21/2005, (20-Jun-2006)

H. Huang, K. Pavek, B. Novak, J. S. Albus, E. R. Messina, "*A Framework for Autonomy Levels for Unmanned Systems (ALFUS)*", AUVSI's Unmanned Systems North America 2005, Baltimore, MD, USA, 06/01/2005 to 06/01/2005, (26-Jun-2006)

R. Madhavan, T. H. Hong, E. R. Messina, "*Temporal Range Registration for Unmanned Ground and Aerial Vehicles*", Journal of Intelligent and Robotic Systems (2005) DOI: 10.1007/s10846-005-9025-1, (30-Nov-2005)

R. Madhavan, C. I. Schlenoff, "*The Effect of Process Models on Short-term Prediction of Moving Objects for Autonomous Driving*", International Journal of Control Automation and Systems, Vol. 3, pp. 509-523, (28-Jun-2006)

(R) R. Madhavan, T. H. Hong, E. R. Messina, "*Temporal Range Registration for Unmanned Ground and Aerial Vehicles*", Journal

Legend:
R - Refereed
I - Invited

March 20, 2008

of Intelligent and Robotic Systems (JIRS), (01-Nov-2005)

R. Madhavan, E. R. Messina, J. S. Albus, "*Intelligent Vehicle Systems: A 4D/RCS Approach*", Book Nova Science Publishers Inc.| |2006, , (14-Jun-2006)

(R) R. Madhavan, C. I. Schlenoff, "*The Effect of Process Models on Short-Term Prediction of Moving Objects for Autonomous Driving*", International Journal of Control Automation and Systems (IJCAS), Vol. 3, No. 4, pp. 509-523, (01-Dec-2005)

R. Madhavan, E. R. Messina, " *Performance Evaluation of Temporal Range Registration for Autonomous Vehicle Navigation*", Integrated Computer-Aided Engineering, Vol. 12, pp. 1-13, (28-Jun-2006)

E. R. Messina, A. S. Jacoff, "*Performance Standards for Urban Search and Rescue Robots*", Proceedings of the SPIE Defense and Security Symposium, SPIE Defense and Security Symposium, Orlando, FL, USA, 04/17/2006 to 04/21/2006, (26-Jun-2006)

E. R. Messina, "*Performance Standards for Urban Search and Rescue Robots*", -, Standardization News, -, -, -, USA, (01-Aug-2006)

C. I. Schlenoff, J. S. Albus, E. R. Messina, T. Barbera, R. Madhavan, S. B. Balakirsky, "*Using 4D/RCS to Address AI Knowledge Integration*", Submitted to the Special Issue of AI Magazine: Achieving Human-Level Intelligent through Integrated Systems and Research., (26-Jun-2006)

C. I. Schlenoff, E. R. Messina, "*A Robot Ontology for Urban Search and Rescue*", 2005 CIKM Conference: Workshop on Research in Knowledge Representation for Autonomous Systems, Bremen, Germany, 10/31/2005 to 11/05/2005, (26-Jun-2006)

C. I. Schlenoff, B. A. Weiss, M. P. Steves, A. M. Virts, M. O. Shneier, M. Linegang, "*Overview of the First Advanced Technology Evaluations for ASSIST*", Proceedings of the Performance Metrics for Intelligent Systems (PerMIS) Workshop | | 2006|, Performance Metrics for Intelligent Systems
(PerMIS) Workshop, Gaithersburg, MD, USA, 08/21/2006 to 08/23/2006, (31-Jan-2006)

C. I. Schlenoff, R. Washington, A. J. Barbera, C. Manteuffel, "*A Standard Intelligent System Ontology*", Proceedings of the Unmanned Ground Vehicle Technology VII Conference, Part of the 2005 SPIE Defense and Security Symposium, Kissimmee, FL, USA, 03/28/2005 to 04/01/2005, (27-Jun-2006)

C. I. Schlenoff, R. Washington, A. J. Barbera, "*An Intelligent Ground Vehicle Ontology for Multi-Agent System Integration*", Proceedings of the 2005 Knowledge Intensive Multi-Agent Systems (KIMAS) Conference, 2005 Knowledge Intensive Multi-Agent Systems (KIMAS) Conference, Waltham, MA, USA, 04/18/2005 to 04/21/2005, (27-Jun-2006)

C. I. Schlenoff, J. G. Ajot, R. Madhavan, "*Towards a Tool for Performance Evaluation of Autonomous Vehicle Navigation in Dynamic, On-Road Environments*", Submitted to the Integrated Computer-Aided Engineering Journal, (26-Jun-2006)

C. J. Scrapper Jr, S. B. Balakirsky, E. R. Messina, "*MOAST and USARSim-A Combined Framework for the Development and Testing of Autonomous Systems*", Proceedings of the SPIE Defense and Security Symposium, SPIE Defense and Security

Legend:
R - Refereed
I - Invited

Symposium, Orlando, FL, USA, 04/17/2006 to 04/21/2006, (26-Jun-2006)

M. O. Shneier, T. Y. Chang, T. H. Hong, W. P. Shackleford, "*Learning Traversability Models for Autonomous Mobile Vehicles*", Submitted to the Journal of Autonomous Robots, (26-Jun-2006)

K. A. Stouffer, " *NIST Industrial Control System Security Activities*", ISA Expo, Chicago , IL, USA, 10/25/2005 to 10/27/2005, (26-Jun-2006)

S. Szabo, R. J. Norcross, "*Recommended Objective Test Procedures for Road Departure Crash Warning Systems*", NIST Interagency/Internal Report (NISTIR) 7288, (06-Jan-2006)

S. Szabo, R. J. Norcross, "*An Independent Measurement System for Performance Evaluation of Road Departure Crash Warning Systems*", NIST Interagency/Internal Report (NISTIR) 7287, (04-Jan-2006)

(R) T. Tsai, "*Dynamic Simulation and Modeling of a Road Vehicle*", Journal of Dynamic Systems, Measurements and Control, (02-Feb-2006)

S. Venkatesh, D. Odendahl, X. W. Xu, J. L. Michaloski, F. M. Proctor, T. R. Kramer, "*Validating Portability of Step-NC Tool Center Programming*", IDETC/CIE ASME International 25th Computers and Information in Engineering Conference, Long Beach, CA, USA, 09/24/2005 to 09/28/2005, (26-Jun-2006)

FY2005 Publications:

(R) S. B. Balakirsky, E. R. Messina, C. I. Schlenoff, S. J. Smith, M. Uschold, "*Knowledge Representation For A Trash Collecting Robot: Results From The 2004 AAAI Spring Symposium*", Robotics and Autonomous Systems Journal - Special Issue on Knowledge Representation for Autonomous Systems, Vol. 49, No. No. 1-2, (01-Nov-2004)

S. B. Balakirsky, C. J. Scrapper Jr, E. R. Messina, "*Hierarchical Control and Performance Evaluation of Multi-Vehicle Autonomous Systems*", Proceedings, SPIE Defense and Security Symposium, 03/28/2005 to 04/01/2005, (04-May-2005)

(R) S. B. Balakirsky, C. J. Scrapper Jr, "*Knowledge Representation and Planning for On-Road Driving*", Robotics and Autonomous Systems Journal - Special Issue on Knowledge Representation for Autonomous Systems, Vol. 49, No. No. 1-2, (01-Nov-2004)

(R) A. J. Barbera, J. S. Albus, E. R. Messina, C. I. Schlenoff, J. A. Horst, "*How Task Analysis Can Be Used to Derive and Organize the Knowledge for the Control of Autonomous Vehicles*", Robotics and Autonomous Systems Journal - Special Issue on Knowledge Representation for Autonomous Systems, Vol. 49, No. No. 1-2, (01-Nov-2004)

A. J. Barbera, J. A. Horst, C. I. Schlenoff, D. Aha, "*Task Analysis of Autonomous On-Road Driving*", Mobile Robots 2004 | 17th | Proceedings of SPIE--the International Society for Optical Engineering | SPIE, Proceedings of SPIE--the International Society for Optical Engineering, 10/26/2004 to 10/28/2004, Vol. 5609, (01-Oct-2004)

R. V. Bostelman, T. H. Hong, R. Madhavan, "*Towards AGV Safety and Navigation Advancement - Obstacle Detection Using a TOF Range Camera**", International Conference on Advanced Robotics (ICAR), 12th International Conference on Advanced

March 20, 2008

Robotics (ICAR), Seattle, WA, USA, 07/18/2005 to 07/20/2005, (20-Jul-2005)

T. H. Hong, A. Takeucki, M. Foedisch, M. O. Shneier, "*Performance Evaluation of Road Detection and Following Systems*", Mobile Robots 2004 | 17th | Proceedings of SPIE--the International Society for Optical Engineering | SPIE, Proceedings of SPIE--the International Society for Optical Engineering, 10/26/2004 to 10/28/2004, Vol. 5609, (01-Oct-2004)

H. Huang, E. R. Messina, R. Wade, W. English, B. Novak, J. S. Albus, "*Autonomy Measures for Robots*", Proceedings of the ASME Dynamic Systems and Control Division - 2004, IMECE International Mechanical Engineering Congress and Exposition, 11/13/2004 to 11/19/2004, Vol. 73, No. No. 2, (01-Nov-2004)

M. Juberts, A. J. Barbera, "*Status Report on Next Generation LADAR for Driving Unmanned Ground Vehicles*", Mobile Robots | 17th | | SPIE, Proceedings of SPIE--the International Society for Optical Engineering, 10/25/2004 to 10/28/2004, Vol. 5609, (01-Oct-2004)

B. H. Kang, J. T. Wen, N. G. Dagalakis, J. J. Gorman, "*Design Optimization for a Parallel MEMS Mechanism with Flexure Joints*", Proceedings of ASME Design Engineering Technical Conferences, ASME Design Engineering Technical Conference, Salt Lake City, UT, USA, 09/28/2004 to 10/02/2004, Vol. DETC2004/MECH-57455, (04-Oct-2004)

E. R. Messina, A. M. Meystel, "*Performance Metrics for Intelligent Systems, Proceedings of PerMIS '04 Workshop*", Special Publication (NIST SP) 1036, (15-May-2005)

(R) E. R. Messina, S. B. Balakirsky, "*Knowledge Representation and Decision Making for Mobile Robots*", Autonomous Robots, (13-Jul-2005)

R. J. Norcross, "*HiCASS Target Tracking Sensor Study*", NIST Interagency/Internal Report (NISTIR) 7220, (20-May-2005)

(R) R. Provine, C. I. Schlenoff, S. B. Balakirsky, S. J. Smith, M. Uschold, "*Onotology-Based Methods for Enhancing Autonomous Vehicle Path Planning*", Robotics and Autonomous Systems Journal - Special Issue on Knowledge Representation for Autonomous Systems, Vol. 49, No. No. 1-2, (01-Nov-2004)

W. G. Rippey, "*AIAG Demonstrates Metrology Interoperability: To Save You Time and Money*", International Dimensional Workshop (IDW 2005), International Dimensional Workshop (IDW 2005), Nashville, TN, USA, 05/09/2005 to 05/13/2005, (31-May-2005)

C. I. Schlenoff, J. L. Evans, A. J. Barbera, J. S. Albus, E. R. Messina, S. B. Balakirsky, "*Achieving Intelligent Performance in Autonomous On-Road Driving*", Mobile Robots 2004 | 17th | Proceedings of SPIE--the International Society for Optical Engineering | SPIE, Proceedings of SPIE--the International Society for Optical Engineering, 10/26/2004 to 10/28/2004, Vol. 5609, (01-Oct-2004)

Legend:
R - Refereed
I - Invited

Manufacturing Systems Integration Division

List of Publications

For

FY2005 to FY2008

(September 30, 2004 to March 20, 2008)

March 20, 2008

S. C. Feng, T. V. Vorburger, C. B. Joung, J. N. Fu, R. G. Dixson, L. Ma, *"Computational Models of the Nana Probe Tip for Static Behaviors (Abstract Only)",* Abstract for Proceedings of the Eighth Annual International Scientific Meeting on Scanning Mircoscopies, USA, to , (01-Feb-2007)

S. C. Feng, T. V. Vorburger, C. B. Joung, L. Ma, *"Computational Models of the Nano Probe Tip for Static Behaviors",* Journal of Scanning Microscopies, (01-Jun-2007)

S. Fenves, E. Subrahmanian, P. Goyal, J. Angbo, F. Daoud, R. D. Sriram, *"The Architecture Development Facilitator (ADF) First Year Report",* NIST Interagency/Internal Report (NISTIR) 7411, (01-Mar-2007)

X. Fiorentini, I. Gambino, V. C. Liang, S. Foufou, S. Rachuri, M. Mani, C. Bock, *"An Ontology for Assembly Representation",* NIST Interagency/Internal Report (NISTIR) 7436, (01-Jul-2007)

N. Ivezic, P. Snack, *"An Athena Validation Pilot Showcase for Automotive Industry",* AIAG ATHENA Project Newsletter, (01-Jan-2007)

N. Ivezic, B. Kulvatunyou, M. Vujasinovic, P. Snack, Z. Marjanovic, H. Cho, *"Standards-Based Semantic Middleware",* Proceedings of the eChallenges 2007 Conference and Exhibition, The Hague, Netherlands, to , (01-Jul-2007)

S. Jain, C. R. McLean, Y. T. Lee, *"Towards Standards for Integrated Gaming and Simulation for Incident Management",* Proceedings of the 2007 Summer Computer Simulation Conference, USA, to , (01-Jul-2007)

S. Jain, F. H. Riddick, A. Craens, D. Kibira, *"Distributed Simulation for Interoperability Testing Along the Supply Chain",* Proceedings of the 2007 Winter Simulation Conference, USA, to , (01-Jul-2007)

M. Jankovic, N. Ivezic, T. Knothe, Z. Marjanovic, P. Snack, *"A Case Study in Enterprise Modelling for Interoperable Cross-Enterprise Data Exchange",* Proceedings of the 3rd International Conference on Interoperability for Enterprise Software and Applications (IESA '07), USA, to , (01-Feb-2007)

S. Jayaram, U. Jayaram, Y. J. Kim, C. Dechenne, K. W. Lyons, C. Palmer, T. Mitsui, *"Industry Case Studies in the Use of Immersive Virtual Assembly",* Virtual Reality Journal, (01-Apr-2007)

B. Jeong, J. Woo, H. Cho, B. Kulvatunyou, J. Lee, *"A Web Service-Based Reconfigurable Testbed for Business-to-Business (B2B) Integration",* Proceedings of the IEEE International Conference on Web Services, International Conference on Web Services (ICWS), USA, 09/18/2006 to 09/22/2006, (01-Jun-2007)

M. Johansson, S. K. Leong, Y. T. Lee, F. H. Riddick, G. Shao, B. J. Johansson, A. Skoogh, P. Klingstam, *"A Test Implementation of the Core Manufacturing Simulation Data Specification",* Proceedings of the 2007 Winter Simulation Conference, USA, to , (01-Jul-2007)

S. J. Kemmerer, *"NIST Focuses Attention on Clinical Informatics and Healthcare IT Standards",* Health Industry Business Communication Council (HIBCC) quarterly, (01-Feb-2007)

Legend:
R - Refereed
I - Invited

March 20, 2008

FY2008 Publications:

S. C. Feng, S. P. Frechette, "*The State of Container Security Standards*", NIST Interagency/Internal Report (NISTIR) 7153, (17-Oct-2007)

S. C. Feng, C. B. Joung, T. V. Vorburger, "*A Characterization of Probe Dynamic Behaviors in Critical Dimension Atomic Force Microscopy*", Scanning 2008, Gaithersburg, MD, USA, 04/15/2008 to 04/17/2008, 2 pp., (17-Mar-2008)

(R) S. Jain, C. R. McLean, "*Components for an Incident Management Simulation and Gaming Framework and Related Developments* ", Simulation-Transactions of the Society for Modeling and Simulation International, 52 pp., (12-Mar-2008)

R. D. Sriram, A. S. Deshmukh, A. G. Banerjee, S. K. Gupta, "*Content-Based Assembly Search: A Step Towards Assembly Reuse*", To Appear in the Journal of CAD, (07-Nov-2007)

R. Sudarsan, E. Subrahmanian, "*Engineering Informatics: Introduction to the Special Issue*", Special Issue of ASME Journal of Computing and Information Science in Engineering, (31-Jan-2008)

M. Vujasinovic, N. Ivezic, B. Kulvatunyou, E. J. Barkmeyer, M. Missikoff, F. Taglino, Z. Marjanovic, I. Miletic, "*An Industrial Validation of a Semantic Mediation Architecture*", IEEE Internet Computing, (24-Oct-2007)

FY2007 Publications:

E. J. Barkmeyer, P. O. Denno, "*On Capturing Information Requirements in Process Specifications*", Proceedings of the 3rd International Conference on Interoperability for Enterprise Software and Applications (IESA "07), USA, to , (01-Feb-2007)

E. J. Barkmeyer, B. Kulvatunyou, "*An Ontology for the e-Kanban Business Process*", NIST Interagency/Internal Report (NISTIR) 7404, (01-Apr-2007)

C. Bock, "*Interprocess Communication in the Process Specification Language*", NIST Interagency/Internal Report (NISTIR) 7348, (01-Oct-2006)

C. Bock, M. Gruninger, D. Libes, J. Lubell, E. Subrahmanian, "*Evaluating Reasoning Systems*", NIST Interagency/Internal Report (NISTIR) 7310, (01-Jun-2007)

C. Bock, X. Zha, "*Ontological Product Modeling for Collaborative Design*", Advanced Engineering Informatics, (01-Sep-2007)

S. Brockmans, R. Colomb, P. Haase, E. Kendall, E. K. Wallace, G. Xie, "*A Model-Driven Approach for Building OWL DL and OWL Full Ontologies*", Proceedings of the International Semantic Web Conference (ISWC), USA, to , (01-Oct-2006)

P. O. Denno, "*MOSS - Material Off-Shore Sourcing*", Automotive Industry Action Group (AIAG) ActionLine Magazine, (01-Jan-2007)

P. O. Denno, "*Notes on an Information Model for Production Rules*", NIST Interagency/Internal Report (NISTIR) 7363, (01-Oct-2006)

Legend:
R - Refereed
I - Invited

March 20, 2008

S. C. Feng, T. V. Vorburger, C. B. Joung, J. N. Fu, R. G. Dixson, L. Ma, "*Computational Models of the Nana Probe Tip for Static Behaviors (Abstract Only)*", Abstract for Proceedings of the Eighth Annual International Scientific Meeting on Scanning Mircoscopies, USA, to , (01-Feb-2007)

S. C. Feng, T. V. Vorburger, C. B. Joung, L. Ma, "*Computational Models of the Nano Probe Tip for Static Behaviors*", Journal of Scanning Microscopies, (01-Jun-2007)

S. Fenves, E. Subrahmanian, P. Goyal, J. Angbo, F. Daoud, R. D. Sriram, "*The Architecture Development Facilitator (ADF) First Year Report*", NIST Interagency/Internal Report (NISTIR) 7411, (01-Mar-2007)

X. Fiorentini, I. Gambino, V. C. Liang, S. Foufou, S. Rachuri, M. Mani, C. Bock, "*An Ontology for Assembly Representation*", NIST Interagency/Internal Report (NISTIR) 7436, (01-Jul-2007)

N. Ivezic, P. Snack, "*An Athena Validation Pilot Showcase for Automotive Industry*", AIAG ATHENA Project Newsletter, (01-Jan-2007)

N. Ivezic, B. Kulvatunyou, M. Vujasinovic, P. Snack, Z. Marjanovic, H. Cho, "*Standards-Based Semantic Middleware*", Proceedings of the eChallenges 2007 Conference and Exhibition, The Hague, Netherlands, to , (01-Jul-2007)

S. Jain, C. R. McLean, Y. T. Lee, "*Towards Standards for Integrated Gaming and Simulation for Incident Management*", Proceedings of the 2007 Summer Computer Simulation Conference, USA, to , (01-Jul-2007)

S. Jain, F. H. Riddick, A. Craens, D. Kibira, "*Distributed Simulation for Interoperability Testing Along the Supply Chain*", Proceedings of the 2007 Winter Simulation Conference, USA, to , (01-Jul-2007)

M. Jankovic, N. Ivezic, T. Knothe, Z. Marjanovic, P. Snack, "*A Case Study in Enterprise Modelling for Interoperable Cross-Enterprise Data Exchange*", Proceedings of the 3rd International Conference on Interoperability for Enterprise Software and Applications (IESA '07), USA, to , (01-Feb-2007)

S. Jayaram, U. Jayaram, Y. J. Kim, C. Dechenne, K. W. Lyons, C. Palmer, T. Mitsui, "*Industry Case Studies in the Use of Immersive Virtual Assembly*", Virtual Reality Journal, (01-Apr-2007)

B. Jeong, J. Woo, H. Cho, B. Kulvatunyou, J. Lee, "*A Web Service-Based Reconfigurable Testbed for Business-to-Business (B2B) Integration*", Proceedings of the IEEE International Conference on Web Services, International Conference on Web Services (ICWS), USA, 09/18/2006 to 09/22/2006, (01-Jun-2007)

M. Johansson, S. K. Leong, Y. T. Lee, F. H. Riddick, G. Shao, B. J. Johansson, A. Skoogh, P. Klingstam, "*A Test Implementation of the Core Manufacturing Simulation Data Specification*", Proceedings of the 2007 Winter Simulation Conference, USA, to , (01-Jul-2007)

S. J. Kemmerer, "*NIST Focuses Attention on Clinical Informatics and Healthcare IT Standards*", Health Industry Business Communication Council (HIBCC) quarterly, (01-Feb-2007)

Legend:
R - Refereed
I - Invited

March 20, 2008

D. Kibira, C. R. McLean, "*Generic Simulation of Automotive Assembly for Interoperability Testing*", Proceedings of the 2007 Winter Simulation Conference, USA, to , (01-Jul-2007)

J. Kim, M. Pratt, R. G. Iyer, R. D. Sriram, "*Data Exchange of Parametric CAD Models Using ISO 10303-108*", NIST Interagency/Internal Report (NISTIR) 7433, (01-Jul-2007)

J. Kim, M. Pratt, R. G. Iyer, R. D. Sriram, "*Standardized Data Exchange of CAD Models with Design Intent*", Journal of CAD, (01-Sep-2007)

B. Kulvatunyou, J. Kim, "*An Interactive Procedure for Efficient Testing of B2B: A Case in Messaging Service Tests*", 3rd International Conference on Interoperability for Enterprise Software Applications, USA, to , (01-Jan-2007)

B. Kulvatunyou, B. Jeong, D. Lee, H. Cho, "*A Novel Approach to Measuring Structural Similarity Between XML Documents*", Proceedings of the 20th International Conference on Industrial Engineering and Other Applications of Applied Intelligent Systems, USA, to , (01-Apr-2007)

B. Kulvatunyou, J. Durand, J. Woo, M. Martin, "*Testing and Monitoring E-Business Using the Event-Driven Test Scripting Language*", 3rd International Conference on Interoperability for Enterprise Software, USA, to , (01-Jan-2007)

B. Kulvatunyou, J. Jang, B. Jeong, J. Chang, H. Cho, "*Discovering and Integrating Distributed Manufacturing Services with Semantic Manufacturing Capability Profile*", International Journal of Computer Integrated Manufacturing, (01-Apr-2007)

B. Kulvatunyou, N. Ivezic, A. W. Jones, Y. Peng, Z. Ding, R. Pan, Y. Yu, H. Cho, "*A Probabilistic Framework for Semantic Similarity and Ontology Mapping*", Proceedings of the 2007 Industrial Engineering Research Conference, USA, to , (01-Apr-2007)

Y. T. Lee, Y. Luo, "*Machine Shop Information Model Application, Next Step*", NIST Interagency/Internal Report (NISTIR) 7388, (01-Jan-2007)

Y. T. Lee, S. K. Leong, F. H. Riddick, M. Johansson, B. J. Johansson, "*A Pilot Implementation of the Core Manufacturing Simulation Data Information Model*", Proceedings of the Systems Interoperability Standards Organization 2007 Fall Simulation Interoperability Workshop, USA, to , (01-Jul-2007)

D. Libes, T. O'Connell, "*Applying Serious Games to Intelligence Analysis*", Proceedings of the 11th IASTED International Conference on Software Engineering and Apps (SEA 2007), Cambridge, MA, USA, to , (01-Sep-2007)

J. Lubell, S. Rachuri, E. Subrahmanian, W. Regli, "*Long Term Knowledge Retention Workshop Summary*", NIST Interagency/Internal Report (NISTIR) 7386, (01-Jan-2007)

J. Lubell, S. Rachuri, E. Subrahmanian, M. Mani, "*Sustaining Engineering Informatics: Toward Methods and Metrics for Digital Curation*", Proceedings of the 3rd International Digital Curation Conference, Washington, DC, USA, to , (01-Sep-2007)

Legend:
R - Refereed
I - Invited

March 20, 2008

Y. Luo, Y. T. Lee, "*The Interface Development for Machine Shop Simulation*", International Journal of Knowledge Management Studies, Vol. 1:3/4, (01-Oct-2006)

Y. Luo, Y. T. Lee, "*Data Exchange Strategy for Manufacturing Simulation of Shop Floor Information Systems*", International Journal of Manufacturing Technology and Management (IJMTM), (01-Feb-2007)

K. W. Lyons, "*Integration, Interoperability, and Information Management: What are the Key Issues to Nanomanufacturing?*", Proceedings of the SPIE Optics and Photonics NanoScience and Engineering Conference 2007, USA, to , (01-Sep-2007)

C. R. McLean, "*Distributed Simulation - A Necessity or Ivory Tower Research?*", Proceedings of the Winter Simulation Conference 2007, Washington, DC, USA, to 12/01/2007, (01-Aug-2007)

C. R. McLean, S. Jain, F. H. Riddick, Y. T. Lee, "*A Simulation Architecture for Manufacturing Interoperability Testing*", Proceedings of the Summer Computer Simulation Conference '07, San Diego, CA, USA, 07/11/2007 to 07/13/2007, (01-May-2007)

C. R. McLean, Y. T. Lee, S. Jain, "*Integration of Incident Management Simulation-based Training Applications*", Proceedings of the 2007 Fall Simulation Interoperability Workshop (SIW), Orlando, FL, USA, to 09/01/2007, (01-Sep-2007)

C. R. McLean, S. Jain, Y. T. Lee, G. Shao, "*An Integrated Simulation Environment for Incident Management Training*", Proceedings of the Huntsville Simulation Conference (HSC), USA, 10/30/2007 to 11/01/2007, (01-Sep-2007)

C. R. McLean, S. Jain, A. Craens, D. Kibira, "*A Virtual Manufacturing Environment for Interoperability Testing*", Proceedings of the Delft University of Technology Conference, Netherlands, 06/11/2007 to 06/13/2007, (01-May-2007)

I. Miletic, M. Vujasinovic, N. Ivezic, Z. Marjanovic, "*Enabling Semantic Mediation for Business Applications: XML-RDF, RDF-XML and XSD-RDFS Transformations*", Proceedings of the 3rd International Conference on Interoperability for Enterprise Software and Applications (IESA ''07), USA, to , (01-Feb-2007)

E. L. Morse, M. P. Steves, J. C. Scholtz, "*Metrics and Methodologies for Evaluating Technologies for Intelligence Analysts*", Proceedings of the 2005 International Conference on Intelligence Analysis, USA, to , (01-Oct-2006)

I. Novicic, Z. Kokovic, N. Jakovljevic, V. Ljubicic, M. Bacetic, N. Anicic, Z. Marjanovic, N. Ivezic, "*A Case Study in Business Applications Development Using Open Source and Semantic Web Technologies*", Proceedings of the 3rd International Conference on Interoperability for Enterprise Software and Applications (IESA ''07), Conference on Interoperability for Enterprise Software and Applications, Funchal, Madeira Island, Portugal, 03/28/2007 to 03/30/2007, (01-Apr-2007)

S. Rachuri, "*Science based Information Metrology for Engineering Informatics* ", PerMIS '07, Gaithersburg, MD, USA, to , (01-Sep-2007)

S. Rachuri, R. D. Sriram, M. Sarigecili, M. M. Baysal, U. Roy, "*An Evaluation Mechanism for Defining Gaps and Overlaps of Product Information Exchange Standards*", Proceedings of the IMECE '2007 Conference, Seattle, WA, USA, to 11/01/2007,

Legend:
R - Refereed
I - Invited

March 20, 2008

(01-Sep-2007)

G. Shao, C. R. McLean, "*Simulation Prototypes for Incident Management Training*", Proceedings of the Brooks Automation"s 13th Annual Worldwide Symposium, USA, to , (01-Oct-2006)

G. Shao, Y. T. Lee, "*Simulation Modeling of Emergency Response Facility Based on Software Product Line Technology* ", NIST Interagency/Internal Report (NISTIR) 7444, (01-Sep-2007)

E. Subrahmanian, Y. Reich, "*Advancing Problem Definition and Concept Generation for Improved Product Life Cycle Management*", NIST Interagency/Internal Report (NISTIR) 7430, (01-Jul-2007)

P. Szczypinski, R. D. Sriram, P. Sriram, D. Reddy, "*A Model of Deformable Rings for Interpretation of Wireless Capsule Endoscopic Videos*", IEEE Transactions on Medical Imaging, (01-Nov-2006)

FY2006 Publications:

N. Anicic, Z. Marjanovic, N. Ivezic, A. W. Jones, "*Semantic Enterprise Application Integration Standards*", International Journal of Manufacturing Technology and Management (IJMTM), (01-Apr-2006)

A. Biswas, S. Fenves, V. Shapiro, R. D. Sriram, "*Representation of Heterogeneous Material Properties in the Core Product Model*", To appear in Engineering with Computers, (01-Jun-2006)

C. Bock, "*Part-part Relations in an RDF/S and OWL Extension*", Journal of Web Semantics, (01-Sep-2006)

P. O. Denno, N. Ivezic, "*Message Validation with a Semantic Reasoning Tools*", NIST Interagency/Internal Report (NISTIR) 7347, (01-Sep-2006)

L. Deshayes, S. Foufou, M. Gruninger, "*An Ontology Architecture for Standards Integration and Conformance in Manufacturing*", Proceedings of the IDMME 2006, Grenoble, France, 05/17/2006 to 05/19/2006, (01-Jan-2006)

L. Deshayes, L. A. Welsch, M. A. Donmez, R. W. Ivester, D. E. Gilsinn, R. L. Rhorer, E. P. Whitenton, F. Potra, "*Smart Machining Systems: Issues and Research Trends*", Life Cycle Engineering and Sustainable Development, SPRINGER, Edt. D. Brissaud, S. Tichkiewitch, P.Zwolinski, USA, (01-Nov-2005)

A. S. Deshmukh, M. V. Karnik, S. K. Gupta, R. D. Sriram, "*A System for Performing Content-Based Searches on a Database of Mechanical Assemblies*", Proceedings of IMECE2005, 2005 ASME International Mechanical Engineering Congress and Exposition, Orlando, FL, USA, 11/05/2005 to 11/11/2005, (01-Jan-2006)

S. C. Feng, K. A. Stouffer, K. K. Jurrens, "*Manufacturing Planning and Predictive Process Models Integration Using Software Agents*", Advanced Engineering Informatics, Vol. 19, pp. 135-142, (01-Oct-2005)

S. C. Feng, "*Preliminary Design and Manufacturing Planning Integration Using Web-Based Intelligent Agents*", Journal of Intelligent Manufacturing, Vol. 16:4-5, pp. 423-437, (01-Jan-2006)

S. Fenves, S. Foufou, C. Bock, R. D. Sriram, "*CPM: A Core Model for Product Data*", Journal of Computing and Information

Legend:
R - Refereed
I - Invited

March 20, 2008

Science in Engineering, (01-Oct-2005)

N. Ivezic, E. J. Barkmeyer, B. Kulvatunyou, A. W. Jones, P. Snack, Z. Marjanovic, H. Cho, "*A Validation Architecture for Advanced Interoperability Provisioning*", Proceedings of the 2006 e-Challenges Conference, USA, to , (01-Aug-2006)

S. Jain, C. R. McLean, "*An Integrated Gaming and Simulation Architecture for Incident Management Training*", NIST Interagency/Internal Report (NISTIR) 7295, (01-Mar-2006)

S. Jain, C. R. McLean, "*A Concept Prototype for Integrated Gaming and Simulation for Incident Management*", Proceedings of the 2006 Winter Simulation Conference, USA, to , (01-Aug-2006)

S. J. Kemmerer, "*NIST Supply Chain Integration Solutions*", Manufacturing Interoperability Program Supply Chain Brochure, (01-Nov-2005)

B. Kulvatunyou, B. Jeong, H. Cho, N. Ivezic, A. W. Jones, "*Evaluating Suitability for Replacement of an Integrated Software Component*", Proceedings of the Schema Matchmaking and Resource Retrieval Workshop, VLDB Conference, USA, to , (01-Aug-2006)

Y. T. Lee, C. R. McLean, Y. Luo, "*Information Modeling and Model Implementation*", Proceedings of the International Simulation Conference 2006, Palermo, Italy, to , (01-Jan-2006)

S. K. Leong, Y. T. Lee, F. H. Riddick, "*A Core Manufacturing Simulation Data Information Model for Manufacturing Applications*", Proceedings of the Systems Interoperability Standards Organization 2006 Fall Simulation Interoperability Workshop, USA, to , (01-Aug-2006)

M. Li, A. S. Deshmukh, A. W. Jones, "*An Infrastructure to Support Performance Analysis in Complex Systems*", Proceedings of the PERMIS Conference, PerMIS, Gaithersburg, MD, USA, 08/21/2006 to 08/23/2006, (01-Aug-2006)

D. Libes, E. L. Morse, J. C. Scholtz, "*A Study on Search Engine Use by Intelligence Analysts*", 18th IASTED International Conference on Parallel and Distributed Computing Systems, Dallas, TX, USA, 11/13/2006 to 11/15/2006, (01-Sep-2006)

J. Lubell, B. Kulvatunyou, K. C. Morris, B. Harvey, "*Implementing XML Schema Naming and Design Rules*", Proceedings of the Extreme Markup Languages 2006 Conference, USA, to , (01-Jun-2006)

L. Obrst, L. Hughes, S. R. Ray, "*Prospects and Possibilities for Ontology Evaluation: The View from NCOR*", Proceedings of the 4th International EON Workshop - Evaluation of Ontologies for the Web, USA, to , (01-Apr-2006)

L. Obrst, P. Cassidy, S. R. Ray, B. Smith, D. Soergel, M. West, P. Yim, "*The 2006 Upper Ontology Summit Joint Communique*", To appear in the Applied Ontology Journal, (01-Jun-2006)

L. Obrst, B. Ashpole, W. Ceusters, M. Mani, S. R. Ray, B. Smith, "*The Evaluation of Ontologies*", Semantic Web: Revolutionizing Knowledge Discovery in the Life Sciences, Springer, USA, (01-Aug-2006)

L. Patil, R. D. Sriram, "*Ontology Formalization of Product Semantics for Product Lifecycle Management*", NIST

Legend:
R - Refereed
I - Invited

March 20, 2008

Interagency/Internal Report (NISTIR) 7274, (01-Nov-2005)

S. Rachuri, S. Foufou, S. J. Kemmerer, "*Analysis of Standards for Lifecycle Management of Systems for US Army --- a preliminary investigation*", NIST Interagency/Internal Report (NISTIR) 7339, (01-Aug-2006)

S. R. Ray, A. W. Jones, "*Manufacturing Interoperability*", Special Issue of JIM - Journal of Intelligent Manufacturing (International Scientific Journal), Vol. 17, No. 6, pp. 681-688, (01-May-2006)

G. Shao, C. R. McLean, S. K. Leong, "*User Interface of Simulation of the Shipbuilding Operations*", NIST Interagency/Internal Report (NISTIR) 7320, (01-Jun-2006)

R. D. Sriram, S. Szykman, D. Durham, "*Special Issue on Collaborative Engineering*", To appear in the Journal of Computing and Information Science in Engineering (JCISE), (01-Jun-2006)

R. D. Sriram, "*Artificial Intelligence in Engineering: Personal Reflections*", Editorial to appear in Advanced Engineering Informatics, (01-Jan-2006)

E. Subrahmanian, S. Rachuri, A. Bouras, S. Fenves, S. Foufou, R. D. Sriram, "*The Role of Standards in Product Lifecycle Management Support*", NIST Interagency/Internal Report (NISTIR) 7289, (01-Jan-2006)

J. Woo, H. Cho, B. Kulvatunyou, "*Allocation of Manufacturers through Internet-based Collaboration for Distributed Process Planning*", International Journal of Production Research, (01-Aug-2006)

X. Zha, R. D. Sriram, "*Knowledge-Intensive Collaborative Decision Support for Design Process*", Intelligent Decision-Making Support Systems (i-DMSS): Foundations, Applications and Challenges, Springer-Verlag, USA, (01-Oct-2005)

X. Zha, R. D. Sriram, "*Feature Technology and Ontology for Embedded System Design and Development*", Proceedings of the DETC 2006 ASME Design Engineering Technical Conference, Philadelphia, PA, USA, to , (01-Aug-2006)

X. Zha, R. D. Sriram, "*Platform-based Product Design and Development: A Knowledge Intensive Support Approach*", Journal of Knowledge-based Systems, (01-Aug-2006)

X. Zha, S. Fenves, R. D. Sriram, "*A Feature-Based Approach to Embedded System Hardware and Software Co-Design*", Proceedings of the DETC 2005 ASME Design Engineering Technical Conference, Long Beach, CA, USA, 09/24/2005 to 09/28/2005, (01-Dec-2005)

FY2005 Publications:

N. Anicic, N. Ivezic, A. W. Jones, "*An Architecture for Semantic Enterprise Application Integration Standards*", Interoperability of Enterprise Software and Applications, Springer, Edited by D. Konstantas, J.P. Bourrieres, and M. Leonard, USA, (01-Apr-2005)

M. M. Baysal, U. Roy, S. Rachuri, R. D. Sriram, K. W. Lyons, "*Product Information Exchange Using Open Assembly Model: Issues Related to Representation of Geometric Information*", Proceedings of the 2005 ASME International Mechanical

Legend:
R - Refereed
I - Invited

March 20, 2008

Engineering Congress and Exposition, IMECE 2005, Orlando, FL, USA, 11/05/2005 to 11/11/2005, (01-Aug-2005)

C. Bock, L. J. Carnahan, S. Fenves, M. Gruninger, V. Kashyap, B. B. Lide, J. G. Nell, R. S. Raman, R. D. Sriram, "*Healthcare Strategic Focus Area: Clinical Informatics*", NIST Interagency/Internal Report (NISTIR) 7263, (01-Sep-2005)

C. Bock, "*UML 2 Activity and Action Models, Part 6: Structured Activities*", Journal of Object Technology, Vol. 4:4, pp. 43-66, (01-Apr-2005)

C. Bock, M. Gruninger, "*Messaging in the Process Specification Language*", NIST Interagency/Internal Report (NISTIR) 7258, (01-Sep-2005)

C. Bock, "*SysML and UML 2 Support for Activity Modeling*", Journal of the International Council on Systems Engineering, Vol. 9:2, pp. 160-186, (01-Jun-2005)

C. Bock, "*UML 2 Composition Model*", Journal of Object Technology, Vol. 3:10, pp. 47-73, (01-Oct-2004)

C. Dartigues, P. Ghodous, M. Gruninger, D. Pallez, R. D. Sriram, "*CAD/CAPP Integration using Feature Ontology*", Journal of CAD, (01-Jan-2005)

L. Deshayes, L. A. Welsch, M. A. Donmez, R. W. Ivester, D. E. Gilsinn, R. L. Rhorer, E. P. Whitenton, F. Potra, "*Smart Machining Systems: Issues and Research Trends*", Proceedings of the 12th CIRP Seminar on Life Cycle Engineering, Grenoble, France, to , (01-Jan-2005)

L. Deshayes, J. L. Evans, R. W. Ivester, D. G. Bhat, S. A. Batzer, "*Mechanical and Thermal Behavior for Machining TI-6AI-4V with AIMgB^d14^ and WC-CO Tools*", Proceedings of the IMECE 2005 Conference, Orlando, FL, USA, 11/05/2005 to 11/11/2005, (01-Aug-2005)

J. L. Evans, L. Deshayes, D. G. Bhat, S. A. Batzer, "*A Failure Analysis of an Experimental AIMgB14 Cutting Tools*", Proceedings of the Microscopy and Microanalysis 2005, Microscopy and Microanalysis 2005, Honolulu, HI, USA, 07/31/2005 to 08/04/2005, (01-Jan-2005)

S. C. Feng, H. Helaakoski, H. Haapasalo, J. Kipina, "*Software Agents-Enabled Systems Coalition for Integrated Manufacturing Processes and Supply Chain Management*", International Journal of Manufacturing Technology and Management - Special Issue on Modeling and Optimization of Supplier-based Manufacturing and Management, (01-Jan-2005)

S. Fenves, S. Foufou, C. Bock, N. Bouillon, R. D. Sriram, "*CPM 2: A Revised Core Product Model for Representing Design Information*", NIST Interagency/Internal Report (NISTIR) 7185, (01-Jan-2005)

S. Foufou, S. Fenves, C. Bock, S. Rachuri, R. D. Sriram, "*A Core Product Model for PLM with an Illustrative XML Implementation*", Proceedings of the International Conference on PLM, Lyons, France, to , (01-Mar-2005)

P. Goyal, "*An XML Schema Naming Assister for Elements and Types*", NIST Interagency/Internal Report (NISTIR) 7143, (01-Oct-2004)

Legend:
R - Refereed
I - Invited

March 20, 2008

M. Gruninger, J. Kopena, "*Semantic Integration through Invariants*", AI Magazine, Vol. 26: 1, pp. 11-20, (01-Sep-2005)

N. Ivezic, N. Anicic, A. W. Jones, Z. Marjanovic, "*Towards Semantic-Based Supply Chain Integration*", Proceedings of the IFIP 5.7 Advances in Production Management Systems Conference, Rockville, MD, USA, 09/18/2005 to 09/21/2005, (01-Jul-2005)

S. Jain, C. R. McLean, "*Integrated Simulation and Gaming Architecture for Incident Management Training*", Proceedings of the 2005 Winter Simulation Conference, USA, to , (01-Sep-2005)

S. Jain, S. K. Leong, "*Stress Testing a Supply Chain Using Simulation*", Proceedings of the 2005 Winter Simulation Conference, USA, to , (01-Aug-2005)

A. W. Jones, A. S. Deshmukh, "*Test Beds for Complex Systems*", Special Issue of Communications of the ACM on Complex Adaptive Enterprises, (01-Jan-2005)

S. J. Kemmerer, "*Exchanging Technical Product Data, The Story of ISO TC 184/SC4*", NSF NSDL/CODATA Workshop on International Scientific Data, Standards and Digital Libraries, Denver, CO, USA, 06/10/2005 to 06/11/2005, (01-Jun-2005)

R. A. Kirsch, "*What We Learned From Building and Using the First Computer*", NIST Colloquium Series, USA, (01-Dec-2004)

R. A. Kirsch, "*Standards Electronic Automatic Computer (SEAC)*", NIST Interagency/Internal Report (NISTIR) 1005, (01-Nov-2004)

B. Kulvatunyou, N. Ivezic, A. W. Jones, "*Content-Level Conformance Testing: An Information Mapping Case Study*", Proceedings of the Testcom 2005 Conference, Montreal , Canada, to , (01-Mar-2005)

B. Kulvatunyou, K. C. Morris, "*XML Schema Design Quality Test Requirements*", NIST Interagency/Internal Report (NISTIR) 7175, (01-Oct-2004)

Y. T. Lee, Y. Luo, "*Data Transfer Strategy for Machine Shop Simulation*", NIST Interagency/Internal Report (NISTIR) 7239, (01-Jul-2005)

Y. T. Lee, Y. Luo, "*Data Exchange for Machine Shop Simulation*", Proceedings of the 2005 Winter Simulation Conference, USA, to , (01-Jul-2005)

Y. T. Lee, Y. Luo, G. Shao, "*Prototype Implementation Based on the Machine Shop Information Model*", Proceedings of the 2005 IFIP5.7 Conference, Rockville, MD, USA, 09/18/2005 to 09/21/2005, (01-Jul-2005)

D. Liu, J. Peng, K. Law, G. Wiederhold, R. D. Sriram, "*Composition of Engineering Web Services with Distributed Data Flows and Computations*", ACM Transactions on Internet Technology Journal, (01-Apr-2005)

J. Lubell, B. Kulvatunyou, "*A Tool Kit for Implementing XML Schema Naming and Design Rules*", Proceedings of XML 2005,

Legend:
R - Refereed
I - Invited

March 20, 2008

USA, to , (01-Sep-2005)

Y. Luo, Y. T. Lee, "*Application of Machine Shop Data Model in Manufacturing Simulation*", Proceedings of the 2005 International Conference on Modeling, Simulation and Visualization Methods (MSV 05), USA, 06/27/2005 to 06/30/2005, (01-May-2005)

C. R. McLean, Y. T. Lee, G. Shao, F. H. Riddick, "*Shop Data Model and Interface Specification*", NIST Interagency/Internal Report (NISTIR) 7198, (01-Jan-2005)

C. R. McLean, F. H. Riddick, Y. T. Lee, "*An Architecture and Interfaces for Distributed Manufacturing Simulation*", Special Issue of the Transactions of the Society for Modelling and Simulation International on Applications of Parallel and Distributed Simulation in Industry, (01-Nov-2004)

C. R. McLean, S. Jain, Y. T. Lee, F. H. Riddick, "*A Simulation and Gaming Architecture for Manufacturing Research, Testing, and Training*", NIST Interagency/Internal Report (NISTIR) 7256, (01-Sep-2005)

P. Meade, L. C. Rabelo, A. W. Jones, "*Applications of Chaos and Complexity Theories to the Technology Adoption Life Cycle*", International Journal of Technology Management, (01-Jul-2005)

K. C. Morris, B. Kulvatunyou, S. P. Frechette, J. Lubell, P. Goyal, "*XML Schema Validation Process for CORE.GOV*", NIST Interagency/Internal Report (NISTIR) 7187, (01-Dec-2004)

L. Patil, D. Dutta, R. D. Sriram, "*Ontology-based Exchange of Product Data Semantics*", IEEE Transactions on Automation Science and Engineering, (01-Mar-2005)

S. Rachuri, M. M. Baysal, U. Roy, S. Foufou, C. Bock, S. Fenves, E. Subrahmanian, K. W. Lyons, R. D. Sriram, "*Information Models for Product Representation: Core and Assembly Models*", International Journal of Product Development, (01-Mar-2005)

S. Rachuri, Y. H. Han, S. Foufou, S. C. Feng, U. Roy, F. Wang, R. D. Sriram, K. W. Lyons, "*Assembly Model Representation from Conceptual to the Detailed Design*", Journal of Computing and Information Science in Engineering, (01-Mar-2005)

S. Rachuri, M. M. Baysal, U. Roy, S. Foufou, S. Fenves, E. Subrahmanian, K. W. Lyons, R. D. Sriram, C. Bock, "*Information Models for Product Representation: Core and Assembly Models*", NIST Interagency/Internal Report (NISTIR) 7173, (01-Dec-2004)

J. A. Ramirez-hernandez, H. Li, E. Fernandez, C. R. McLean, S. K. Leong, "*A Framework for Standard Modular Simulation: Application to Semiconductor Wafer Fabrication*", NIST Interagency/Internal Report (NISTIR) 7236, (01-Jun-2005)

V. Ravichandran, R. D. Sriram, "*Toward Data Standards for Proteomics Data*", Nature Biotechnology Journal, (01-Mar-2005)

G. Shao, C. R. McLean, S. K. Leong, "*A Simulation System with Neutral Data Interface for Shipbuilding Operation*", Proceedings of the Industrial Simulation Conference, USA, to , (01-May-2005)

Legend:
R - Refereed
I - Invited

March 20, 2008

Y. J. Son, B. Kulvatunyou, H. Cho, S. C. Feng, "*A Semantic Web Service and Simulation Framework to Intelligent Distributed Manufacturing*", Proceedings of the 2005 ASME International Mechanical Engineering Congress and Exposition, USA, to , (01-Sep-2005)

E. Subrahmanian, S. Rachuri, S. Fenves, S. Foufou, R. D. Sriram, "*Challenges in Supporting Product Design and Manufacturing in a Networked Economy: A PLM Perspective*", Proceedings of the International Conference on Product Lifecycle Managment - PLM 05, USA, to , (01-Mar-2005)

E. Subrahmanian, S. Rachuri, S. Fenves, S. Foufou, R. D. Sriram, "*Product Lifecycle Management Support: A Challenge in Supporting Product Design and Manufacturing in a Networked Economy*", NIST Interagency/Internal Report (NISTIR) 7211, (01-Mar-2005)

R. Tongia, E. Subrahmanian, V. Arunachalam, "*Information and Communications Technology for Sustainable Development: Defining a Global Research Agenda*", Allied Publishers, Bangalore, USA, (01-Sep-2005)

S. Umeda, S. Jain, "*Integrated Supply Chain Simulation System (ISSS) -- Modeling Requirements and Design Issues*", NIST Interagency/Internal Report (NISTIR) 7180, (01-Oct-2004)

K. Verspoor, O. Bodenreider, P. Karp, H. Kelly, S. Loranger, M. Musen, R. D. Sriram, C. Wroe, C. Joslyn, J. Ambrosiano, "*Knowledge Integration for Bio-Threat Response*", Los Alamos Technical Report, LA-UR-05-0907, USA, to , (01-Sep-2005)

C. Xu, S. K. Gupta, Z. Yao, M. Gruninger, R. D. Sriram, "*Toward Computer-Aided Conceptual Design of Mechatronic Devices with Multiple Interaction-States*", Proceedings of 2005 ASME Design Engineering Technical Conference, Long Beach, CA, USA, 09/24/2005 to 09/28/2005, (01-May-2005)

X. Zha, R. D. Sriram, "*Distributed Modeling and Framework for Collaborative Embedded System Design*", Proceedings of the DETC '2005 ASME Design Engineering Technical Conference, Long Beach, CA, USA, to , (01-Jul-2005)

X. Zha, R. D. Sriram, M. G. Fernandez, F. Mistree, "*Knowledge-Intensive Collaborative Decision Support for Design Process, Part 1: A Hybrid Decision Model and Multi-Agent Framework*", Journal of Mechanical Design, (01-Jul-2005)

X. Zha, S. Foufou, S. Rachuri, R. D. Sriram, "*Analysis and Evaluation for STEP-Based Electro-Mechanical Assemblies*", Journal of Computing and Information Science, (01-Aug-2005)

X. Zha, R. D. Sriram, "*Feature-Based Component Model for Design of Embedded Systems*", Proceedings of the 2004 SPIE''s International Symposium on Optics East, Conference on Intelligent Systems in Design and Manufacturing VI (OE111), Philadelphia, PA, USA, 10/25/2004 to 10/28/2004, (01-Nov-2004)

X. Zha, R. D. Sriram, S. K. Gupta, "*Information and Knowledge Modeling for Computer Supported Micro Electro-Mechanical Systems Design and Development*", Proceedings of the DETC '2005 ASME Design Engineering Technical Conference, Long Beach, CA, USA, 09/24/2005 to 09/28/2005, (01-Jul-2005)

Legend:
R - Refereed
I - Invited