The Inspection Workstation-based Testbed Application for the Intelligent Systems Architecture for Manufacturing

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Abstract

A reference model control architecture is being developed to support the development and implementation of intelligent control systems for manufacturing. This paper presents some background on the project , a discussion of the approach being used and a description of the initial implementation testbed.

Introduction

The High Performance Computing and Communications (HPCC) Program was formally established following passage of the High Performance Computing Act of 1991. The Systems Integration for Manufacturing Applications (SIMA) program activity is one activity under the Information Infrastructure Technology and Applications (IITA) component of the HPCC Program. Since 1994, the SIMA program has partially funded work on the development of a standard reference model architecture for the control of complex, intelligent systems. This effort builds on earlier related work in several projects at the National Institute of Standards and Technology (NIST) dating back to the early 1980s and leverages current efforts in other programs.

In particular, the NIST efforts have included developing the Real-time Control System (RCS) architecture [1] , Manufacturing Systems Integration (MSI) architecture [2] and the Quality in Automation (QIA) architecture [3]. Each of these was developed with specific attention given to different areas of application in the manufacturing domain. For example, while RCS primarily focused on real-time control issues in machine tools, robots, autonomous and teleoperated vehicles, underwater vehicles, mining machines, cranes and others, MSI focused on manufacturing activities above the shop floor. At the same time, application of QIA concepts focused on problems of in-process and process-intermittent inspection on machine tools.

The reference model control architecture developed under this project includes important concepts from these efforts, as well as the resolution of architectural issues where

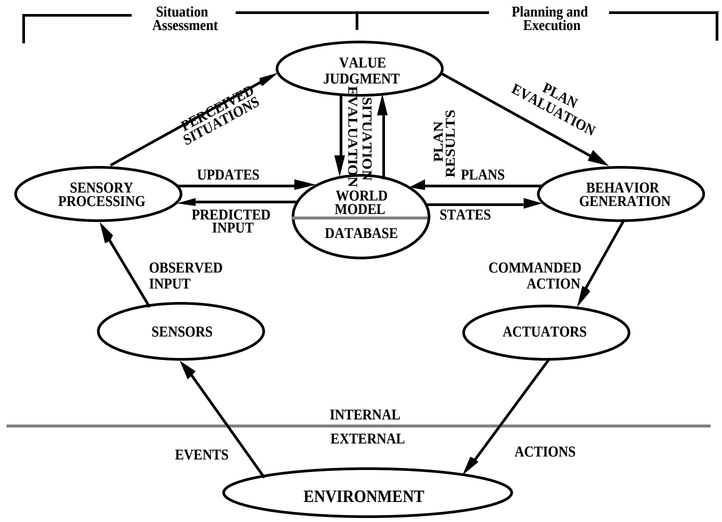

Figure 1. Components of an Intelligent System

differences exist. This reference model is the Intelligent Systems Architecture for Manufacturing (ISAM). Figure 1 is a high-level, conceptual view of an ISAM control node.

ISAM is a reference model architecture for intelligent manufacturing systems. It is intended to provide a theoretical framework for developing standards and performance measures for intelligent manufacturing systems, as well as engineering guidelines for the design and implementation of intelligent control systems for a wide variety of manufacturing applications. A draft ISAM document has been prepared. ISAM is intended to anticipate the future needs of industry.

The implementation of a testbed to evaluate the applicability of the reference architecture is currently under way. The testbed development leverages the work of several industry/government consortia. This ensures attention to current industry issues. These relationships are described briefly in the Approach section below.

The primary goals of this project are, 1) to develop a detailed design of the NIST Reference Model Architecture for intelligent control of manufacturing processes and 2) to demonstrate, validate, and evaluate the NIST Reference Model Architecture through analysis and performance measurements of a simulated and prototype implementation.

These objectives address the NIST Manufacturing Engineering Laboratory (MEL) goals of providing U.S. industry with state-of-the-art manufacturing architectures and models, fostering the development and implementation of advanced manufacturing systems and anticipating and addressing the needs of U.S. manufacturing industry for the next generation of advanced manufacturing systems and standards.

Approach

The approach is to proceed with the reference model design, while simultaneously choosing and developing a testbed. Results of the architectural design effort are currently captured in various documents referenced here. It is intended that a single ISAM specification document will serve as an overarching guide, providing background and theory, as well as the reference model itself.

At this point, enough of the architecture has been defined to warrant evaluation in a testbed implementation. The initial implementation was chosen to be a Coordinate Measuring Machine (CMM)-based Inspection Workstation (IWS) at NIST. Choice of this facility permits this project to take advantage of capabilities in advanced inspection currently being developed there under the Next Generation Inspection System (NGIS) [4] program. That project's use of vision and scanning probe technologies provides a sensory rich environment for testing aspects of the architecture. This workstation is also a test node in the Computer Integrated Manufacturing (CIM) Framework Project [5]. As such, it operates in NIST's National Advanced Manufacturing Testbed (NAMT). Ultimately, the reference model architecture will be tested with this workstation and other simulated and implemented factory components. Another key element of the approach is to leverage the work of the DOE Technologies Enabling Agile Manufacturing (TEAM) programs [6] in message API definitions and Enhanced Machine Controllers (EMC) [7].

The development approach includes parallel activity areas. Several important ones are described next.

Generic Control Module Shell

Figure 1 represents concepts of control that are present in each control node. An implementation contains many such nodes arranged in a hierarchy. This effort is to define a software structure, interface definitions and task frame specifications that permit this core control node model to be standardized to the extent possible. As such, the software organization and development support for the Behavior Generation, World Modeling, Value Judgment and Sensor Processing components of a control node and their interfaces are being examined and developed.

The initial implementation employs a set of standard C++ software templates that simplify node development. These were derived from earlier versions of templates used in an EMC open architecture control system for machine tool control developed by NIST and installed for evaluation at GM Powertrain.

Application Design for Prototype System Implementations

The Inspection Workstation was chosen as the initial implementation, in part, because of the complexity of the control issues and richness of its sensor suite, including vision. Through the joint efforts of RCS, MSI, QIA and NGIS experts, a draft scenario for the activities of the IWS that can exercise the architecture in important ways has been written. First, a list of capabilities that will sufficiently exercise the architecture was generated. Activities that required these capabilities were then included in the scenario.

These capabilities include, on-line task planning, processing and handling errors, explicit quality loops, advanced human interaction, interface with legacy software and hardware, simulation, design, plan and production data interface, administrative functions, learning, multiple simultaneous tasks per node, and interaction between CAD and sensed features.

The scenario identifies visible activities and data exchanges that reflect characteristics of typical inspection activities determined through various factory visits. A subset of the activities is being used for an initial implementation in September 1996.

The scenario serves as an indispensable starting point in the implementation design. From this point, task descriptions and task trees, control node hierarchies and state representations for all tasks for each intended testbed mission have been developed. Part of this effort is the continued interaction and collaboration with software tool vendors that produce products that may be adapted to assist control system developers in this phase of implementation.

Leveraging EMC Technologies

In addition to providing the baseline control module templates, the EMC program has also provided additions to the template structure to support Neutral Manufacturing Language (NML) communications interfaces, an API specification, a development environment with version control and source check-in and check-out mechanisms, operator interfaces, and advanced control system diagnostic capabilities.

Leveraging DOE TEAM Message Definition Efforts

The Intelligent Closed Loop Processing (ICLP) activity of TEAM is defining a set of message APIs for manufacturing. A member of the Reference Model Architecture project team actively participates in that effort and applies and extends applicable results to the APIs used in the IWS testbed implementation. These specifications support communication between control nodes.

Planning

Planning at an ISAM node is conducted in the Behavior Generation module. An extensive study of planning/scheduling algorithms has been performed and performance experiments have been conducted. Further work to develop standard interfaces to planners, plan simulators and evaluators, and schedulers is needed. These interfaces are to be tested in the IWS testbed. Issues in discrete event planning are also being examined under a university grant.

Feature-based Control

Initial developments in feature-based machining are being extended to the inspection domain. The method will employ solid models in STEP form and use STEP tools where possible.

World Modeling/CAD

This effort seeks to formalize world modeling definition within the generic template and to design possible API access for world model information. Experiments are planned for integration of product data and CAD API's with inspection controller code. This work will also include developing Knowledge Base entities of ISAM which include task frames, command frames, plans, algorithms and resources.

Operator Interfaces

The operator interface work has included integration of EMC operator interface technologies and integration of a contractor supplied diagnostic tool. This work also includes the analysis of operator interface specification requirements with respect to the ISAM Generic Control Module and World Model and MSI Guardian. Longer term developments are expected to include remote access capabilities via developments under the SIMA Operator Interface project.

Prototype Development and Implementation

The development sequence for the initial prototype employs the existing RCS-based control systems for the control of the CMM motion and Vision systems. These were developed under the NGIS program. New higher levels of control are introduced at the Task and Workstation levels. These first test control nodes are being extended from initial EMC-based versions. This configuration will provide a working testbed for initial evaluation. Over time, the remaining nodes will be made consistent with ISAM concepts. More

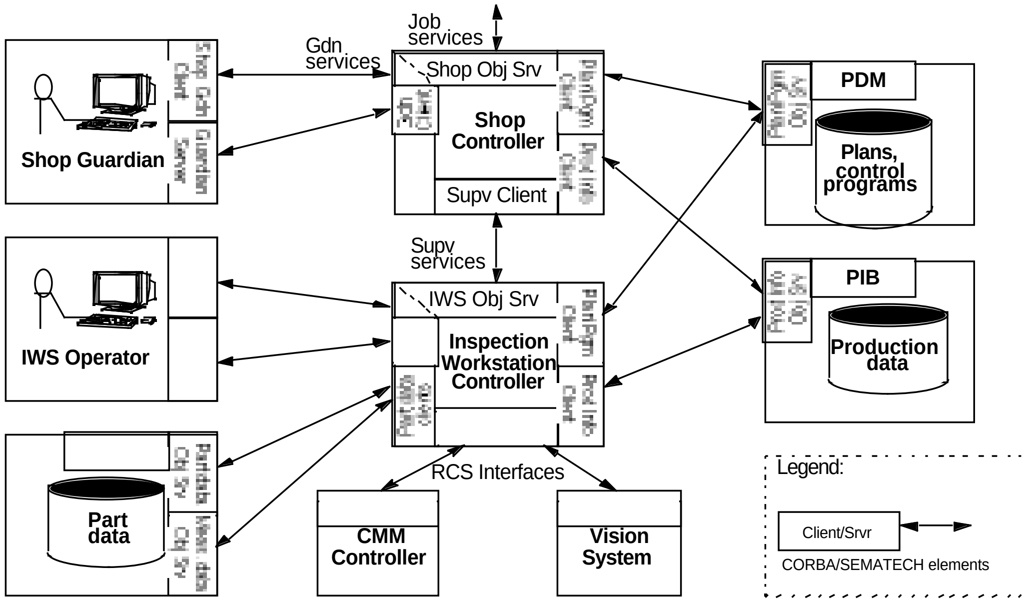

Figure 2. NAMT Framework FY96

implementation details are provided in the following section.

As mentioned earlier, the IWS testbed is a node in the NAMT. A portion of the NAMT is being used to study integration issues within the NAMT CIM Framework project. The IWS testbed is a part of that effort. Figure 2 shows the Framework project system configuration for FY96, including the IWS. Among other things, the Framework project is studying issues which are derived from experiments with the SEMATECH CIM Framework and implementation issues related to use of CORBA.

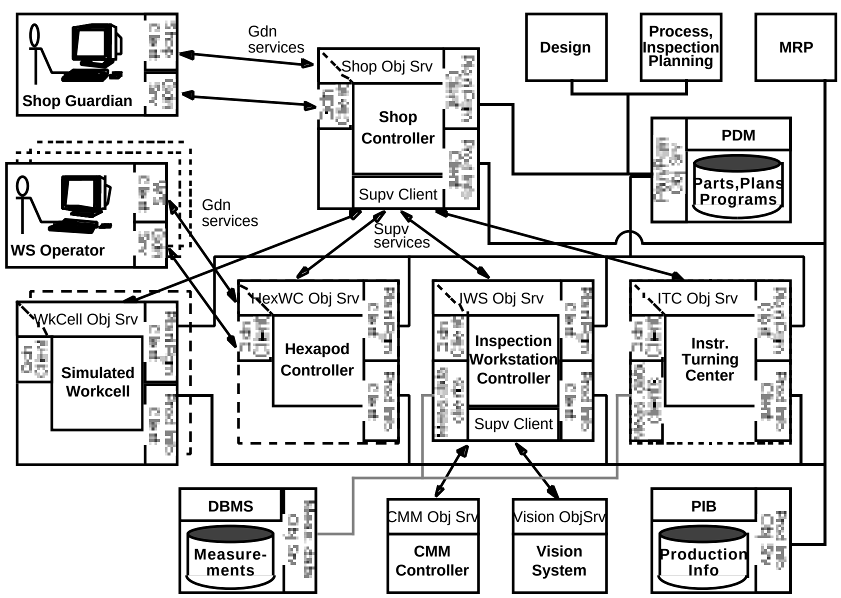

Figure 3. NAMT Framework FY97

The NAMT plan for FY97 builds on this initial testbed and adds additional workstations and services. This provides a more complex testbed that can be used in refining the ISAM Reference Model. Figure 3 depicts a possible configuration for FY97.

The IWS Implementation

The previous diagrams provided an overview of the configuration of the NAMT and the role of the IWS. We now focus more specifically on the IWS and its near term configuration.

Figure 4 illustrates the control nodes and their interfaces for the FY96 implementation. The Primitive (Prim) and Servo levels handle low level motion control. These levels and the Elemental move (Emove) level were adopted from the NGIS implementation. The Emove level was further developed to handle the command set provided by the DMIS interpreter. DMIS is a language for specifying inspection plans. Note that the emove level contains nodes for both CMM motion control and for tool changing. The tool changing activities are performed by a human who responds to the commands and indicates the status to close the control loop.

The Task level contains control nodes to support the measurement subsystem and the fixturing subsystem of the workstation. The Task level Measurement node coordinates the CMM tool changing and motion activities. This node also is responsible for interpretation of the DMIS

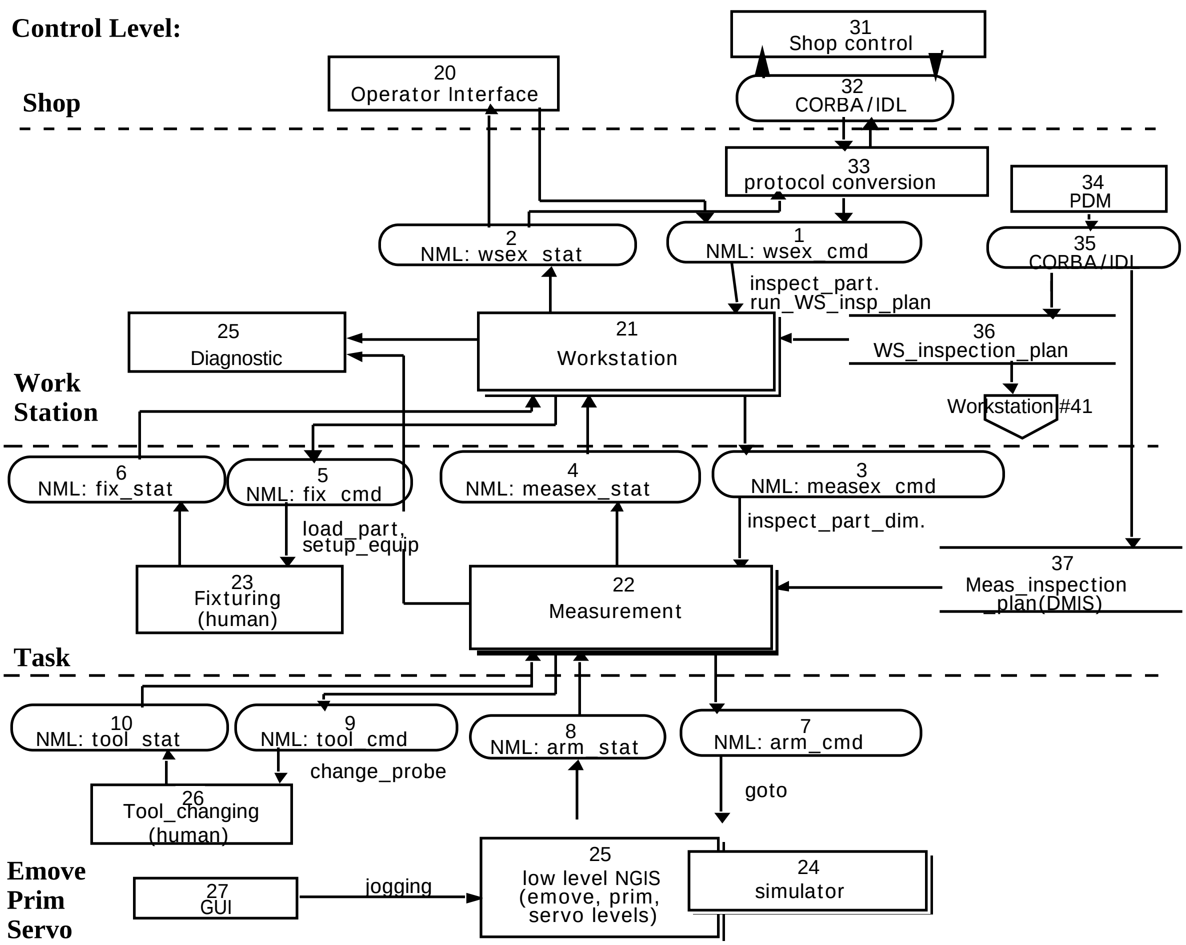

Figure 4. IWS Control Node Hierarchy

inspection plan. The Fixturing node handles loading, unloading, and refixturing parts. In this implementation, these are executed by a human.

The Workstation level control node accepts jobs from the Shop level and coordinates the activities of the Measurement and Fixturing nodes to carry out the job on a particular part lot via a Workstation level plan.

The Shop level obtains orders and develops the jobs for the workstation based on these orders.

A hierarchy of control that supports integrated vision and inspection activities nodes is also operational. Integration of these capabilities into this testbed will occur after the development of the initial implementation described here.

The Workstation node, Task-Measurement node, Task Fixturing node and Emove-Tool Change node employ the generic control module template extended from EMC. Control node communication is supported by NML at the workstation level and below as Figure 4 indicates. A diagnostic tool that permits a display of the hierarchy and other information in real-time for control nodes employing the generic control module template has been developed by Advanced Technologies Research Corporation (ATR).

As part of the NAMT Framework project, communication between the Shop and Workstation and between the Workstation and Task-Measurement nodes and the Production Data Base (PDM) are being implemented using CORBA.

Figure 5 shows the hardware configuration for the FY96 testbed implementation. It illustrates the computing hardware and the mapping of the control nodes previously described into the hardware. Also shown is the physical configuration of the communications connections, via ethernet or shared memory mechanisms. (Bit 3 is a commercial product used to provide shared memory-like communication between backplanes.) Items indicated in parenthesis are part of the existing NGIS configuration, but not used in the initial FY96 implementation described here. They are required for support of the vision system and various inspection probes and their interfaces.

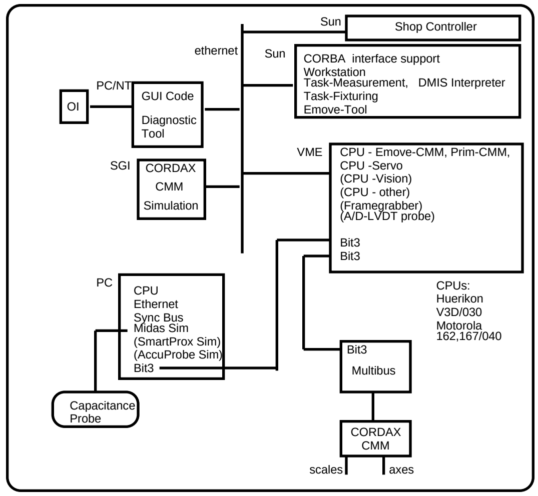

Figure 5. Hardware Configuration

References

1. Albus, J.S., Meystel, A. M., "A Reference Architecture for Design and Implementation of Intelligent Control in Large Complex Systems," International Journal of Intelligent Control and Systems, Vol. 1, No. 1 (1996) 15-30.

2. Wallace, S., Senehi, M.K., Barkmeyer, E., Luce, M., Ray, S., Wallace, E., "Control Entity Interface Specification," NISTIR 5272, September 1993.

3. "Progress Report of the Quality in Automation Project for FY90," Edited by Domnez, M. A., NISTIR 4536, March 1991.

4. Nashman, M., Hong, T., Rippey, W. G., Herman, M., "An Integrated Vision Touch-Probe System for Inspection Tasks", Machine Vision Applications, Cleveland, Ohio, June 1996.

5. Bloom, H. M., Christopher, N., "A Framework for Distributed and Virtual Discrete Part Manufacturing, to be published in the proceedings of CALS EXPO 96, October 1996, Long Beach, CA.

6. Technologies Enabling Agile Manufacturing (TEAM) Application Programming Interfaces, web location http://isd.cme.nist.gov/info/team

7. Proctor, F. M., Michaloski, J., "Enhanced Machine Controller Architecture Overview," NISTIR 5331, December 1993.