Proceedings of ASME 2012 International Design Engineering Technical Conferences &
Computers and Information in Engineering Conference
IDETC/CIE 2012
August 12–15, 2012, Chicago, IL, U.S.A.

DETC2012-71133

WEB-ENABLED REAL-TIME QUALITY FEEDBACK FOR FACTORY SYSTEMS USING MTCONNECT

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ABSTRACT

Quality is a key element to success for any manufacturer, and the fundamental prerequisite for quality is measurement. In the discrete parts industry, quality is attained through inspection of parts but typically there is a long latency between machining, quality measurement, and part/process assessment. Since manufacturing systems are by their nature imperfect, it is imperative to identify and rectify out-of-tolerance processes as soon as possible. Rapid quality feedback into the factory operation is not a complex concept, however, the collection and dissemination of the necessary measurement data in a timely and tightly integrated manner is challenging. This paper discusses web-enabled, real-time quality data based on the integration of MTConnect and quality measurement reporting data. MTConnect is an open factory communication standard that leverages the Internet and uses XML for data representation. The quality data is represented in MTConnect as XML to represent Geometric Dimensioning and Tolerancing (GD&T) output results. A pilot implementation to produce web-enabled, real-time quality results in a standard MTConnect XML representation from Coordinate Measuring Machine (CMM) inspections will be discussed.

Keywords

MTConnect, inspection, quality assurance, tolerance, manufacturing

Nomenclature

API	Application Programming Interface
CMM	Coordinate Measuring Machine
CNC	Computer Numerical Control
COM	Component Object Model
DOM	Document Object Model
GD&T	Geometric Dimensioning and Tolerancing
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
MTC	Manufacturing Technology Connect
OEE	Overall Equipment Effectiveness
REST	REpresentational State Transfer
SPC	Statistical Process Control
XML	eXtensible Markup Language
XPATH	XML Path Language
XSD	XML Schema Definition

INTRODUCTION

Quality of a product may be defined as “its ability to fulfill the customer’s needs and expectations” [1]. Clearly, no manufacturing process can make a perfect part; therefore, designers must specify the acceptable variations to determine whether an actual part is a “good” part. Hence, quality is defined in terms of performance requirements, which vary from product to product. For discrete parts, the primary performance requirements, commonly referred to as characteristics, are dimension (e.g., length, diameter, thickness, or area), geometric tolerances (e.g., flatness, cylindricity, etc.), and appearance (e.g., surface finish, color, or texture). To ensure overall quality, delivered parts must meet the required quality characteristics. Thus, part quality is measured by its conformance to the performance requirements.

Since uncontrolled machining process variability can hinder manufacturers in their effort to maintain acceptable part quality, inspection is used to provide insight and visibility to potential production problems so that they can be rectified in a timely manner. The result of unacceptable process quality is defective parts quality that leads to increased costs to the manufacturer due to reworking or waste. The longer inspection feedback takes to be integrated into the production chain, the more vulnerable the resulting quality analysis is to solving antiquated problems negatively impacting production yield. Real-time inspection results characterizing the manufactured parts and reported in an easily-accessible, standardized format can lead to better and more optimized performance of the manufacturing processes.

In order to guarantee quality, manufacturers should use real-time knowledge garnered from ongoing and continuous collection and evaluation of factory-floor inspection data. In discrete parts manufacturing, factory quality monitoring has been difficult, due primarily to closed, proprietary automation equipment that make potential analysis difficult. Recently, there has been interest in applying the web-based, data acquisition concepts of the MTConnect standard to the real-time acquisition of quality data. MTConnect is an open, free specification aimed at overcoming the "Islands of Automation" quandary on the shop floor. Broad industry support has resulted in the development of cost-effective tools for factory floor data acquisition, process measurement, and production analysis. With fact-based analysis, manufacturers can improve production to become lean, efficient, and effective.

The focus of this paper will be on the use of MTConnect to provide web-enabled real-time XML communication of inspection OEE and quality results. In conjunction with this goal, the implementation of a prototype web-based real-time implementation was done using a Coordinate Measuring Machine on a shop-floor with inspection planning and measurement capabilities. However, the same principles to implement web-enabled real-time quality results for CMMs could be used for any number of physical inspection systems such as CNC, laser, optical and digital measurement devices, or hand held devices. The purpose of this pilot project was to validate web-based real-time quality paradigm using MTConnect and explore the potential benefits from such an implementation. The implementation scope was end-to-end – from on-machine part inspection to web-based client access of the measurement results, and included implementations for all the subsystems.

The second section gives a brief overview of MTConnect and the extensions to the MTConnect information model to implement real-time quality reporting. The third section describes the implementation of the web-based real-time quality data on a shop floor machine tool. The final section contains a discussion on the benefits of web-based real-time quality data as well as the problems encountered developing real-time quality feedback and the future work envisioned in this area.

MTCONNECT OVERVIEW

In order to reduce costs, increase interoperability, and maximize enterprise-level integration, the MTConnect specification has been developed for the manufacturing industry. MTConnect is a specification based upon prevalent Web technology including XML [2] and HTTP [3]. MTConnect uses the Web "REST" model interface [4], basically a "connectionless" interface in which an Agent only services single requests, and it is the responsibility of the client application to maintain any session information. Using prevailing technology and providing free software development kits minimize the technical and economic barriers to MTConnect adoption.

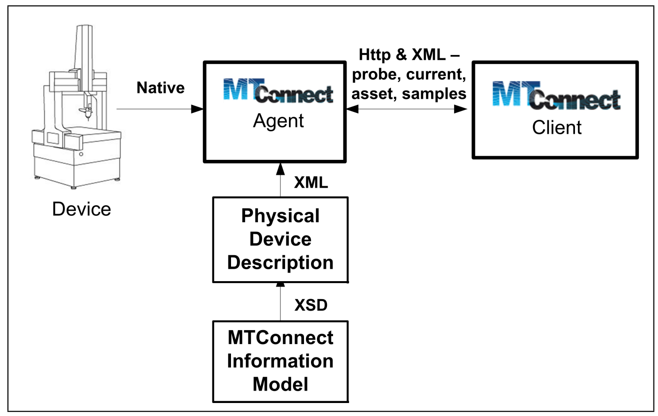


FIGURE 1. MTCONNECT OVERVIEW

Figure 1 shows the basic system architecture of the MTConnect specification, and includes the following concepts:

Client – is typically a factory application, such as shop floor dashboard visualization, OEE, and data mining of asset and process knowledge.

Agent – acts much like a Web Server that acts as an intermediary between a Device and a Client. The MTConnect Agent receives and stores single or a time series of data samples or events from the device. Clients use HTTP to communicate four basic requests to the MTConnect Agent:

- "Probe" provides the configuration of the device data items,
- "Current" gives a snapshot of the device's data items' most recent values, or
- "Sample" provides historical range of values for samples, events, or conditions stored within the device.
- "Asset" provides data about more unvarying items associated with the device for a limited period of time, such as, parts, tools, and fixtures. Such assets would not generally have any controller of their own, and would be managed by another device.

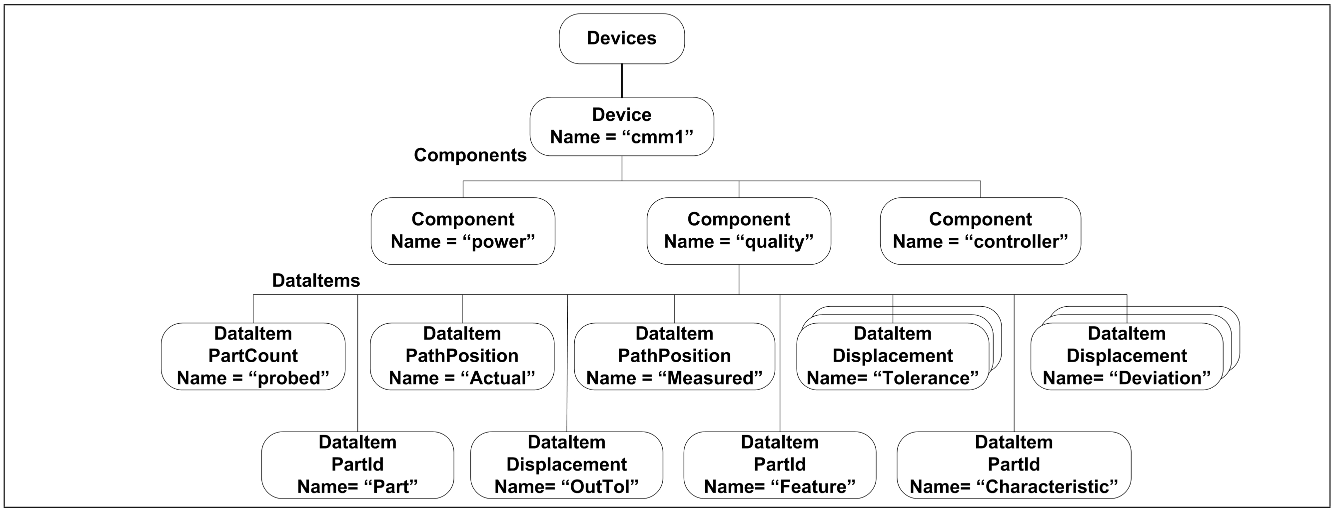


FIGURE 2. MTConnect Quality Data Items

Device – is a piece of factory equipment organized as a set of components that provide data.

Physical Device Data Model – provides the Device(s) description that the world will see, which will be typically a subset of the total possible data from a CNC. It is expressed in an XSD provided by MTConnect. Clients use a "probe" command to read this device configuration.

Information Model – is an XSD information model that describes the entirety of permissible device "Data items and mobile "Assets". The information is flexible in that some new data items can be established. This capability is used to prototype the quality measurement data.

MTConnect models a device as a set of components with constituent data items. Initially the MTConnect specification is targeted at machine tools and their constituent components – axes, power, controller, and control sequencing. In this information model structure, one or more devices contain a series of components, of some Component type: controller, linear axis, rotary axis, etc. Each component then has event or sample Data Item definitions. MTConnect further provides XML attributes in which to help refine the Device information models. Such XML attributes include Category, Name, Type, Subtype, and Units.

Overall, an MTConnect Device model is not hardwired; rather users assemble an XML information model to match their devices. MTConnect allows independent development of versions, with new extensions coexisting with legacy functionality. From [5], "MTConnect data items are self-describing and messages carry a protocol version number, and extensions can be added to MTConnect without jeopardizing backwards compatibility; principals that do not understand the extensions can safely ignore them." For example, in previous work, we were able to add a "PartCount" DataItem, which at the time was not explicitly part of the MTConnect specification, without any trouble [6]. Since the MTConnect model is flexible, it is possible to construct a series of measurement samples and events in order to do quality reporting which will be explored next.

MTCONNECT QUALITY MODEL

Previous work explored the use of the QMResults XML scheme within MTConnect as an "asset", and established that a thorough and more exhaustive approach is possible [7]. However, the goal of this MTConnect quality data effort is to provide a mechanism to report measurement data generated from one or more inspections in as lightweight and concise a means as possible. This has appeal for MTConnect client customers who require quality dashboard information with less software development and maintenance, and faster turnaround on potential quality control issues.

As part of the factory continuum, quality results are outputs from a measurement device that must be managed in the context of overall factory operation. Obviously, when a CMM is down, no measurement results are possible. The asset management of the CMM is an important first step in understanding quality results. In this context, the definition of asset management is to capture the current status of factory equipment using plant communication for the effective administration of devices and systems for automation and control [8]. The key performance indicator for asset management is termed the Overall Equipment Effectiveness (OEE), and the tags in MTConnect that make this possible include: power(on/off), mode (auto, manual), execution(running, ready), and conditions.

The next step for information modeling of quality must deal with the measurement results themselves. Quality results are reported by measurement software, and require their own MTCon-

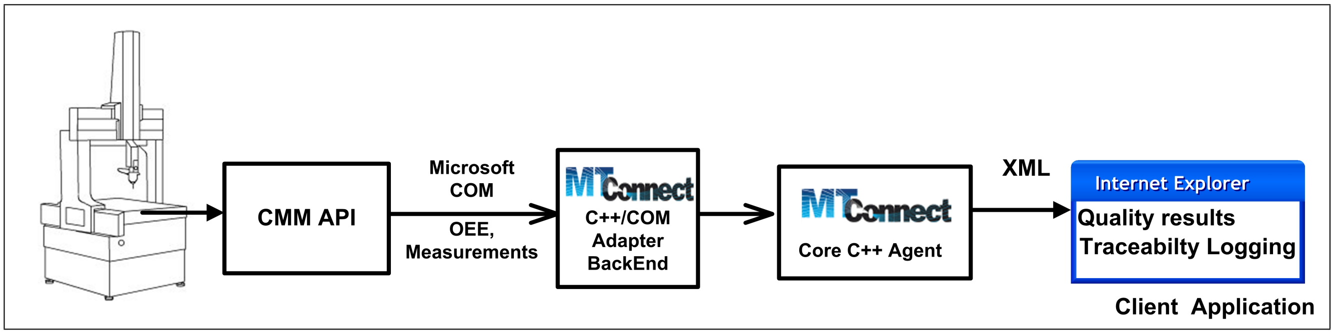


FIGURE 3. Real-time web-enabled Quality Prototype

nect tags (i.e., either Event or Sample data.) In general, inspection results consist of information for parts, features, characteristics, and measurement data. The two primary quality modeling concepts of interest for web-based Real–time quality feedback are features and characteristics. In quality, features are defined to be parametric shapes associated with attributes such as intrinsic geometric parameters (length, width, depth, etc.), position and orientation, geometric tolerances, material properties, and references to other features [9]. Characteristics are an attribute of a material, process, or part (includes assemblies) whose variation within the specified tolerance has a significant influence on product fit, performance, service life, or manufacturability. For example, a hole can be expressed with geometric design data for the hole location, diameter, and depth. A hole can also be associated with GD&T data to ascribe the tolerance of the hole location, diameter, and depth as well as relationships to other features.

To model our quality feedback, characteristics are indicated by the nominal feature setpoint with a tolerance specified by two limits (maximum and minimum), between which the nominal point lies. Example characteristics are X, Y, Z, or diameter setpoints. The nominal point is then measured, which produces an actual point and a deviation from the nominal setpoint. If there are multiple measurements on the same point, maximum and minimum deviations from the setpoint are provided. Based on the measurement, the out-of-tolerance value of the measurement is positive if the deviation exceeds the tolerance or zero if within tolerance. The list below shows the mapping of the measurement information model into MTConnect:

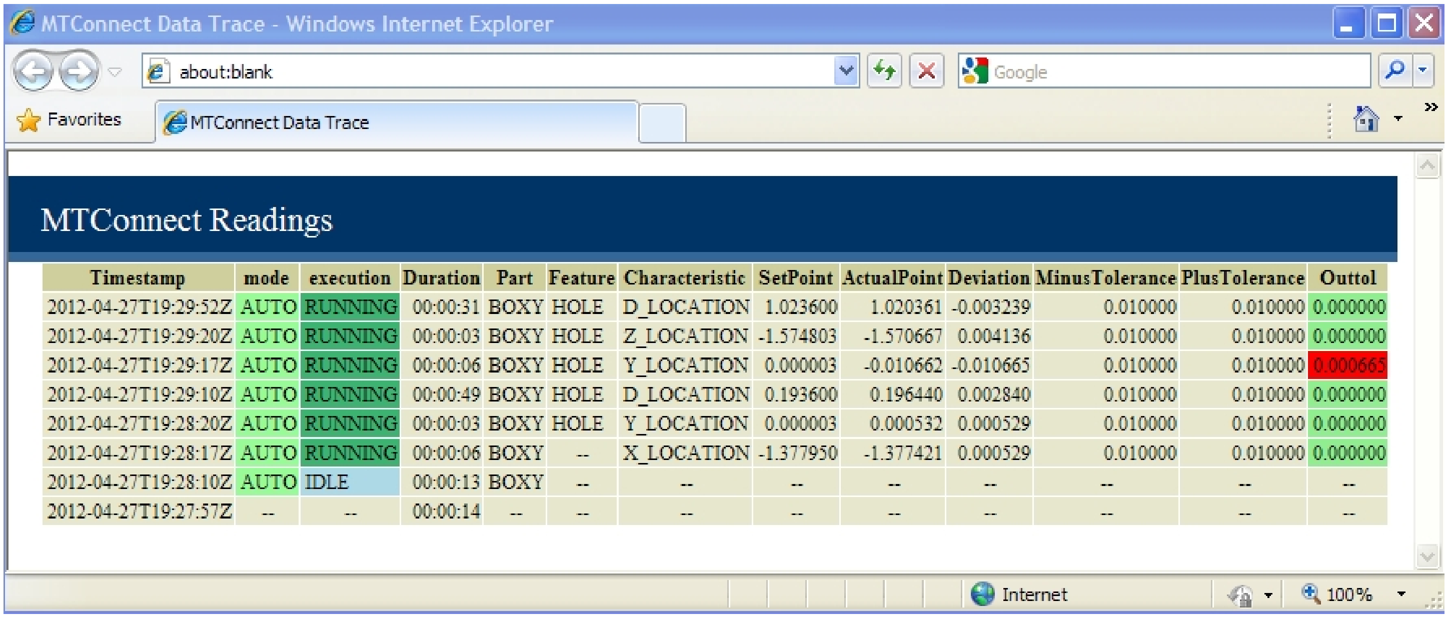
Probed – Event to signal a probing operation has completed
SetPoint– Setpoint to measure, if any
ActualPoint – Probing actual measurement
Tolerance – Tolerance (assume +/-) amount or use Plus/MinusTolerance
PlusTolerance – Plus tolerance amount
MinusTolerance – Minus tolerance amount
Deviation – Deviation of measurement (assume max) or use Min/MaxDeviation
Outtol – Out-of-tolerance amount, zero if within tolerance
Characteristic – Characteristic measurement type: will be enumeration- point (x,y,z,etc), diameter, flatness, perpendicularity, etc.
Feature – Associated feature to be probed.
Part – Name of the part being measured.

The MTConnect implementation of this measurement information model can vary depending on the desired level of quality feedback. For example, for a part with multiple features, MTConnect can provide all the features and associated tolerance characteristics information or can provide a single part OutTol reading based on all the underlying feature/characteristic measurements.

PROTOTYPE IMPLEMENTATION

Currently, production knowledge is often only gathered at a higher level of operation. Workorders enter the shop floor and then overall part quality and yield is evaluated retrospectively upon completion. Typically, shop floor quality knowledge may require manually documenting the inspection results. Analysis of process quality and the associated costs involved are then generally estimated. For our initial quality measurement prototype, we concentrated on understanding the inspection process on a simple part with multiple features and characteristics that were deliberately constrained by over–tolerancing to understand out–of–tolerance conditions.

Figure 3 shows the system architecture of the various components that were used to implement the web-enabled, real-time quality CMM feedback. The implementation used a CMM inspection system that also has a multi-directional (3D) touch-trigger probe to perform the part inspections. The CMM provides measuring capabilities for various part features (i.e., point, hole, shaft, slot, inside/outside rectangle, boss, and surface) and characteristics (e.g., position, diameter, straightness). For each inspection program, the inputs include a nominal setpoint value, an inspection characteristic, and upper and lower tolerance limits as measurement parameters. For example, to measure a hole, the center of a hole is set as reference setpoint. The probe is then



Timestamp	mode	execution	Duration	Part	Feature	Characteristic	SetPoint	ActualPoint	Deviation	MinusTolerance	PlusTolerance	Outtol
2012-04-27T19:29:52Z	AUTO	RUNNING	00:00:31	BOXY	HOLE	D_LOCATION	1.023600	1.020361	-0.003239	0.010000	0.010000	0.000000
2012-04-27T19:29:20Z	AUTO	RUNNING	00:00:03	BOXY	HOLE	Z_LOCATION	-1.574803	-1.570667	0.004136	0.010000	0.010000	0.000000
2012-04-27T19:29:17Z	AUTO	RUNNING	00:00:06	BOXY	HOLE	Y_LOCATION	0.000003	-0.010662	-0.010665	0.010000	0.010000	0.000665
2012-04-27T19:29:10Z	AUTO	RUNNING	00:00:49	BOXY	HOLE	D_LOCATION	0.193600	0.196440	0.002840	0.010000	0.010000	0.000000
2012-04-27T19:28:20Z	AUTO	RUNNING	00:00:03	BOXY	HOLE	Y_LOCATION	0.000003	0.000532	0.000529	0.010000	0.010000	0.000000
2012-04-27T19:28:17Z	AUTO	RUNNING	00:00:06	BOXY	--	X_LOCATION	-1.377950	-1.377421	0.000529	0.010000	0.010000	0.000000
2012-04-27T19:28:10Z	AUTO	IDLE	00:00:13	BOXY	--	--	--	--	--	--	--	--
2012-04-27T19:27:57Z	--	--	00:00:14	--	--	--	--	--	--	--	--	--

FIGURE 4. Quality Results Client Sample Display

positioned at approximately the center of the hole for measuring hole center setpoints and diameter. The measurement cycle moves the probe to sample four points on the inner surface of the hole. After the probing, the CMM control system outputs the actual measured feature value, and the dimensional differences.

To allow web-enabled, real-time feedback, the CMM was connected to the Internet via MTConnect technology. The MTConnect Institute provides an open-source C++ Agent implementation that was used off-the-shelf to integrate the various software components. The bulk of the effort was to develop an MTConnect Adapter to communicate with the both the CMM controller to retrieve measurement results and the MTConnect Agent. In our case, the CMM controller supported Microsoft Component Object Model (COM) API, but it could be any open-architecture communication technology. The MTConnect Back-end used synchronous communication 1) to cyclically read the CMM status variables in order to update the MTConnect data, and 2) to receive a notification when the inspection program was done and had posted measurement results. The MTConnect Back-end then posted the measurement-related data based on cycling through the program dimensional measuring operations and retrieving the tolerance definition and the quality results.

Data visualization of quality results in a time-line fashion can help analyze and compare the data to the expected outcome. Intuitive and useful visualization of web-enabled, real-time, quality results would help in understanding the association between quality events and production, and form the basis for more immediate responsiveness to problems. Equally as important an outcome of web-enabled real-time quality is the simplification of the process for archiving the data with mainstream information technology (IT) tools. In this manner, traceability and reporting can be accomplished which will allow more sophisticated analysis, such as SPC, discrete event simulation, and data mining, to be used.

The client software is a C++ application that monitors for new inspection results by reading the XML returned from the MTConnect Agent attached to the CMM by using HTTP to query the agent's Internet Protocol (IP) address. The client application leverages the Microsoft Web Browser COM component embedded in Internet Explorer, which handles the parsing and rendering of HTML documents. Using the Web Browser component, the client application then uses the XML Document Object Model (DOM) to integrate a periodic live update of an HTML table built as a worksheet of color-coded inspection results. In general, clients can simply use XML DOM and XPATH alone to parse the relevant XML which provides a lightweight but powerful programming paradigm.

Figure 4 shows a simple display interpreting the ongoing quality results from the CMM that is inspecting the holes on the "Boxy" part. The spreadsheet displayed in Internet Explorer shows the progression of the inspection. At the bottom, the spreadsheet shows an empty row, that signifies that the CMM is "Down". Next, the execution tag becomes "Idle", and the part tag is "Boxy" signifying that the CMM is ready to inspect the "Boxy" part. Next, the CMM is "Running", measuring the part. Then a sequence of quality outputs is displayed, with one row having an "Outtol" value greater than zero. Finally, the CMM goes off-line again, and the execution tag is "Idle".

The user is provided on-line quality results that are continuously being updated in real–time. By using automated technology, manufacturers can better handle quality by removing error-prone manual operations, formalizing quality procedures, and simplifying quality results archiving for ongoing qualitative analysis. Parts may be rejected but now with more timely notification of the feature defect(s) and, more importantly, poor quality trends; production problems can be identified faster and more easily. A significant amount of time and money can be saved by harnessing the power of immediacy in the production process.

Of note, since MTConnect is a REST communication paradigm, simple client polling may not be sufficient for data acquisition. Under many real-time circumstances pure polling could be a problem, as the client could miss data if the polling cycle time is too slow in comparison to the CMM update rate. However, as a part of the "sample" methodology of saving historical data, MTConnect provides a sequence number mechanism to allow the tracking of historical data. In our prototype, the Feature/Characteristics quality data was being output from the CMM in a burst mode, that is, when the inspection program was complete, all the measurements were output within one second. A simple client polling would miss portions of quality data. However, because the underlying CMM data was being thoroughly tracked and logged into the MTConnect Agent, a complete historical trace was available to the Client using sequence numbers to retrieve the entire quality data stream.

DISCUSSION

The use of MTConnect eases the integration of quality results into production processes through its use of prevalent Internet communication technologies. A web-based real–time quality feedback system will help in improving production since informative, accurate, and timely production knowledge is considered vital to lean manufacturing. If manual inspection exists, replacing it with reporting by the automated MTConnect recording system will lead to easier and more complete tracking of quality data while reducing the frequency of reporting errors. Moreover, with an automated process, operators are able to spend less time on non-value added reporting activities and more on productivity-oriented tasks.

The use of in-or-out of tolerance CMM inspection feedback in a quality dashboard offers many benefits, but still requires manual human interpretation. It would be preferable to provide a greater level of automated interpretation of the quality feedback within the production to improve manufacturing. Because the use of a CMM to measure parts introduces latency between machining and quality assessment, the application of Statistical Process Control (SPC) can take a longitudinal view of the data to improve process quality. SPC uses statistical techniques to analyze data and maintain a state of acceptable statistical variance, and when out of variance, to take appropriate actions to improve the process. SPC, in combination with MTConnect, can provide valuable real-time performance indicators of the manufacturing process, such as, trending, shifting, and out of control measures [10]. For example, if a part with a hole feature has a diameter that is trending towards a minimum allowable deviation, then tool wear may be involved. The use of SPC is not trivial. Interpreting the SPC would require mapping the part feature (i.e., hole) and characteristic (i.e., diameter) deviations to a production process (e.g., drilling hole) and determining appropriate preventive or remedial action. Thus, trending and shifting variability can be monitored but must be associated to particular features and machining operations, which require additional part knowledge, i.e., part program with not only quality data but machine, feature operation, and tooling descriptions that are often not available.

In summary, proactive use of web-based, real-time quality information in manufacturing production is feasible, cost-effective, and helpful. MTConnect provides a straightforward factory integration paradigm. From experience with MTConnect, we found that XML provides a convenient format for transferring the contents of data to and from remote clients, as it is easily viewable in any web browser (e.g., Firefox, Internet Explorer, or Chrome). MTConnect was easily able to provide real-time shop floor measurement data to help understand quality issues. Given our experience with the underlying CMM open architecture (i.e., Microsoft COM), the MTConnect quality data acquisition was deployed in a matter of weeks. With our work, we felt that the MTConnect specification makes real-time web-enabled quality data feasible by lowering the cost of data acquisition, and by increasing the productivity and usability of such services. By lowering the barriers to and maintaining the proper commitment toward continuous process improvement, manufacturers can routinely implement real-time quality control in their factory.

ACKNOWLEDGMENTS

The authors would like to thank Shawn Moylan of NIST; and Gen Lin and Leta Holt of Hexagon for their help in making this effort successful.

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