Title:

Improving Machine Tool Interoperability Using Standardized Interface Protocols: MT Connect

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Publication Date:

06-23-2008

Series:

Green Manufacturing Group

Publication Info:

Green Manufacturing Group, Laboratory for Manufacturing and Sustainability, UC Berkeley

Additional Info:

Vijayaraghavan A., Sobel W., Fox A., Warndorf P., D. Dornfeld "Improving Machine Tool Interoperability using Standardized Interface Protocols: MTConnect(TM)", Submitted to International Symposium on Flexible Automation, 2008

Keywords:

MT Connect, Interoperability, XML Schema, Green Manufacturing

Abstract:

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Proceedings of 2008 ISFA
2008 International Symposium on Flexible Automation
Atlanta, GA, USA June 23-26, 2008

IMPROVING MACHINE TOOL INTEROPERABILITY USING STANDARDIZED INTERFACE PROTOCOLS: MTCONNECT™

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ABSTRACT

This paper introduces MTConnect™ [1], a data exchange standard that allows for disparate entities in a manufacturing system along with their associated devices to share data seamlessly in a common format. MTConnect™ aims to provide a common means for communication between these varied devices, and is not creating special purpose hardware or software for this purpose. This paper also presents a case-study of using MTConnect™ data from a machine tool for process planning verification. The potential of improved machine-tool interoperability through MTConnect™ is also discussed, with an emphasis on enabling "green manufacturing" through better interoperability.

INTRODUCTION

The creation of a seamless "manufacturing pipeline" from design to production has long been a goal of many industries. The development of digital factory concepts connecting the product and process designer to shop floor/equipment/operation level data and feedback for simulation, optimization and control is moving closer to reality [2]. While there has been extensive work in developing "islands" of technology in areas such as tool design, tool path planning, process parameter optimization, cutting force prediction, and expert systems, the challenge lies in connecting them seamlessly [3, 4].

Moreover, a typical manufacturing facility has hundreds or thousands of machines and independent systems operating in consortia to ensure a product is manufactured in a timely, quality and cost-effective manner. Each of these machines and systems accumulates information on its operation and, usually, is unable to communicate it to anyone or anything else. While this may not always be the case, but overall, it is difficult to communicate information and process data among these machines and system. As a result, coordination, optimization or data tracking to insure the machine, factory or system is operating at an acceptable level (think machine efficiency, process flow, energy usage, toolpath validation, etc.) is very difficult [5].

There is a need for standardized interfaces for machine tools and other manufacturing equipment, bringing tight integration and interoperability. This provides two main benefits, first, the improvements from the technology "islands" can be fully realized, and secondly, communication between and to machine tools can happen in a common language.

In this paper we introduce MTConnect™ [1], a data exchange standard that allows for disparate entities in a manufacturing system and their associated embedded devices to share data seamlessly and in a common format. MTConnect™ aims to provide a common means for communication between these varied devices and is not creating hardware or special purpose software to link machines and systems together. MTConnect™ is designing an open communication standard for interconnectability, which allows devices, equipment, and systems to output data in an understandable format that can be read by any other device using the format. The standard, MTConnect™, is based on XML (Extensible Markup Language), which offers widely recognized and accepted flexible representation for exchanging semi-structured machine-readable data. The standard will be open and free to insure the widest possible acceptance and utility. This approach allows connectivity from the lowest end of the process chain, nearest the workpiece or shop floor, to the highest design or process-planning tool. Additionally, the interoperability afforded by MTConnect™ will enable a host of third party solution providers to develop software and hardware to make the entire manufacturing enterprise more productive. Figure 1 shows a "big picture" schematic detailing the integration of a manufacturing system using MTConnect™ for both intra- and inter-system interoperability.

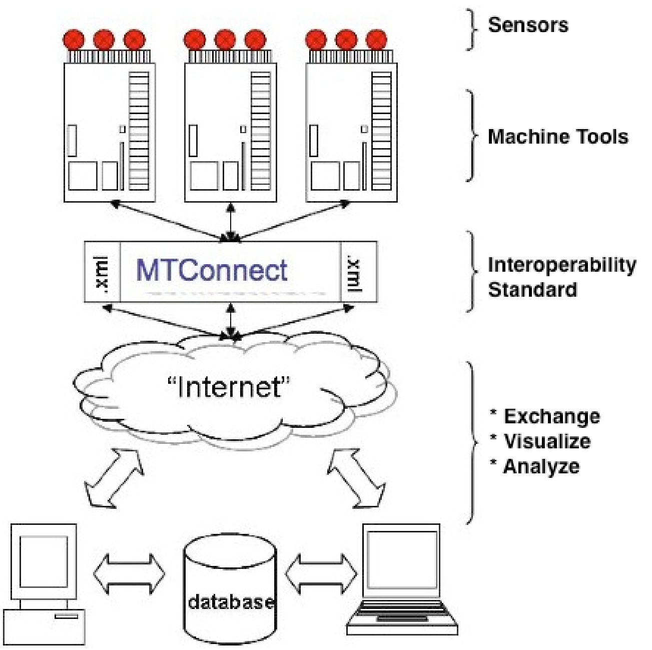

Figure 1: Integration of Manufacturing System using MTConnect™

Given the importance of interoperability standards in the manufacturing industry, several have been proposed and are in development to address this issue. The most significant of these are IPC-CAMX [6], OPC [7], and STEP/STEP-NC [8]. These standards take a more comprehensive view of the problem of enabling communication between "smart machines". MTConnect™ does not aim to replace them, and instead serves two important roles relative to them. Firstly, it facilitates basic communication between the entities of a manufacturing system by standardizing a simple communication protocol, and acts as an enabler for the higher-level standards. Secondly, it provides a lightweight alternative for simple deployments when a more comprehensive standard is not required. MTConnect™ is designed to be quick to deploy and is easy to retrofit to existing equipment. The "business logic" of the manufacturing system is also not coded into MTConnect™ unlike in some of the other standards, and hence it can be flexibly deployed in a variety of situations.

The next section discusses MTConnect™ in more detail. This is followed by a case study of applying MTConnect™ in achieving better integration between machine tool operation and CAD/CAM process planning. We conclude with discussions on the future potential of MTConnect™, especially in the domain of "green" or sustainable manufacturing.

WHAT IS MTCONNECT™

MTConnect™ is a standard based on an open protocol for data integration, not data transmission or data use. It is not intended to replace the functionality of existing products, but it strives to enhance the data acquisition capabilities of devices and applications and move toward a plug-and-play environment to reduce the cost of integration. Figure 2 shows a schematic of a factory system with MTConnect™ integration. Legacy tools can also participate in this system by communicating via an MTConnect™ agent.

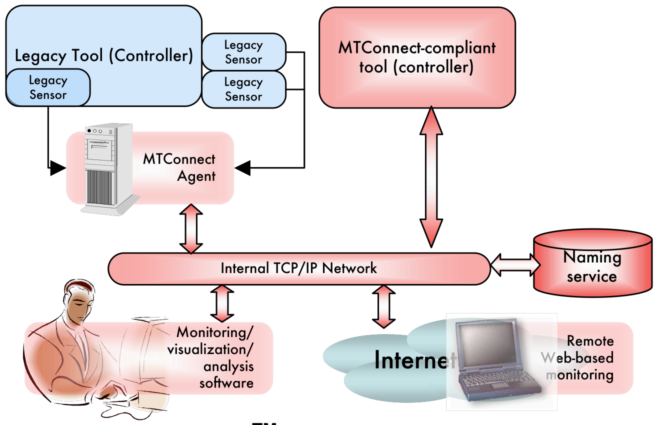

Figure 2: MTConnect™ -compliant as well as legacy equipment are connected to each other, to onsite data monitoring, and to offsite analysis tools (via the Internet), all using open protocols and technologies.

MTConnect™ is built upon the most prevalent standards in the manufacturing and software industry, which maximizes the number of tools available for its implementation and provides a high level of interoperability with other standards and tools in these industries.

To facilitate this level of interoperability, a number of objectives are being met. Foremost is the ability to transfer data via a standard protocol, which includes:

- Device identity (i.e. model number, serial number, calibration data, etc.)
- Identity of all the independent components of the device

- Device's design characteristics (i.e. axis length, maximum speeds, device thresholds, etc.)
- Data occurring in real or near real-time (i.e. current speed, position data, temperature data, program block, etc.) by a device that can be utilized by other devices or application (i.e. utilized by maintenance diagnostic systems, management production information systems, CAM products, etc.,)

The types of data that can be addressed in MTConnect™ includes:

- Physical and actual device design data
- Measurement or calibration data
- Near-real-time data from the device

With the vast amount of different types of devices and information that may come into play, MTConnect™ will provide a common high-level vocabulary and structure. The first version of MTConnect™ will focus on a limited set of the characteristics mentioned above, selected based on their ability to have an immediate impact on the efficiency of operations.

XML-Based Schema

MTConnect™ is an XML-based standard and messages are encoded using XML (eXtensible Markup Language), a streamlined descendant of SGML (Standard Generalized Markup Language) that was used for decades as a portable way of specifying data interchange formats [9]. A machine-readable XML schema defines the format of MTConnect™ messages and how the data items within those messages are represented.

Since MTConnect™ data items are self-describing and messages carry a protocol version number, extensions can be added to MTConnect™ or custom data messages can be created for a specific scenario without jeopardizing backwards compatibility; principals that do not understand the extensions safely ignore them.

An added benefit of XML is that it is a hierarchical representation, and this is exploited by setting up the hierarchy of the MTConnect™ schema to resemble the hierarchy of a conventional machine tool. Thus the schema itself functions as a metaphor for the machine tool and makes the parsing and encoding of messages intuitive. The hierarchical representation also allows related data items to be grouped together. For example, a spindle will have associated with it load and rotational velocity. All relevant data items for that spindle can be retrieved by a single command, rather than having to specify each data item separately. Figure 3 shows an example hierarchy for a machine tool represented in the MTConnect™ schema.

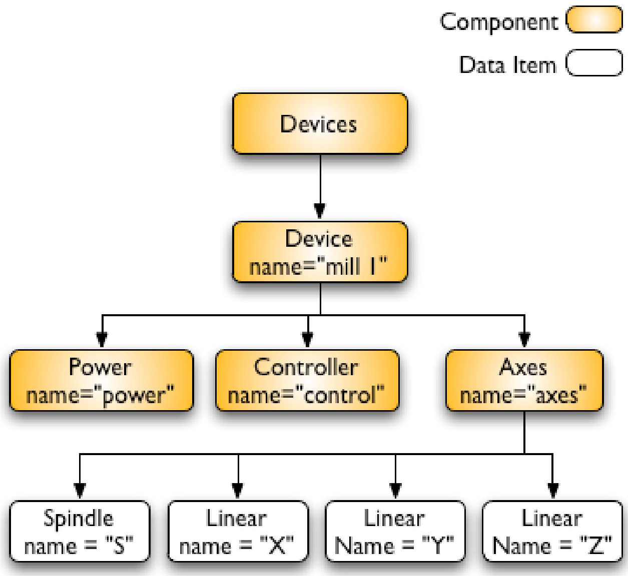

Figure 3: Example hierarchy for a three-axis Mill having a power controller, a controller, three linear axes, and one spindle.

CASE STUDY: PROCESS PLANNING VERIFICATION

Process planning is a critical step in the design and manufacture of complex parts. The effectiveness of process planning algorithms largely determine the precision and accuracy of the manufactured parts. In the case of machining, process planning includes toolpath generation, tooling design, and process parameter selection. Traditionally, process planning is done a priori to the manufacturing without any feedback from the physical manufacturing process. The effectiveness of the process planning is verified only after the part is fully manufactured by comparing metrology measurements of the part to its CAD model [4]. While this is a very capable method to estimate the conformance of the physical part to its model, it only provides an implicit connection between the process planning and the part features. We need information from the machine tool taken during machining to fully inform us of the effectiveness of the process planning algorithms.

The challenge for this lies in extracting data from a machine tool in a usable format so that it can be applied in developing better process planning algorithms. This process can be very cumbersome if individual programs and subroutines have to be written for every type of machine tool being used. This is greatly simplified by the use of standardized interoperability protocols such as MTConnect™. With MTConnect™, the process planning tools only need to "talk" to an MTConnect™ agent and understand the MTConnect™ XML-schema. The agent offers a standardized way of interacting with a variety of machine tools and other machine shop equipment. Thus with the MTConnect™ standard, software designers can easily integrate process planning algorithms with "real" machine tool data.

In this case study we look at an example where data from an MTConnect™ agent connected to a machine tool is used to study the correlation between the programmed process plan and the actual machining process.

Setup

In this case study we look at the machining of a workpiece using a conventional 3-Axis milling tool. The workpiece is first modeled in a CAD package and based on this a toolpath is generated. The toolpath is then converted to the machine-tool specific G-Code format and is transferred into the memory of the machine tool. The machine tool is connected over Ethernet to an MTConnect™ agent, which captures data corresponding to the axes position, process parameters, and system alarms. This data is captured continuously as the machine tool steps through the G-Code to machine the part. A schematic of this setup is shown in Figure 4.

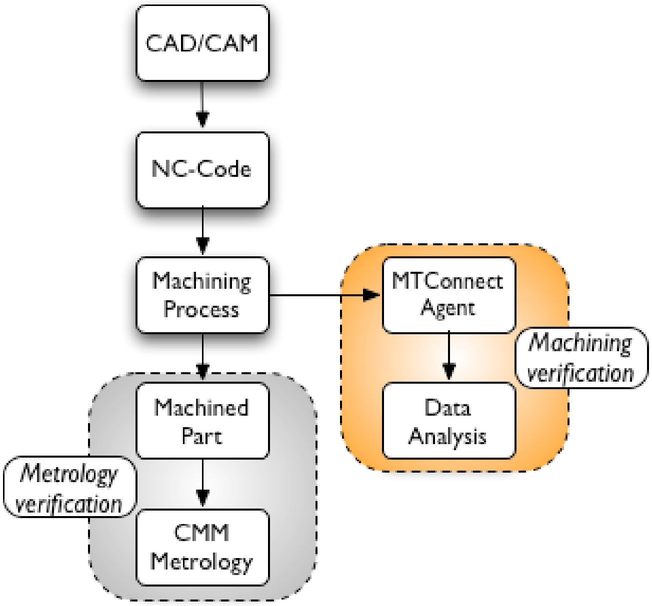

Figure 4: Schematic of process planning, machining, and data capture used in the case study

Figure 5 shows a wire-frame model of the workpiece that was machined. A custom CAD/CAM program was used to both generate the model as well as generate its end-milling toolpaths. The workpiece was Aluminum 6061 and a 0.375" diameter ball-nose end-mill was used for the machining.

Data from the machine tool was logged using the MTConnect™ agent for the entire duration of the machining process. The agent was configured to log the data whenever any of the parameters being measured changed. The parameters logged were the X, Y, and Z position of the machine axes, the spindle speed, the surface feed, and the current line number being executed by the controller. Since the MTConnect™ agent interfaced with the machine tool across an Ethernet connection, the data collection rate was limited by the speed of the Ethernet connection.

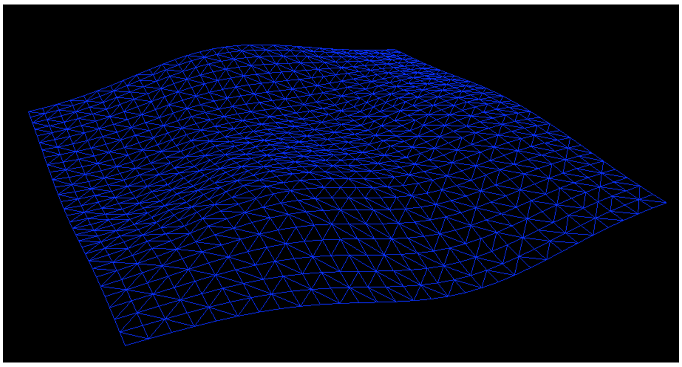

Figure 5: Wire-frame model of machined free-form surface workpiece

Data Analysis

To demonstrate the use of MTConnect™ in enabling better integration between process planning and execution, we studied the conformance of the actual cutting parameters to the programmed cutting parameters.

Tool Position Analysis

First, the programmed tool position was compared to the actual tool position during cutting. Figure 6 shows a visualization comparing the programmed tool path to the actual tool path during machining. We can see that the actual tool position conforms to the programmed tool position during most of the time in the cutting process.

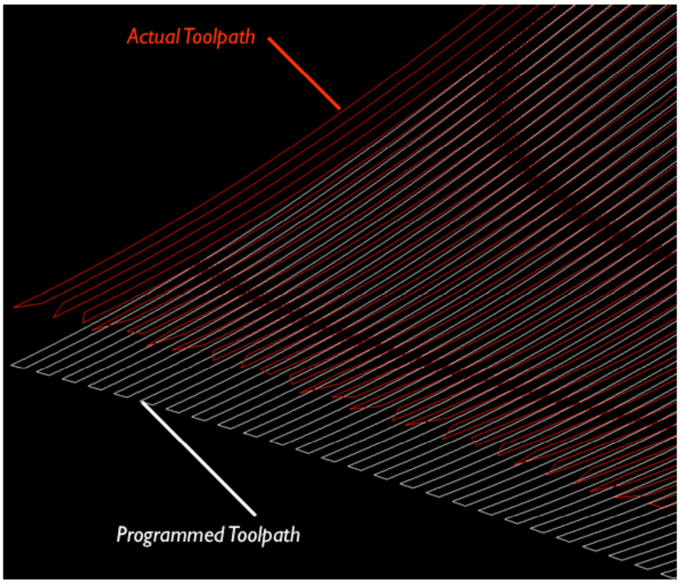

Figure 6: Programmed toolpath compared to the actual machined toolpath (shown here with a small offset in the z-direction)

This type of analysis is valuable in identifying regions of the workpiece where there is a discrepancy in the actual and programmed tool positions. The performance of the machine tool in axes interpolation can also be studied using this analysis.

Feed-rate Analysis

The machining feedrate is an important process parameter as it impacts both the quality of the machined surface as well as the time taken for the machining process. The selection of the feed-rate is based on the tool material, the workpiece material, the finish required, and the machining time required. However, due to dynamics of the machining process the actual feed can be different from the programmed feed. Hence, it is very important to know the discrepancy between the actual feed and the programmed feed during the machining process.

Using the logged data from the MTConnect™ agent, we compared the actual feed during the machining process to the programmed feed. Figure 7 shows a plot of the actual federate varying during the machining process. A small time window – corresponding to 60 seconds – is shown in the figure to highlight the significant variation seen in the federate.

This information is valuable for process planning, as engineers can incorporate the effect of these variations in designing toolpaths. This data can also be applied in making more accurate predictions for parameters such as surface finish etc.,

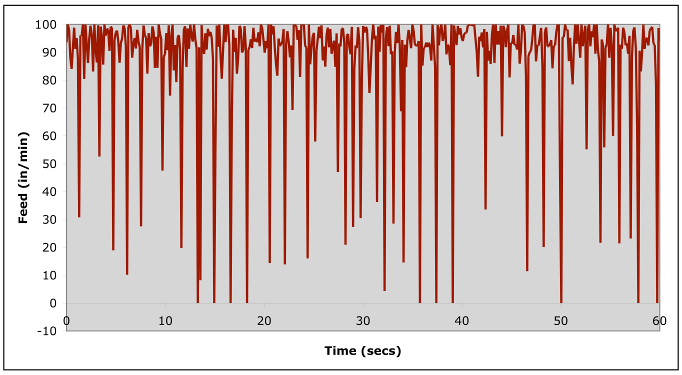

Figure 7: Variation of federate in 60 sec time interval of the machining process. The programmed federate is 100 inches/minute.

Discussion

We have seen in this case study the potential for MTConnect™ to improve the accuracy and impact of process planning. MTConnect™ brings two main advantages to this: (1) it simplifies information access from machine tools and (2) it standardizes information access from machine tools. By offering a simple method for information transfer, MTConnect™ greatly decreases the developmental overheads required for implementing feed-back driven process planning algorithms. Engineers now have an easy way to access machine tool data, which can be applied in improving the efficiency of the manufacturing process. Also, since MTConnect™ serves as a standard interface across various machine tool platforms, information from different machine tool types can be captured using the same set of software tools. This further decreases the developmental and deployment time for implementation in factory environments.

CONCLUSIONS

The interoperability enabled by MTConnect™ supports the manufacturing pipeline covering the four levels of integration (shown in Figure 8) for the design to fabrication cycle from the highest at the design stage to the lowest as we move towards the factory. Since our flexibility to make changes that impact manufacturing requirements reduces as we move down this pipeline we look to create capable process models linked to computer aided design tools so it is possible for the designer to "look down the manufacturing pipeline" to see if there are any problems with the design, from a manufacturing perspective, that will prevent the efficient manufacturing of the product. The reverse can be true also. That is, the manufacturing engineer can look back up the pipeline to suggest changes to the designer that would make manufacturing easier but, hopefully, not cause any problems with the design.

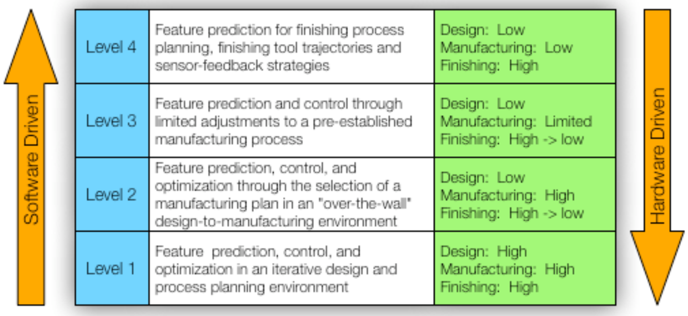

Figure 8: Four levels of integration from design to fabrication [10]

Figure 9 shows a schematic of this integration with respect to the case study discussed in the previous section. A fully integrated design and manufacturing system will allow process planners and designers to get feedback from measured metrology data, on-line manufacturing data, and the appropriate analytical and numerical process modes from off-line databases. This can be used in design refinement/modification and in the development of more efficient process planning algorithms.

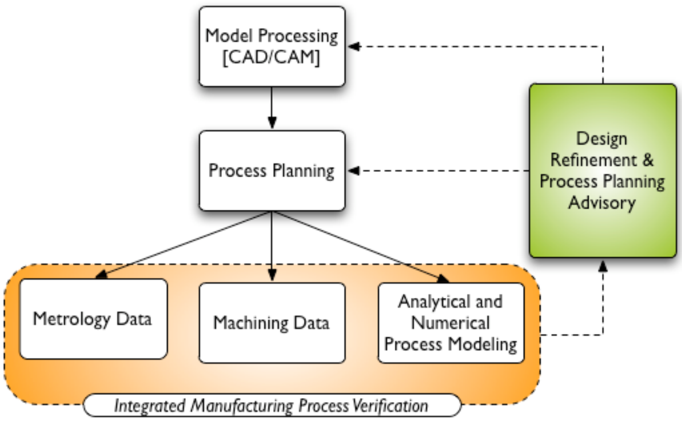

Figure 9: Integrated manufacturing process planning verification

Enabling green manufacturing with better interoperability

An important consideration these days is energy and resource consumption in manufacturing – leading to "green" manufacturing. The information on the efficient use of machines and systems in the production facility (including use of consumables such as water, fluids, etc.) will be valuable to designers of tools, processes and systems as we try to develop green manufacturing systems and facilities. The interoperability enabled by MTConnect™ can provide the mechanism for process and system monitoring and optimization with respect to energy and resources. This will become an important element of the manufacturing pipeline along with our tradition metrics for performance (such as lead time, work in process, production rate, quality and reliability).

ACKNOWLEDGMENTS

MTConnect™ is supported by the Association for Manufacturing Technology (AMT). For additional information refer to www.MTConnect.org.

REFERENCES

[1] MTConnect™, 2008, www.mtconnect.org.
[2] Merchant, M. E., Dornfeld, D. A., and Wright, P. K., 2005, "Manufacturing — Its Evolution and Future", Trans. North American Manufacturing Research Institute, 33, pp. 211-218.
[3] Vijayaraghavan, A., and Dornfeld, D. A., 2007, "Automated Drill Modeling for Drilling Process Simulation", Journal of Computing and Information Science in Engineering, 7(3), pp. 276-282.
[4] Byrne, G., Dornfeld, D., and Denkena, B., 2002, "Advancing Cutting Technology," STC 'C' Keynote, CIRP Annals, 52(2), pp. 483-507.
[5] Rangarajan, A., Dornfeld, D. A., and Wright, P. K., 2003, "Probabilistic Precision Process Planning", Trans. North American Manufacturing Research Institution, 31, pp. 539-546.
[6] IPC WebStandards, 2008, "IPC-2451", http://webstds.ipc.org/.
[7] OPC Foundaction, 2008, "What is OPC?," http://www.opcfoundation.org.
[8] ISO TC184/SC4 Trinity, 2008, "STEP Overview", http://www.tc184-sc4.org/.
[9] World Wide Web Consortium (W3C), 2008, "Extensible Markup Language (XML)," http://www.w3.org/XML/.
[10] Stein, J., and Dornfeld, D. A., 1996, "Integrated Design and Manufacturing for Precision Mechanical Components," Proc. 1st Int'l. Conf. on Integrated Design and Manufacturing, PRIMECA, Nantes, France, pp.195-204.