THE OPEN SOURCE MANUFACTURING STACK

Pierce Kuhnell
kuhnelp@email.uc.edu

Department of Electrical Engineering
University of Cincinnati
Cincinnati, Ohio USA 45221

Amit Deshpande*
deshpande@techsolve.org

TechSolve, Inc.
6705 Steger Drive,
Cincinnati, Ohio USA 45237

***Corresponding Author**

Abstract: Manufacturing is plagued by communication issues due to proprietary and closed architecture systems. In this paper, we outline the various methods, utilizing open source applications, to create Open Source Manufacturing Stack (OSMS) for use in the manufacturing sector. These open source applications include Ubuntu, LinuxCNC, MTConnect, and Firefox. The OSMS has been implemented as part of the supervisory system thrust area for the Smart Machine Platform Initiative (SMPI). MTConnect is a royalty-free, open communication standard for interconnect ability in manufacturing systems. MTConnect's free and open standard allows devices and systems to send out understandable information in the required format. The importance of the architecture, found in OSMS and MTConnect implementation, is also explained. Additionally, this paper provides details regarding why an open source bundle is so vital to the manufacturing community as well as the potential benefits of applying open source to manufacturing data management solutions. These benefits include knowledge management, real-time data access, scalability, plug-and-play functionality, and data mining capabilities.

Key Words: Manufacturing standards; MTConnect; Open Source Manufacturing Stack; Process monitoring and control; Smart Machine Platform Initiative; Supervisory system

1. Introduction: The open source software community has grown exponentially over the past several years and it continues to do so along with expanding to previously closed source territory [3]. More and more, processes once run by closed source software are moving in the direction of open source software in order to take advantage of its reliability, accessibility, and lower cost. One well known open source software bundle is the LAMP stack for building software applications. Each portion (**L**-Linux, **A**-Apache, **M**-MySQL, **P**-PHP (Perl, or Python)) is open source and free for anyone to obtain. More and more companies are using LAMP as a medium for creating software applications. However, the manufacturing community has failed to embrace these paradigms and lower the costs associated with manufacturing information technology. Manufacturing continues to remain closed source, proprietary, and non-scalable. There are a few efforts

in place that are developing open source applications like CAD system- BRL-CAD and FEA/CFD programs – OpenFOAM and OpenFlower; however these applications still remain in the laboratory environment and are not utilized widespread in the industry.

A search for manufacturing on SourceForge, which is the one of the largest repository of open source projects, produces approximately 100 results. From Table I, we can see that most of these projects are related to ERP and not related to actual manufacturing processes on the shop floor. The ranking is based on the number of downloads and considers the projects which are not only active but also at least in Stage 4 (beta testing phase).

Table I: Open source projects

Rank	Project	Description
1	Compiere ERP + CRM Business Solution	Compiere ERP+CRM is the leading open source ERP solution for distribution, retail, manufacturing, and service industries. Compiere automates accounting, supply chain, inventory, and sales orders. Compiere ERP is distributed under GPL V2 by Compiere, Inc.
2	Openbravo ERP	Openbravo ERP is a web-based ERP for SME built on proven MVC & MDD framework that facilitate its customization. Already in production, Openbravo ERP encompasses a broad range of functionalities such as finance, supply chain, manufacturing and much more.
3	Neogia	The ERP solution Neogia leans on OFBiz ERP sturdy technical foundations which is a set of technical and business components well known for their high coverage, flexibility, and great sturdy. OFBiz Neogia solution covers finance, manufacturing, CRM, and e-commerce.
4	Kompiere Libero (Manufacturing)	Kompiere Libero Manufacturing joined Adempiere project. http://sourceforge.net/projects/adempiere/ is 100% integrated to Compiere and it covers all manufacturing activity within the various types of production environments. The main modules are Ros.
5	Suniant ERP	Suniant offers a framework solution for small to medium-sized businesses. This solution includes integrated accounting (payable, receivable, general ledger, etc…), order and inventory management, CRM, payroll, and extensions to add SCM and manufacturing.

The success of the internet can be attributed to well-established and accepted standards and hardware standardization. No wonder any printer, webcam, or flash drive can work with any computer and communicate seamlessly without installing any drivers through a

Universal Serial Bus (USB). The lack of well accepted standard and closed architecture controllers has been the primary reasons for the manufacturing back lag.

Recently, efforts like OSACA (Europe), OMAC (USA), and OSEC (Japan) have been initiated to develop an open architecture controller. However, these efforts still remain in the lab environment and have not percolated in commercial applications. Suh et. al describes the requirements for an intelligent CNC in terms of function-level requirements, data-interface level requirements, and implementation level requirements [10]. Principles of open architecture manufacturing state that we need a high level object oriented language, common operating systems, and open hardware [11]. STEP-NC is being developed which is an object-oriented data model that connects the CAD design data used to determine the machining requirements for an operation with the CAM process data. Some controller vendors have started to open up their native application programming interface like GE Fanuc FOCAS libraries and OKUMA THINK.

In this paper, we describe the implementation of an open source manufacturing stack consisting of Ubuntu, LinuxCNC, MTConnect and Firefox. Ubuntu (a distribution of the Linux operating system) is the operating system, Enhanced Machine Controller (EMC) is the controller, MTConnect is the XML based standard enabling data access, and Mozilla Firefox internet browser serves as the data visualization application. This stack includes all of the components necessary to display data from a machine tool controller. Additionally, each of these pieces is an open source in juxtaposition to those that are currently in use.

The paper is organized as follows. Section 2 gives an introduction to the Smart Machine Platform Initiative (SMPI) followed by the definition of a supervisory system in section 3. Section 4 describes the technologies & implementation details followed by benefits in Section 5. Finally, we conclude with the limitations and future work needed in Section 6.

2. Smart Machine Platform Initiative (SMPI): The Smart Machine Platform Initiative is the brainchild of the Coalition on Manufacturing Technology Infrastructure (CMTI). CMTI was formed to address critical issues troubling the US manufacturing sector like global competition, increasing labor expenditures, offshore outsourcing, and a call for better quality.

TechSolve, Inc. has been one of the cornerstones of CMTI and is currently managing the SMPI program with supported from organizations like the Association for Manufacturing Technology (AMT). SMPI also receives part of its funding from the Department of Defense. TechSolve aims to address the long standing call for increased innovation in manufacturing through the SMPI program. SMPI is a reinvention of the basic manufacturing environment, enabling dramatic improvements in the productivity and cost

of designing, planning, producing, and delivering high-quality product within short cycle times [3]. TechSolve has established an advisory group that represents academia, industry, and government institutions.

The Smart Machine program at TechSolve consists of seven thrust areas: Machine tool metrology (MTM), On-machine probing (OMP), Tool condition monitoring (TCM), Health and maintenance (H&M), Intelligent machining (IM), Intelligent machining network (IMN) and the Supervisory system (SS). Figure 1 illustrates the Smart Machine Supervisory System concept encompassing all of the thrust areas within SMPI.

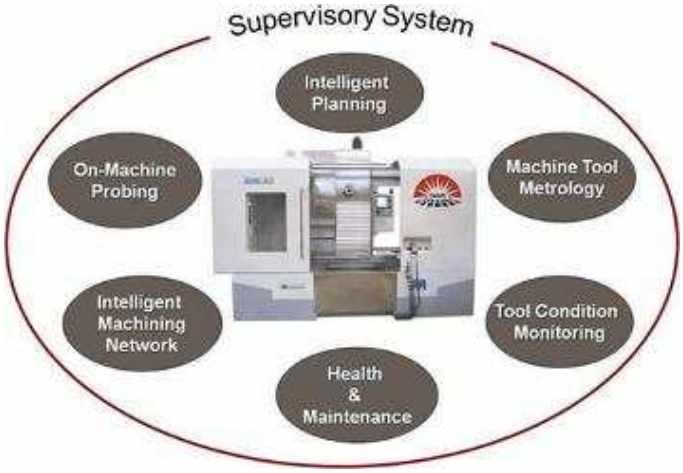

Figure 1: SMPI Thrust Areas

3. Supervisory System: A smart machine is defined as a machine that knows its capabilities and is able to come up with the most efficient method to produce a correct part the first time, every time while monitoring itself and utilizing data to assist "closing the gap" between the designer, manufacturing engineer, and the shop floor. The supervisory system is the manufacturing expert system which works like the "brain" of a smart machine. The supervisory system collects information from individual thrust areas and makes a decision based on predefined business logic. The supervisory system also addresses the need for an "all encompassing system" that is responsible for the coordination of manufacturing activities, monitoring technologies, construction inputs, and the initiation of outputs to accomplish the "First Part Correct" philosophy. The supervisory system can also be defined as a system that integrates and coordinates individual process monitoring and control systems such that a globally optimal machining solution can be delivered real time for desired quality and maximum productivity.

The architecture of the supervisory system is classified into two hierarchy levels [2].

i. Decision Level (Responsiveness)
ii. Communication Level (Awareness)

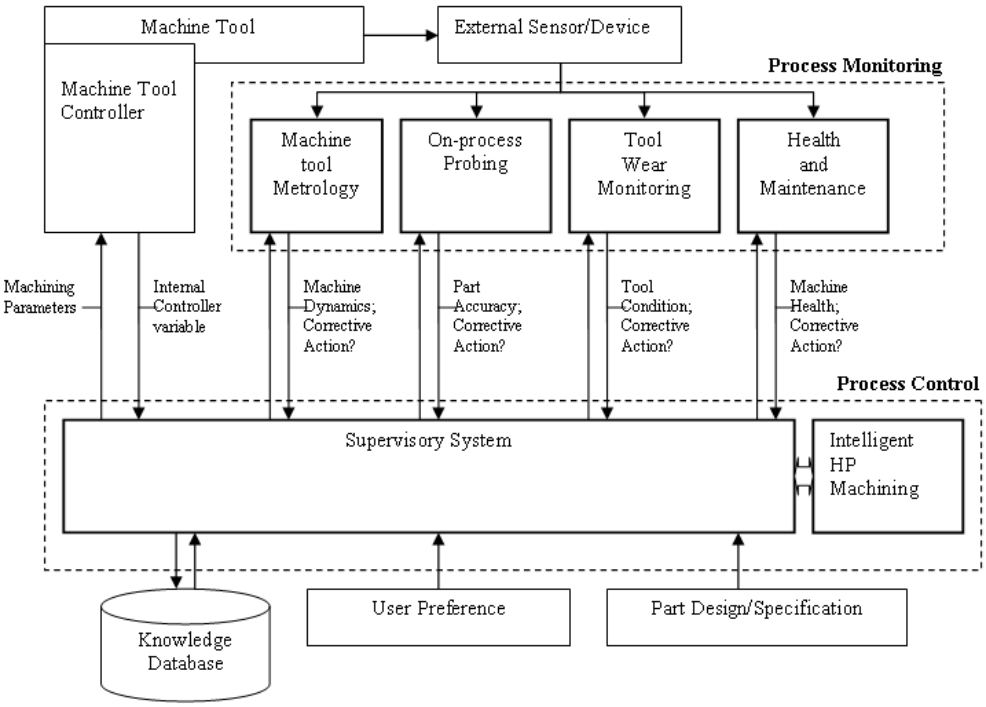

Figure 2: Supervisory System Architecture

The decision level of the supervisory system is focused on the generation of the response which is based on the current functioning of the machine, previously stored machine data (knowledge base), and pre-programmed effectors (adaptive optimization agent). All the responses pertaining to the adjustment and calibration of the machine tool need to be initiated in real time. The communication level of the supervisory system is responsible for maintaining 'awareness' of the function/non-function of the various component subsystems on the smart machine. It is also accountable for ensuring the real time information flow (responses and inputs) among all the subsystems of different thrust areas within the smart machine. The crux of the problem lies in obtaining "real-time" information from the machine and its subsystem. In order to address this issue, the data that has been acquired from the CNC is utilized by the decision level within the supervisory system. Seamless flow of data can be accommodated into the supervisory system by incorporating structured input/output within the supervisory system which will facilitate real-time relaying of CNC and PMC data to the subsystems of various thrust areas within the smart machine.

4. Technologies and Implementation Details: Ubuntu is an open source operating system based on Debian GNU/Linux licensed under GNU. Ubuntu stands by the fact that it will always be free to use and that all programs Ubuntu distributes, with its operating system, are also free to use. For more information, visit their webpage at http://www.ubuntu.com/.

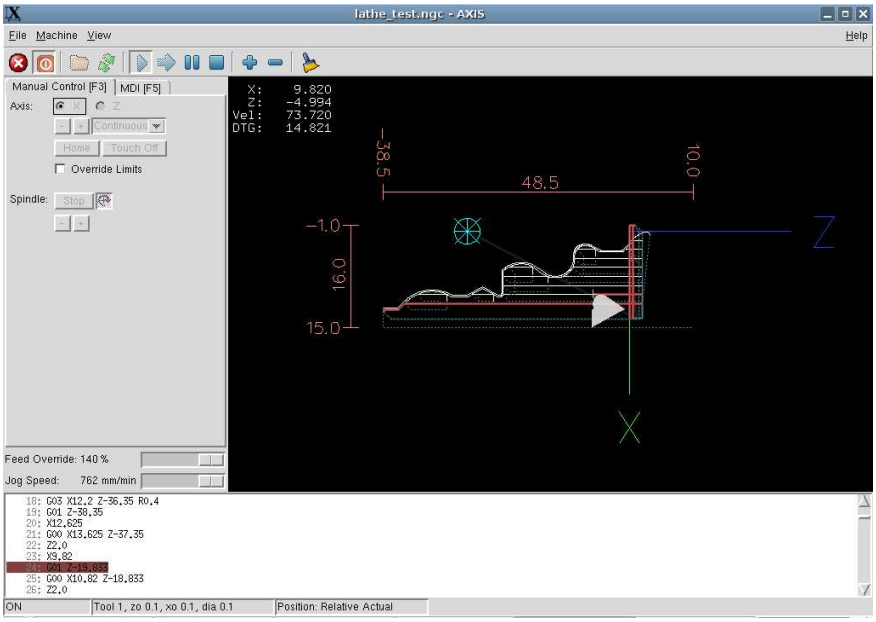

Figure 3: Enhanced Machine Controller

The EMC (Enhanced Machine Controller) is a fully functional CNC controller developed by NIST and maintained by the online community at http://www.linuxcnc.org. It was originally developed for testing concepts and standards; however it has expanded with the work of the LinuxCNC community. As interest in expanding the EMC project has grown, the EMC product was moved from the original operating system of Windows NT to a much easier to obtain operating system - Ubuntu. Current versions of EMC are entirely licensed under the GNU General Public License and Lesser GNU General Public License (GPL and LGPL). There are multiple ways to install the product including downloading and compiling the source code as well as a unique feature of downloading two separate CD images (ISO files) containing Ubuntu that already include the EMC2 installation. Some important features of the EMC2 product include:

- Multiple graphical user interfaces
- An interpreter for the RS-274 machine tool programming language
- A real-time motion planning system with look ahead
- A software PLC programmable with ladder diagrams

It has an inbuilt simulator or as a fully functional control which can move simultaneously up to 9 axes.

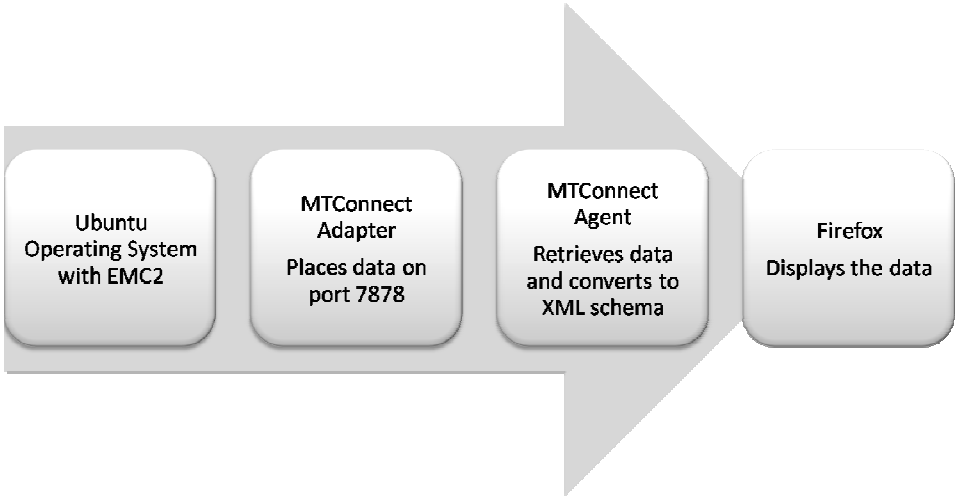

Figure 4: Data Flow

MTConnect is an emerging standard which has the goal of making data passing easier and friendlier to use. The goal is to create it in a matter that all data comes out as an XML schema that can be easily read by using many existing technologies. MTConnect has two main parts: the adapter and the agent. The MTConnect adapter is the portion that obtains the data from the machine and feeds it to the agent. The adapter has been developed in multiple programming languages including C++ and Python. The second portion of MTConnect is the MTConnect agent that obtains the data from the adapter and converts it into MTConnect XML schema format. The agent has been developed on multiple platforms including Microsoft .NET and Ruby on Rails. Figure 4 depicts the data flow in the system. For more information on MTConnect, visit the website located at http://www.mtconnect.org.

Currently, machine tools that have implemented MTConnect are obtaining the following data: X, Y, Z, X_{actual}, Y_{actual}, Z_{actual}, and machine on/off status.

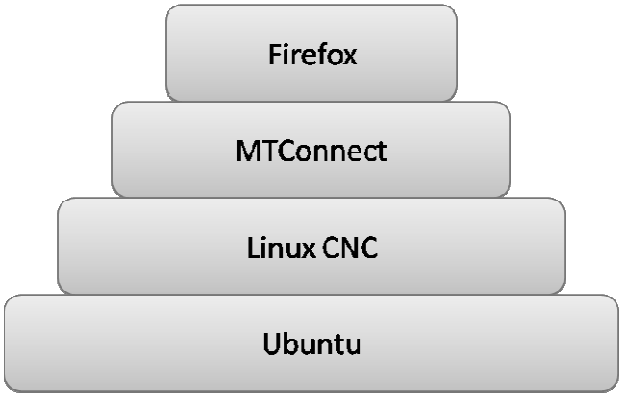

Figure 5: OSMS Design

MTConnect allows simple data management and data viewing through the use of the next portion of OSMS - Firefox internet browser. Firefox is an open source internet browser

distributed by Mozilla. Similar to the products describe in the previous section, Firefox is free for users to download and install. The goal of Mozilla is similar to that of LinuxCNC, MTConnect (standard), and Ubuntu in that they would like to keep their product free of charge and open source. Firefox is able to display XML data, including XML schema data, so it can be used to view the data that is recorded through the usage of the MTConnect agent. The OSMS design is shown in Figure 5.

5. MTConnect Benefits:

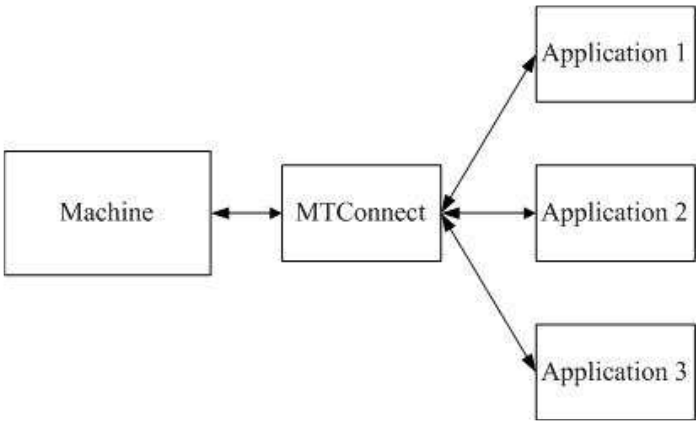

Figure 6: MTConnect

Currently, most of the human machine interfaces are tied to a particular CNC that uses a proprietary connection which makes it non-modular and results in costlier integration [9]. The acceptance of XML standards, like MTConnect, will provide a standard data definition without the need to reveal the vendor's internal architecture details. Thus, if the vendor does not want to open up its internal API, MTConnect can be embedded and still communicate with the peripheral applications as depicted in Figure 6. In this scenario, if the machine is changed, the applications running on it will not be affected as long as the new machine is MTConnect enabled. MTConnect will provide a neutral interface to develop applications irrespective of the hardware running behind it. The potential benefits are far reaching and include knowledge management, real-time data access, scalability, and plug-and-play functionality. Since MTConnect is royalty free open standard, it can be extended, used, modified, or redistributed. Additionally, the exiting IT infrastructure need not be modified as MTConnect is based on well-established standards like REST, XML, HTTP, etc… Thus, MTConnect is vital platform for lean manufacturing initiatives.

6. Conclusion and Future Work: The closed systems and proprietary nature of manufacturing systems have hindered innovation and technological advances. Instead of using the established base functionalities, each vendor "reinvents the wheel". This closed approach has led to higher costs and complicated efforts. Manufacturing IT has seen "cathedral" style development instead of a "bazaar". Cathedral and bazaar are common terms in the open source world indicating a closed or open software development model. [5]. In order for open source to flourish, open architecture controller (hardware),

established communication standards, and high level parsable language is required. In this respect, the MTConnect standard will prove a boon to the industry if accepted and absorbed. It still needs an open hardware (or embedded in proprietary hardware) to access the data. Currently, the standard is in its infancy and has some limitations. The current implementation only supports read-only access and does not support write functionality, thus monitoring and visualization of assets is possible. However, adaptive control and real-time fault correction techniques may not be implemented. Another limitation is the non-adoption of PMC data, tooling, fixture, and process information in the specification. The analysis of PMC and tooling data is highly critical to various visualization and optimization processes.

It will be interesting to assess development of similar efforts like OPC Unified Architecture and application of Web Services and SOA (Service Oriented Architecture) in manufacturing. Also, the network capability, software design, and deployment and computing power will play a vital role in determining the real-time ability of the data received.

Note

Research was sponsored by the U.S. Army Benét Laboratories and was accomplished under Cooperative Agreement Number W15QKN-06-2-0100. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the U.S. Army Benét Laboratories or the US Government. The US Government is authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation here on.

References and Bibliography

1. Atluru S., Amit Deshpande, Data To Information: Can MTConnect Deliver The Promise?, 37th Annual North American Manufacturing Research Conference (NAMRC 37), May 19 - 22, 2009, Greenville, South Carolina
2. Smart Machine Platform Initiative (SMPI), Technology Plan, Coalition on Manufacturing Technology Infrastructure (CMTI), TechSolve, March 2004
3. Deshpande A., Dirk Riehle, “The Total Growth of Open Source”, The Fourth International Conference on Open Source Systems; 7-10 Sep 2008, Milan, Italy.
4. Atluru S., Deshpande A., Huang S., Snyder J., Smart Machine Supervisory System: Concept, Definition and Application, Society for Machinery Failure Prevention Technology 62nd Conference; 6-8 May 2008, Virginia Beach, VA.
5. Raymond E., The Cathedral and the Bazaar: Musings on Linux and Open Source by an Accidental Revolutionary, O'Reilly, 2001, ISBN 0596001088
6. Riehle D. "The Economic Motivation of Open Source Software: Stakeholder Perspectives." IEEE Computer, vol. 40, no. 4 (April 2007). Page 25-32.
7. http://www.linuxcnc.org/
8. Sobel W., MTConnect Standard Specifications Version V0.9.12, Dec 2008.

9. Michaloski J., Sushil Birla and Jerry Yen, Software Models for Standardizing the Human-Machine Interface Connection to a Machine Controller, National Institute of Standards and Technology, 2000 (http://www.isd.mel.nist.gov/documents/michaloski/wac2000hmi.pdf)
10. S.-H. Suh, S.-U. Cheon, A Framework for an Intelligent CNC and Data Model, The International Journal of Advanced Manufacturing Technology, Volume 19, Issue - 10, 2002
11. Wright P., Principles of Open-Architecture Manufacturing, Journal of Manufacturing Systems, Vol/14/No. 3, 1995.