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Open architecture control technology trends

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Abstract

This report describes the recent trends in the area of Open Architecture Control (OAC) for manufacturing, particularly focused on machine tool industry and machining applications. It reviews several concepts of OAC, summarizes a survey of products available on the market, and brings views of people in industry about what OAC are.

Finally, it suggests several possible research directions for ERC/RMS as a background material for discussions.

1. Introduction

Open Architecture Control (OAC) is a well known term in the field of machine control. In this report we are focused on OAC for manufacturing and mainly referring to machine tool control issues as used in production lines. The term is borrowed from the terminology used in computers today where the hardware and software systems are designed in an *Open Architecture* approach to meet broad span of applications. The manufacturers of computer hardware do not produce software anymore. There is a true separation of interests in favor of the users or final customers. The size of the personal computer market is over $200B in annual sales and therefore creates true openness of the systems and free competition on the market. The situation is different in the field of machine tools control and in other segments of machinery. The leading control companies, traditionally hardware developers, keep developing systems where the software is embedded in the hardware. In order to run any application one need to use proprietary hardware. It means that there is strong economical interest of the leading control companies to maintain their market share and to avoid openness as long as possible. Today, the value of control components is about 40% of the machine value. This percentage is continuously increasing as machinery electronics technology is advancing. One possible benefit of applying OAC is the potential to separate between hardware and software for machine tools in order to enable design flexibility and to reduce the huge maintenance and upgrade costs.

The goals of this report are:

(1) To inform the reader about recent concepts of Open Architecture Control (OAC); to present new products available commercially on the market and industry trends with regards to this technology.

(2) To summarize discussions industry representatives about OAC. To learn what some prevalent perception of the term OAC and what issues are regarded as important to deal with.

The report is mainly addressed for internal purposes of ERC/RMS researchers. It may serve as input for internal discussions about OAC.

2. Concept of OAC by leading groups

2.1 Definition of OAC

The open architecture (or open system) is not a new concept in the software engineering research. IEEE 1003.0, which is the foundation of the definition of the open system, defines the open system as:

> *An open system provides capabilities that enable properly implemented applications to run on a variety of platforms form multiple vendors, interoperate with other systems applications, and present a consistent style of interaction with the user.*

Since such a definition is too broad to describe the specific of the open architecture control, the research groups in the manufacturing discipline have developed their own definitions that are more meaningful for the manufacturing domain. Professor Koren at the University of Michigan define the OAC as (Koren 1998):

> *A controller that is designed and constructed for integration of new measurement and control devices and software modules by permitting access to a given set of internal controller variables.*

OSACA's definition (Pritschow 1998) stresses more the importance of the interface between software modules:

> *An open control system, as understood by OSACA, consists of a set of logically discrete components. The interfaces between these components and between the components and the implementation platforms are well-defined such that a meaningful combination of components from different vendors can cooperate with each other to form a complete and correctly functioning control that runs on a variety of platforms and presents a consistent interface to the human users as well as other automation systems.*

2.2 OAC research activities by leading groups

2.2.1 OMAC

The OMAC Users Group was formed in 1994 to create an organization through which companies could work together to (1) establish a repository of open architecture control requirements and operating experience from users, software developers, hardware builders and OEMs; (2) facilitate accelerated convergence of industry and government developed APIs (Application Program Interfaces) to one set, satisfying common use requirements; (3) collaborate with European and Japanese user groups in pursuit of a common international API standard; (4) promote open architecture control development among control builders; and (5) derive common solutions collectively for both technical and non-technical issues in the development, implementation, and commercialization of open architecture control technologies.

The OMAC's web page is http://www.arcweb.com/omac/.

2.2.2 OSACA

OSACA (Open System Architecture for Controls within Automation systems) is the European initiative to define a vendor-neutral, open controller architecture in order to improve the competitiveness and flexibility of suppliers and users of control systems: machine tool builders, control vendors and end-users.

OSACA's approach is to develop an application programming interface (API) for control applications and an appropriate infrastructure to achieve the interoperability, portability, scalability and reusability of applications. Three main areas of OSACA are: (1) *Communication system* to define a hardware and system-software independent interface to exchange information between different application modules of a controller, (2) *Reference architecture* to determine the functional units of a controller, such as for example Motion Control (MC) and Logic Control (LC) and specifies the external interfaces of them, (3) *Configuration system* to enable the dynamic configuration of a controller by combining different application modules at boot-up time.

The OSACA's web page is http://www.osaca.org.

2.2.3 JOP

JOP aims to develop the new technology based on open architecture in many phases from controller, production information and data format of facilities to the structure of the whole manufacturing system to establish the common basic technology so that the information process such as data exchange, management and control in manufacturing can be adapted to this new environment. JOP's development activities include: (1) *Distributed manufacturing system structure* to carry out the research and development of system architecture for sharing and exchanging manufacturing information on the network, data exchange mechanism and standard specifications of data frame, aiming at the open manufacturing environment structure; (2) *Communication environment* to use of new communication media as well as network architecture for the real time open communication environment which is to be the pivot of manufacturing systems; and (3) *specification of FA controller* to define the control functions as the common manufacturing system module and the unification of the standards and the architecture of CNC and PLC.

The JOP's web page is http://www.mstc.or.jp/jop.

2.2.4 The University of Michigan

The project was one of the first PC-based OAC developed for 5-axis CNC milling machine. For the first project (1986-1993) the entire control modules (including servo control, interpolator, G-code interpreter, and user interface) for a conventional CNC machine has been implemented as software modules for Intel 486 PC with MS-DOS. The recent project (1993-present) focused on the software engineering side. Object oriented design of a machine controller and inter-process communication between the software modules in a real-time OS (QNX and Windows NT) has been studied.

The OAC research activities at the University of Michigan have been continued at the ERC for RMS. The projects were the further development of the latest UMOAC project described above. The research topics include finite state machine (FSM) based design of machine control, implementation of supervisory control, and development of Windows NT based human machine interface (HMI).

In addition to the continuation of UMOAC, ERC started several projects related to the OAC research: Modular machine tool design and control, Distributed control using computer network and field bus network, Implementation of open architecture controller to an existing machine tool, Simulation for open architecture control, and Common HMI API.

2.2.5 Research at other universities

This section introduces several research projects on the open architecture control conducted by universities.

(1) The University of California at Berkeley

Purpose of the Open-Architecture Assembly Systems & Integration Science (OASIS) project was to enhance basic automation by implementing components of an end-to-end, agile assembly system. The University of California was also a TEAM site. The TEAM (Technologies Enabling Agile Manufacturing) was a program between the industry, government, and academia to enhance the global competitiveness of the U. S. manufacturing technology. The University of California worked for the fabrication of the TEAM standard high precision part on its open-architecture machine tool controller.

(2) Purdue University

Purdue University developed an open architecture controller that uses a standard PC platform with generic hardware components and software, and allows programming in C or Basic languages. This open architecture controller has been interfaced with a high speed milling machine and a MAZAK CNC machining center through an in-house designed board.

(3) University of British Columbia

The University of British Columbia developed PC+DSP-based multi-axis programmable CNC controller with intelligent machining module. This controller uses script language to configure the control software in highly open and modular way. However, since it depends on the DSP technology for the machine control, it is not considered as the PC-based open system.

(4) Tampere University of Technology

The survey-type research carried out at the Tampere University of Technology (TUT) comprehensively covers different commercial products in the field of Open Control Systems including such topics as Hardware Platforms, Operating Systems, PC-based control applications, Fieldbuses and I/O Systems, Human Machine Interfaces, SCADA Systems, Programming, Standardisation, and several case studies.

2.2.6 Globalization of OAC standard

Nevertheless the activities of the OAC research groups' efforts introduced above, due to the physical differences between the existing control products, the conflicts of interests on the market, and the absence of the clear direction of the open architecture control concept the development of a global standard for the open architecture control system is still in very early stage.

Recently, OMAC, OSACA, and JOP initiated a promising effort to develop a *Global HMI Standard* to share a unified API for HMI design for OAC (Mathias and Hellmann 1999). The goal of the effort is to define a HMI API for most of the control products in the world. Major machine tool control manufacturers such as Fanuc, Siemens, Mitsubishi, Rockwell Automation, and end-users, such as GM, Boeing are participating in this endeavor.

3. Available Products on the OAC Market

This section lists and compares the latest open architecture control products from the machine tool related. The typical CNC and PLC products from the leading manufacturers are selected and compared based on the several key aspects of the open systems.

The major manufacturing businesses have started to use PC-based control systems as a part of their production system since 1990s. Conventional machine tool builders, shop floor management software developers, and operating system providers have entered to the PC-based industrial control markets at the time and this *PC-based* trend is more and more popular recently. Uses of the PC-based open architecture control for the CNC machine tool are less popular than that of the PLC systems in the production system because the motion control requires more reliable real-time controls. The hard real-time requirements of the PLC products are more relaxed than that of CNC and thus can be easily achieved by using existing technologies. Because of this reason the PC-based CNC controller has not been convinced on the controller markets. However, already installed PC-based controller shows that the PC-based system is reliable enough for machine tool control.

Even though most of the companies claim that their PC-based products are *open architecture systems*, the use of the PC-based architecture *does not* guarantee the openness of the products without support of the *open* hardware and software. Actually, many PC-based controllers called as open architecture controllers allow only the applications of the Microsoft Windows software technologies (such as DDE) into their control software. In this case, the openness of those PC-based systems is nothing but the inherent characteristic of Windows based systems; is not the realization of the ideas of the OAC at the hardware and control logic software level.

3.1 Systems reviewed

Thirteen PC-based control products (seven CNCs and six PLCs) have been reviewed. The specifications of the products used for review were based on the literature released in 1999 and therefore there could be improvements or changes of the products, which are not considered in this review. The details of the products can be found in the companies' web page listed in the Reference section of this report.

3.1.1 CNC systems

(1) Allen Bradley - 9/PC
(2) ATR - RCC Open CNC
(3) ASAP - ASIC 300
(4) Cimetrix - CIMControl
(5) Cranfield Precision (Unova) - Cranfield Controller
(6) Indramat - System 200
(7) MDSI - OpenCNC

3.1.2 PLC system

(1) Allen Bradley - SoftLogix 5 Version 1.2.1
(2) CJ International - IsaGraf Pro and Version 3.3
(3) Cutler Hammer - NetSolver 4.1.1
(4) Iconics - ControlWorX
(5) Nematron - OpenControl 5.4
(6) Think & Do Software – SoftPLC

3.2 Review criteria

The criteria for comparing *openness* of various products are given in Tables 3.1 and 3.3. The items to be compared have been selected based the requirement of OAC as defined in Section 2 and the comments from users described in Section 5. Since the requirements for CNC and PLC are different, different assessment criteria have been used for each of them. Table 3.1 shows the criteria used to review CNC products and Table 3.3 shows the criteria used to review PLC products. Using the product properties that reflect the *openness* of the system, each item is evaluated as *Full support*, *Partial support*, and *No support*. Full support means the product is *open* in that aspect. No support means the product is *not open* with respect to the specific property.

Please note that the evaluation is limited to only openness property of the product. For example, *full support* to *Interoperability of drives* does not mean that the product has the best performance in drive interface or control. It only means that the product is compatible to a large variety of motor drive standards. The purpose of this review is to check if a product possesses the openness properties. It does not compare its relative performance. In addition to above evaluation, the operating systems and servo drives used for the systems are also displayed in the result.

(1) Operating systems

NT	Windows NT only
NR	Windows NT + third party real-time kernel
CE	Windows CE
VX	VxWorks

(2) Servo drive network

SE	SERCOS
PR	Profibus
TP	Third party motion control device

3.3 Result and discussion

Table 3.2 shows comparison of CNC products, and Table 3.4 shows PLC products. As can be seen in the tables, the recent CNC and PLC products support at least partially some openness requirements. Compared to the PLC products, the CNC products are less open. It happens because (1) CNC uses more proprietary technologies than PLC; (2) openness has more impacts on the reliability due to the complexity of the CNC; and (3) PLC has been used in more networked and mixed-brand environment.

Table 3.1 Evaluation criteria of openness of CNC products

	Item	Full support	Partial support	No support
1	Interface to different actuator and I/O 1.1 Interoperability of drives	Support most servo drive in the market	Support limited drives from different vendors	Proprietary drive is used
	1.2 Interoperability of I/Os	Support most I/O standards in the market	Support limited I/Os from different vendors	Proprietary I/O is used
	1.3 PC-based control	Use conventional PC, unlimited third party control board and, commercial OS	Use conventional PC, limited third party control board and, proprietary OS	Use proprietary controller
2	Customize operator panel (HMI)	HMI can be customized using a library and GUI, and is programmable using standard language such as C++ or VB.	HMI can be partially modified using standard language. No GUI for HMI programming supported	HMI is not programmable
3	Customize servo-level controller algorithm	Fully programmable using standard language	Partially programmable using standard language	Not programmable
4	Integration to enterprise system and third party software	Machine data can be exchanged through network and OS standard such as OPC, DDE, and HTTP	Support part of network and OS connection	No third party software connection available
5	Support conventional programming standards	Support all IEC-61131 (PLC) and RS-274 (CNC) standards	Support part of IEC-61131 (PLC) and RS-274 (CNC)	Use proprietary program language

Table 3.2 Comparison of CNC products

(? - Full support, ? - Partial support, ? - Requires special option, and ✑- No support)

Model	OS	Servo network	1.1	1.2	1.3	2	3	4	5
9/PC (Allen Bradley)	NT	SE	?	?	?	?	?	?	??
RCC Open CNC (ATR)	NR	SE or PR	?	?	?	?	?	?	?
ASIC 300 (ASAP)	CE	TP	?	?	?	?	?	?	?
CIMControl (Cimetrix)	NR	TP	?	?	?	?	?	?	?
Cranfield controller (Unova)	NT + VX	SE or TP	?	?	?	?	?	?	?
System 200 (Indramat)	NT	SE	?	?	?	?	?	?	?
OpenCNC (MDSI)	NR	TP or SE	?	?	?	?	?	?	?

Table 3.3 Evaluation criteria of openness of Software PLC products

	Item	Fully support	Partially support	No support
1	Interface to different actuator and I/O 1.1 Interoperability of I/Os	Support most I/O standards in the market	Support limited I/Os from different vendors	Proprietary I/O is used
	1.2 PC-based control	Use conventional PC, unlimited third party I/O products, and commercial OS	Use conventional PC, limited third party I/O products, and proprietary OS	Use proprietary controller
2	Customize operator panel (HMI)	HMI can be customized using a library and GUI. The interface is programmable using standard language such as C++ or VB.	HMI can be partially modified using standard language. No GUI for HMI programming supported	HMI is not programmable
3	Integrate with enterprise system and third party software	Machine data can be exchanged through network and OS standard such as OPC, DDE, and HTTP	Support part of network and OS connection	No third party software connection available
4	Support conventional programming standards	Support all IEC-61131 language	Support part of IEC-61131 language	Use proprietary program language

Table 3.4 Comparison of PLC products

(? - Full support, ? - Partial support, ? - Requires special option, and ✑- No support)

Model	OS	1.1	1.2	2	3	4
SoftLogix (Allen Bradley)	NT	?	?	??	?	?
IsaGRAF (CJ International)	NT or VX	?	?	?	?	?
NetSolver (Cutler Hammer)	NR	?	?	??	?	?
ControlWorX (Iconics)	NR	?	?	??	??	?
OpenControl (Nematron)	NR	?	?	??	?	?
SoftPLC (Think & Do)	NT or CE	?	?	?	?	?

3.3.1 Operating systems

As can be seen in the tables, Windows NT with a real-time extension is the most popular operating system in use. Since neither Windows 9x nor NT 4.0 support hard real-time environment, the popular OS configurations for the PC-based controls are Windows NT 4.0 with a real-time extension. While VenturCom's RTX is popular for the machine control applications, there are more real-time extension products available from several companies, including proprietary kernels developed only for in-house use.

In 1999 Microsoft introduced new OS products targeting the industrial control market during 1999: *Windows NT 4.0 Embedded* and *Windows CE 3.0 Beta*. Even though the *Windows NT 4.0 Embedded* targets the real-time control market and is proper for the embedded packaging of control devices, it still does not support hard real-time because it is based on the NT 4.0 technologies. On the other hand, the Windows CE 3.0 supports hard real-time multi-tasking with a greater OS functionality and capability than CE 2.1. The share of PC-based real-time Unix, such as VxWorks or QNX is decreasing as Microsoft operating system is clearly dominating the PC-based control market.

3.3.2 Openness of the low-level control algorithm

Only few open-architecture controllers allow users to modify their low-level control algorithms. Regardless of the language or program architecture the companies adopted, the software companies set their own policies in the degree of openness. The policy mostly depends on the software liability issues to protect intellectual properties. The policy is also important to manage the program development cost and to prevent the maintenance and service problems due to incorrect software modification by users.

Even though the programmability of low-level servo control algorithm is sometimes required for the research, the demand of system level programmability from the industry end-user is small. The most machine tools are installed on a turnkey basis by the system integrators or machine tool vendors. Therefore, the majority of end-users do not want the openness of the machine tool with the additional cost for the more openness, especially if their application is fixed. A few control software builders (such as Cimmetrix) who target the research and development, which require frequent application changes (for example, development of special machine tool or robotic devices) may allow users to modify the low-level control logic.

Giving the rights to modify the system code to certain level of customers is more reasonable policy for control software vendors. By this, the control software vendors can reduce the reliability problems related to the end-user program errors yet give more flexibility to OEMs to select various devices and implement special control/user interface software. End-users who do not want to develop the system software by themselves also prefer this policy because the license for run-time module only is less expensive than that for a development kit. In general this type of software does not give the full programmability of the software even to the OEMs. For example, the hard real-time portion of the software of MDSI control (such as servo control) cannot be modified by any level of users. Companies like ATR, Unova, and MDSI fall into this category.

3.3.3 Network connectivity and third party software integration

In addition to the interoperability of the control hardware, another important requirement of the open systems is the easiness in end-user implemented software implementation and connectivity of the enterprise network. Most products show strong capability to connect to the enterprise network and to exchange data with third party software.

There are three methods frequently used to allow the user developed applications in the industry open system: API (Application Program Interface), component programming, and client-server type methods.

For API method, the control software vendors provide APIs to access low-level (system-level) program in their controller software suit. User programs in C, C++, or Visual Basic language (at this moment, it is hard to find a control software which provides Java API. However, the Java API is expected soon.) use the API library. This method gives the users most freedom to program and access the system variables and functions. Some controllers have two levels of APIs: one for system core executives and the other for the HMI level APIs. Using the two-level API policy, the controller vendor restricts the access to core module by user for the security and real-time performance. ATR, Cimetrix, and MDSI provide *system-level* API; Allen Bradley provides *HMI-level* API; and Unova provides the *two-level* API.

The component programming method utilizes Microsoft's ActiveX and Component Object Model (COM) technologies. The required programming knowledge and the programming efforts are similar to the API method. However, the software can be more modular and does not require rebuilding of whole controller software after the program is modified. Allen Bradley supports the ActiveX (or COM) interface. Recently Microsoft proposed a framework called Windows DNA for Manufacturing (Windows Distributed interNet Applications Architecture for Manufacturing, also called as Windows DNA-M). This framework is a further development of the Microsoft Internet technology and component programming technology (based on COM). Common Object Request Broker Architecture (CORBA) is another methodology to use the distribute object component model. Unlike the COM and ActiveX technologies use the Microsoft Windows systems the CORBA is cross-platform technology.

The client-server method is similar to the component programming methods but uses a predefined standard to connect the user programmed modules and controller software. The typical implementation of the client-server method is Microsoft's DDE (Dynamic Data Exchange) technology. To utilize this method, the controller software has DDE server inside. The external application accesses and modifies the controller variable through the DDE. OPC (OLE (Object Linking and Embedding) for Process Control) is another example of this method. Since the interface between system and user developed application uses standard method, this method has an advantage that the users can easily develop applications or even use the third party applications to add required function to the system. Another advantage is easy implementation in the network environment. On the other hand, because of the overhead to implement the standard, the inter process communication speed is relatively slow. Including the OPC, in the existing systems these methods are used only for user interface or low speed application. Most products on the market support DDE. OPC is very popular among process control and HMI products and now being supported by some CNC controllers such as MDSI OpenCNC.

Information and/or specification exchange between the systems is also important for the open system. Recently XML (stands for eXtended Markup Language) is widely considered as a standard data format to exchange/store information on machining data, diagnostic data, and machine tool modules. The XML is a markup language for documents containing structured information which contains both content (words, pictures, etc.) and some indication of what role that content plays (for example, content in a section heading has a different meaning from content in a footnote, which means something different than content in a figure caption or content in a database table, etc.). Almost all documents have some structure. The XML has a good potential to be used in Internet based manufacturing environment. The web page is http://www.xml.com.

Another emerging methodology for the modeling and specifying of a system is Unified Modeling Language (UML). The UML is the industry-standard language for specifying, visualizing, constructing, and documenting the artifacts of software systems. It simplifies the complex process of Object-Oriented software design, making a *blueprint* for construction. The earlier version of the UML called *Rational ROSE* was used to generate and represent the UMOAC controller object model. Recently, the real-time code generators based on the UML are available from several companies. The web page is http://www.rational.com/uml/index.jtmpl.

3.3.4 Enterprise Integration

The trend toward convergence of various control technologies (e.g., PLC, CNC) and their implementations on PC-based computing platforms created and additional benefit of the ability of a CNC to go beyond *motion-centric* applications. The PCs are already a natural part of the information systems, thus when they are used as direct control platforms, they are able to provide very detailed information about the process, machine or system they control. The information created during the manufacturing process can be very valuable to other parts of the organization, e.g., accounting, quality, logistics, purchasing, etc. With PC-based control systems, this information is easy to capture and communicate.

The control system creates information as it works: product quality, machine utilization, throughput, material consumption, etc. This information is captured at the point where it is created. The control system can also directly use information from the larger enterprise: desired product, desired throughput, product mix, special processing instructions, maintenance information, etc.

The effective communication of these types of information enables enterprise integration. It also makes possible tracking of the product through its entire production cycle. This information can be communicated to other processes that will incorporate the product or even directly to the end customer.

PC-based control systems can connect to the information infrastructure through the common services such as Ethernet or TCP/IP, which enable connections with other computers. Then they can exchange data in the form of transactions that can span the complete geographical range. In support of these enterprise-wide applications, software companies are introducing new technologies, such as, for example, Distributed iNternet Architecture for Manufacturing (DNA-M by Microsoft), which provide a standard model and toolset to link various layers of software in standard ways. Nevetheless, a PC-based controller remains a low-level building block that can provide timely manufacturing floor data.

4. Standards and Organizations

4.1 OAC related standards

This section lists several standards which are highly related to the OAC. It is desirable that several standards are proposed for the open system control and diagnostics (such as IEC 61499 and IEEE P1232). Unfortunately, in reality, not many OAC products follow the standard strictly. For example, it is difficult to find a PLC product that supports all IEC 1331-3 languages or easily import and export its program to and from another system. This is because there are already many proprietary standards (for example bus standards for PLC) for each company and each standard has its own advantage. This is different situation compared to the PC peripheral and software market where the standardization is more advanced. This situation makes it difficult to achieve the interoperability between the control systems. However, the PC-based approach will eventually promote the standardization of the PC based control system.

4.1.1 IEC 61499

IEC 61499 is a proposed future standard for the system model of open distributed automation systems with intelligent control component. This proposal is based on the IEC 61331-3 which is the enhanced version of IEC 1331-3. The standard uses the function block model and finite state machine to represent the structure and behavior of a system. The standard proposal can be found in ftp://ftp.cle.ab.com/stds/iec/sc65bwg7tf3/ html/news.htm and ftp://ftp.cle.ab.com/stds/iec/sc65bwg7tf3/html/news.htm.

4.1.2 SERCOS Update 98.1 (IEC 61491)

This is recently updated SERCOS standard. The update include information on additional diagnostics, information on additional drive and motor parameters, description of cyclic data containers, and so on. The new SERCOS ASIC will be available during year 2000. With this, the SERCOS will operate at 2/4/8/16 Mbits/sec, a 400% increase in maximum speed over the present 2/4 Mbit/sec ASIC.

4.1.3 IEEE 1394

IEEE 1394 (also know as *Fire Wire*) is fastest commercial plug and play serial communication bus faster than conventional IEEE 488 or USB (Universal Serial Bus). It is expected that the IEEE 1394 (or USB) will replace the IEEE 488 (or GPIB) bus in the near future. Microsoft Windows CE 3.0 plans to support IEEE 1394. JOP has a subgroup to investigate the use of IEEE 1394 in manufacturing sensor bus. The web page is http://developer.apple.com/hardware/FireWire/.

4.1.4 IEEE 1451 family

IEEE 1451 is a new family of standards proposed for connecting smart transducers to networks. The standard is composed of specification of an *electronic data sheet*; and the interface to access that data sheet, read sensors, and set actuators. The standard is not about the network specification or network standard, but may be used with existing multiple networks. The web page is http://www.ic.ornl.gov/p1451/p1451.html/.

4.1.5 IEEE P1232

The purpose of the Artificial Intelligence and Exchange and Service Tie to All Test Environments (AI-ESTATE) is to standardize the interfaces between functional elements of an intelligent test environment and to standardize the representations of knowledge and data for the functional elements of the intelligent test environment. The standard supports the portability and interoperability of diagnostic reasoning system component. The AI-ESTATE will support the development and applications of artificial intelligence techniques in the field of system test and diagnosis. The web page is http://grouper.ieee.org/groups/1232/index.html

4.1.6 IEEE Std 1003.0

The IEEE 1003.0 *Guide to the POSIX Open System Environment* presents an overview of open system concepts and their applications. Information is provided to persons evaluating systems based on the existence of, and interrelationships among, application software standards, with the objective of enabling application portability and system interoperability. The framework is to identify key information system interfaces involved in application portability and system interoperability and to describe the services across these interfaces. The concept of the guide is discussed with examples from several application domains. The web page is http://standards.ieee.org/reading/ieee/std_public/description/posix/1003.0-1995_desc.html.

4.1.7 ISO 7498-1:1984

The purpose of *ISO 7498 Information Processing Systems - OSI Reference Model - The Basic Model 1* is to provide a common basis for the coordination of standards development for the purpose of systems interconnection, while allowing existing standards to be placed into perspective within the overall *Reference Model*. The web page is http://www.acm.org/sigcomm/standards/iso_stds/OSI_MODEL/ISO_IEC_7498-1.TXT

4.2 OAC related organization

4.2.1 PLCopen

PLCopen is a vendor- and product-independent world wide association supporting IEC 61131-3 founded in 1992. Via this programming standard we want to provide greater value to users of industrial controllers. By implementing this standard on many program development environments (known as Program Support Environments or PSEs in the IEC 61131- terminology), users can move between different brands and types of control with very little training and exchange applications with a minimum of effort. To reach this goal, the members of PLCopen are committed to supply and/or use IEC 61131-3 compliant products. To guarantee compliancy, certification by PLCopen accredited institutes has been realized, increasing the common implementation. Web page is http://www.plcopen.org.

4.2.2 OPC (OLE for Process Control) Foundation

OPC is worldwide working group to develop a standard mechanism for communicating to numerous data sources, either devices on the factory floor, or a database in a control room using Microsoft OLE technology. The current Microsoft's OLE technology is based on the COM. Many control vendors already deploy the OPC standard. Web page is http://www.opcfoundation.org/.

4.2.3 ODVA (Open DeviceNet Vendor Association, Inc.)

ODVA is an independent organization that manages the DeviceNet Specifications and promotes DeviceNet. ODVA works with vendors and provides assistance through developer training, conformance test tools, conformance testing, and support of vendor Special Interest Groups (SIGs) in developing enhancements for the DeviceNet Specifications. The DeviceNet products include not only the communication between PLCs but also actuators, sensors, motion controls, and I/O's

The University of Michigan has the DeviceNet test lab. (U of M Sensorbus Lab, , Director: James Moyne, http://www.eecs.umich.edu/~sbus). The web page of ODVA is http://www.odva.org/.

5. Discussions with Industrial Users and Suppliers

5.1 Summary

Over the last year we have discussed the topic of OAC with several control experts which represents different segments of the machining industry: end users, machine builders R&D experts and suppliers of control systems. During the meetings we have asked a set of similar questions, however, the discussions were open. Appendix **A** present a short summary of the answers. In this chapter we shall try to address some of our observations and conclusions.

First, the perception of what is Open Architecture Control is different according to the field and interests of each person. There is no one common term that is accepted or used, however, the idea of a system that its hardware independent, is interchangeable and easily scalable may represent the common denominator of the answers.

The high costs of machine tool controls which is about 35% of the overall investment in any new machining production line is another major concern for both the users and the suppliers of control systems. Many of them are reluctant weather the new open architecture will reduce the costs. The tendency was to disagree with this assumption. Many believe that the “openness” and flexibility is more expensive than proprietary existing systems. Our observation was that the answer depends on weather the person is involved in the installation of new systems where the initial investment is important or is involved in the production process where maintenance, downtime problems and systems upgrading are the main concern. One way to come up with a better answer to the economic concern is to study and evaluate the life cycle cost of control systems.

The real problem of the industry is the diversity of equipment in the plants and the lack of common standards. As a result of this situation, the downtime of production lines due to maintenance problems is higher and the training process of line operators to use different types of human-machine interfaces (HMI) is expensive. The OAC may introduce standardization to the control industry once the leading companies will decide to enforce unified standard on their suppliers.

Industry expectations from OAC technology are related to lower prices and easier operation of control systems. OAC systems should allow plug and play functionality independent of hardware.

We observed that it was not easy to address the reliability problems of the new technology since there is no enough experience with OAC applications in practice. The proprietary control systems existing today are quite reliable and well supported by the manufacturers. The maintainability and the upgrading of the various control systems in the plant are the main concern. Different control products produced by different companies with no one common standard are a major maintainability problem. The challenge of OAC technology is to suggest new tools to solve it.

5.2 List of specific topics and needs as raised in the meetings

5.2.1 Economical Studies

- Economical study of OAC implementation in a reconfigurable domain or scenario.
- Life cycle estimation of Control Costs - Investments in development and line building vs. Operational costs Up-time, training, maintenance, control systems updating.
- The value of running *one* control system standard vs. multi systems today – Plant Up-time, Training costs, Reduction of spare parts, Increase use of new technology.

5.2.2 Setting Standard

U of M could serve as a third Party between users and machine/control designers and builders to adopt *One* standard.

5.2.3 Universal Logic Translator

The U of M should develop software translator to translate machine logic states that describe one single mechanism, to any logic software language.

5.2.4 Universal Application Programming Interfaces (API) and Unified Human Machine Interface (HMI)

Develop a common API for any control system (GE Fanuc, Siemens, Allen Bradley or Indramat) and a common HMI. Build the system and demonstrate its OPENNESS.
They believe that the traditional suppliers will remain on the market to support the products. By this approach it will be possible to combine any kind of equipment to a single HMI. (Similar to Boeing approach for CNC manufacturing equipment)

5.2.5 Research on the reconfigurability problems of real-time software

To develop both relevant theory and software infrastructure to support reconfigurable real-time software that will also contribute to develop Reconfiguration Science.

6. Discussion

6.1 Trends

Through the market survey and discussion with industry representatives, we found the industry shows great interest in adopting open architecture control. Various products for the OAC are already available on the market. The PC and Windows based control systems become gradually popular in the manufacturing environment. We found that the OAC idea may be achieved using existing technologies that are already available. However, the behavior of manufacturing industry is conservative for changing its production environment. Furthermore, the faster change in technologies related to the OAC that the manufacturing industry's changing speed makes it even more difficult to adopt the new technology. Consequently, the OAC becomes the one of the area where the great gap exists between the state-of-art technology and real world implementation in terms of the PC applications.

The recent activities by OAC initiative groups, such as OMAC, OSACA, JOP, and the University of Michigan ERC/RMS have achieved lot in terms of definition and concept of the OAC, reference architectures and testbed examples, and standardization. However, still continuing efforts to make a standard between these groups and manufacturers are required to leverage the benefit of the OAC and to make the industries accept the OAC idea (Yen 1998). The efforts to set standards for the HMI, API, and communication through Internet are promising in this sense.

6.2 Discussion of possible directions of research for ERC

The following list of research topics is suggested as a background for ERC further discussions about future research direction related to OAC. The list reflects our study, which was focused on market availability of new equipment and on industry needs. Many other topics related to basic scientific research in the field of software and controls are not mentioned here however they may be suggested and discussed as well.

(1) Develop *configuration tool* for modular control design on machine level that is based on open architecture control approach. The design tool will get design specifications and control methods as an input to the desgn process. In the next stage it will approach a library of modular controllers that are available on the market and may be applied in OAC. The tool will configure possible H/W and S/W solutions and will check them in simulation to see if the specification requirements are met. The configured control system will be than applied in h/w, tested and feed back to improve the process.

(2) The area where the U of M researchers may contribute is adding value to existing commercial products by developing software application, which requires interdisciplinary knowledge, analytical abilities and system understanding. For example, integration of Open Front network based execution control system to the OAC. Component of the Open Front software suit such as FSM (finite state machine)

generator and system configuration tool can be integrated to machine level and can be utilized for supervisory control and configuration tool described above.

(3) Economics of OAC systems. There are several economical studies that interest our industrial partners.

a. *Life cycle estimation of Control Costs* - The first topic is related to the evaluation of the current situation of the overall control cost in a typical manufacturing plant, using economical tools. It is understood that the relative part of *Control expenses* is growing every year but the trend should be formally investigated and evaluated as a first step before considering implementation of OAC systems. The research should include estimation of the investments in building the “control” of a production line vs. operational costs, down-time, training, maintenance and control systems updating.

b. The second study may be *The added value of installing OAC control system as compared to current situation* – The study will include evaluation of plant variables such as: up-time, training costs, reduction of spare parts, the value of easier implementation of new information technologies.

c. *Economical study of OAC implementation in a reconfigurable domain* - Finally, the economical advantages and disadvantages of applying OAC system for RMS. This study may be included as a chapter in one of the formerly suggested studies.

7. References

Koren, Y. (1998) "Open-Architecture Controllers for Manufacturing Systems," Koren, Y. et al., Eds. *Open Architecture Control Systems – Summary of Global Acitvity,* ITIA Series, Vol. 2, 15-37.

Mathias, D., and Hellmann, R. (1999). "Boeing implements HMI," Manufacturing Engineering, 78-82.

Pritschow, G. (1998). "Status of Specification and Implementation within OSACA/HÜMNOS Project," Koren, Y. et al., Eds. *Open Architecture Control Systems – Summary of Global Acitvity,* ITIA Series, Vol. 2, 15-37.

Yen, J. (1998). "GM and OMAC in partnership," Manufacturing Engineering, 90-92

Related web pages

CNC and PLC companies

Allen Bradley:
Rockwell Automation: http://www.ab.com/cnc/
Rockwell Software: http://www.openautomation.com/controlpak/
Advanced Technology & Research Corporation: http://www.atrcorp.com/
ASAP Open Control: www.asapinc.com
Cimetrix Incorporated: www.cimetrix.com
CJ International: http://www.isagraf.com/default.htm
Cranfield Precision: www.cranfieldprecision.com
Cutler-Hammer: http://www.cutlerhammer.eaton.com/automation
Iconics: http://www.iconics.com/
Indramat (A division of RexRoth, Germany): www.indramat.com
Manufacturing Data Systems, Inc.: www.mdsi2.com
Nematron Corporation: www.nematron.com
Think & Do Software, Inc: http://www.thinkndo.com

Operating Systems

Windows CE: http://www.microsoft.com/windowsce/embedded/
Windows NT: http://www.microsoft.com/ntworkstation/
Windows NT Embedded: http://www.microsoft.com/embedded/products/winnt.asp
RTX: http://www.vci.com/products/vci_products/rtx/rtx_index.html
iRMX: http://www.radisys.com/products/embedded.html
Hyperkernel:
http://www.nematron.com/solutions/software/hyperkernel/hyperkernel.html
QNX: http://www.qnx.com/

VxWorks: http://www.windriver.com/products/html/vxworks.html

Microsoft DNA for manufacturing

http://www.microsoft.com/Industry/man/developers/initiatives/initiatives.stm

Standards

IEC 61499: ftp://ftp.cle.ab.com/stds/iec/sc65bwg7tf3/html/news.htm
IEEE 1394: http://developer.apple.com/hardware/FireWire/.
IEEE 1451: http://www.ic.ornl.gov/p1451/p1451.html/.
IEEE P1232: http://grouper.ieee.org/groups/1232/index.html
IEEE 1003: http://standards.ieee.org/reading/ieee/std_public/description/posix/1003.0-1995_desc.html.
ISO 7498: http://www.acm.org/sigcomm/standards/iso_stds/OSI_MODEL/ISO_IEC_7498-1.TXT

Organizations

OMAC: http://www.arcweb.com/omac/
OSACA: http://www.osaca.org
JOP: http://www.mstc.or.jp/jop
PLCopen: http://www.plcopen.org/
OPC: http://www.opcfoundation.org/
ODVA: http://www.odva.org/

8. Appendix A - Meetings with Industry Control Experts

8.1 Responses from industry partners

We made an effort to include here all main ideas and to reflect in the best way the various views. Many interesting topics, which were discussed in the meetings, are not included. We appreciate the opportunity to talk to the industrial experts and to learn about the real concerns of control systems in machining plants.

Question 1: What are your views on what Open Architecture Control (OAC)?

- "One controller that runs dozens of axes on a transfer line."
- "Architecture that supports different I/O Communication networks. Distributed control "
- "It should interface with all types of servo controllers."
- "The ability to use interchangeably hardware from different suppliers."
- "Universal control system in a plant that one can train people to maintain it."
- "From development point of view OAC enables adding functionality to the control system."
- "OAC is based on Operating System (OS) which is the best possible, as industry standard not tied to proprietary hardware."
- "Control with open interfaces"
- "OAC equivalent to PC controllers"
- "Any system that must be scalable and enables hardware scalability"
- "Being able to plug in any device which cannot be handled by conventional PLC to Microsoft PC system"
- "Allows user to select device, bus, and software"

Question 2: As a user, please define what are the *real problems* of machine tools control systems.

- The machine tool builder sees too many types of controllers.
- Training and maintaining are key issues. Too many suppliers, large inventory and back up systems.
- Too much *downtime* due to control maintenance.
- Obsolescence: every 3-4 years the control technology changes and the systems are hard to maintain.
- The real problem of the control system is its high cost. (Investments in control)
- The need for integrated sensors as required for real time adaptive control.
- The need to apply lean engineering and the ability to supply on time configured systems.
- Lack of data of root cause of failure of system. Lack of diagnostics on line because of different budgeting inside companies that does not allow implementing such systems.

Question 3: What does a user expect to get when he asks for Open Architecture Control?

- Expects to get it cheaper (which may be not true).
- Believes that it will be easier to operate, again may be not true.
- Any hardware will be accepted by the system. When one buys equipment, he does not look on the name of the supplier.
- To get *plug and play* functionality
- More flexible system
- Exact specification user wanted regardless of availability in the market (which can be done only by OAC in many times)

Question 4: What are the applications that the OAC technology will enable or support?

- Machine documentation on the machine on-line.
- Collect reliability information with regards to machine performance.
- Will enable to utilize technology much faster.
- High-change market (for example consumer electronics)

Question 5: Do you see any reliability and/or maintainability problems due to the openness of the OAC systems?

- Windows NT is not Bug free environment. Proprietary means *clean* system.
- May be a problem of *over flexibility* as encountered in computer industry.
- There may be new types of unique problems related to the implementation OAC.
- OAC should be an *Idiot-proof* system.
- Some people see more problems than advantages. Today control suppliers support the system for 5 years. You cannot expect it from computer industry or s/w suppliers. The disadvantage of having a sole source is an advantage of dual commitment.
- Reliability of the OAC system depends on component used (for example GM plants use PC-based controller for years)
- Diagnostics at the operator level are more important in OAC

Question 6: What would be the preferred research direction that will serve industrial users needs? (Basic research in control and real time software, User interfaces, OAC Standards, Specific application development or any other topic)

- To measure *operating system robustness* or to study *how it crashes*.
- To come up with standard terminology.
- No research is required. Let's just agree on the standards.
- The U of M could serve as a third party between user and machine (control) builders to adopt *one* system.
- Economic research is required to estimate the value of one system vs. multi-systems today.
- U of M may develop an API to demonstrate *openness*. The API research may drive the standards.
- How to establish "Global Architecture" control system, for international supplier of control systems.

- To extend the open bus networking to include more methods.
- Development of programming basis which can be easily transferred to different systems with out throughput variation.
- Use Linux in control.

Other topics that have been discussed:

- The user may lose the support and the service of the control suppliers due to the use of OAC systems coming from various vendors.

- New profession was created: *OAC Integrator* – System house for control integration and service.

- Openness of the system and PC based controlled systems may bring viruses to the manufacturing environment. Security issues become important. PC equipment and software is not *Bug free*.

- Propriety equipment = *Clean* system.

Table 8.1 Discussion participants

Name	Affiliation
Bryan Graham	Lamb Technicon
Larry Streng	University of Michigan (GM retiree)
John Cooper	Ford
Rich Furness	
C.V. Ravishankar	University of Michigan
Bill Grant	Cummins
Steve Hayes	Rockwell Automation
Anthony Maceri	Comau North America
Jim Mooney	
Aldo Marcuzzi	Nematron Corporation

9. Appendix B - Overview of Controller Market

The common view of the automation controls reflects several segments: PLC, CNC, DCS, and Custom. In addition, three layers of control have developed: software, controller, and I/O devices. Lines among the various controller types have blurred due to a convergence of functionalities and technologies. For example, the movement to PC-platform implementation resulted in decoupling I/O modules from the hardware platform.

The current size and structure of the CNC control market is historically linked to the situation in the machine tool market. While in the 70's United States was the single largest market for machine tools, today the leadership in this respect has shifted to Japan (24%) and European Union (19%), when the U.S. has dropped to a distant third (7%); rest of the world accounts for the remainder.

The installed base of NC/CNC machine tools is estimated to be over 3,000,000 machines worldwide. Ninety-five percent are equipped with proprietary closed systems that can't communicate with any other system, and sixty percent of the CNC controls in the world market are older than nine years (and perhaps in need of replacement).

The worldwide consumption of CNC controls in 1998 was 220,000 units, which accounted for 53% of total machine tool sales that year. At a conservative annual growth rate, the market for CNC controls will be 225,000 units per year by 2001.

The current worldwide sales in the CNC controls and unbundled support products exceeds $3.5 billion (1999). The market leaders in this area are the following companies: GE Fanuc, Heidenhain, Indramat, Mitsubishi Electric, and Siemens E&A. GE Fanuc holds over 70% of the U.S. market share.

There are a number of trends taking place in the market, as new products are offered by the leading vendors:

? The control is moving from a proprietary hardware-based system to an unbundled software-only control.

? The control is moving from an "experts-only" supported product to a consumer product that can be supported, upgraded and maintained by the end user.

? CNC controls are moving from standalone islands of technology to network-distributed technologies, enabling the machine tool to become an online peripheral on the network.

Thus it is important to look at the data from the other segments of the automation controls market, which include:

? PLCs (programmable Logic Controllers) in 1999 generated worldwide revenue of $5.3 billion. Market leaders include: Mitsubishi Electric, Omron, Rockwell Automation, Schneider Electric, and Siemens E&A.

? Remote/Distributed I/O market with $2 billion in worldwide revenue. Market leaders: ABB Automation, Fisher Roemount, Foxboro, GE Fanuc, Honeywell, Mitsubishi Electric, Rockwell Automation, and Siemens E&A.

? General motion control products, including, unbundled components, software and services, exceeded $4 billion in sales worldwide. Leading suppliers include: Bosch Electric, Matsushita, Mitsubishi Electric, Siemens E&A, and Yaskawa Electric.