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TECHNICAL PAPERS

Analysis of Open CNC Architecture for Machine Tools

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The evolution of digital circuit technology, leadind to higher speeds and more reliability allowed the development of machine controllers adapted to new production systems (e.g., Flexible Manufacturing Systems - FMS). Most of the controllers are developed in agreement with the CNC technology of the correspondent machine tool manufacturer. Any alterations or adaptation of their components are not easy to be implemented. The machine designers face up hardware and software restrictions such as lack of interaction among system's elements and impossibility of adding new function. This is due to hardware incompatibility and to software not allowing alterations in the source program. The introduction of open architecture philosophy propitiated the evolution of a new generation of numeric controllers. This brought the conventional CNC technology to the standard IBM – PC microcomputer. As a consequence, the characteristics of the CNC (positioning) and the microcomputer (easy of programming, system configuration, network communication etc) are combined. Some researchers have addressed a flexible structure of software and hardware allowing changes in the hardware basic configuration and all control software levels. In this work, the development of open architecture controllers in the OSACA, OMAC, HOAM-CNC and OSEC architectures is described.
Keywords: *Open architecture, CNC, machine tool*

Introduction

The industrial automation evolution in current manufacturing systems demands established rules betweenequipment manufacturers (such as CNC machines) and customers that use production techniques based on operation and integration of automatic equipment (like Computer Integrated Manufacturing – CIM). These rules are needed because of problems during implantation and maintenance of complex factory controller's network.

Engineers and technicians are limited as far as hardware and software are concerned when they need to expand, maintain and integrate the "production islands". Hardware and software problems usually do not allow the use of the same control hardware, elevating costs for nincrease in production

Solutions were proposed which seek the "open way". The meaning of "open way" for Wada (1996) is the independence from the manufacturer's technology, allowing the user to buy hardware and software from several different manufacturers and freely assemble the acquired pieces of equipment.

Thus, the Open Architecture Controller have the capacity to integrate pieces of equipment from several different manufacturers and to obtain control solutions with several programmable application interfaces, maintaining the same performance at lower costs.

The first works on Open Architecture Controller began when the NIST (National Institute of Standards and Technology) proposed the use of RCS (Real-time Control System), which is an architecture model of 15 years ago (Proctor and Albus, 1997). The RCS model was the base to the NGC (Next Generation Controller) program, co-sponsored by NCMS (National Center for Manufacturing Sciences) and the United States Air Force, verifying the industrial needs to next generation controllers. Researches began with the development of the standard SOSAS (Specification for an Open Systems Architecture Standard) (Yamazaki, 1996).

In spite of this effort, the CNC Open Architecture still remains without defining a universal pattern. There are however several developments of architectures in research centers that allow alterations in the software and in the hardware, offering a large number of possible design configurations.

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Specification of an Open Architecture System

An Open Architecture Controller should be flexible in hardware as it is in software for all control levels (Wright et al., 1996). An Open Architecture Controller must be standard to allow hardware and software development by any engineer or technician, and its integration with other controllers, cell control systems and high level planning systems (Schofield, 1996).

The machine tool open controller should permit the integration of independent application program modules, control algorithms, sensor and computer hardware developed by different manufactures (Pritschow et al., 1993).

An Open System allows to program in several platforms that interact with other application systems.

Some specifications of an open architecture system are (Miles, 1998) (Oshiro, 1998):

- Interaction: due to communication of standard data semantics;
- Interoperability: same component function by different manufacturer;
- Portability: the easy with which application software can be transferred fromone environment toanother.
- Scalability: system ability to increase or to decrease according to the demand.

Architecture Types

Some efforts to define an Open Architecture System will be addressed below:

OSACA Architecture (*Open System Architecture for Controls within Automation Systems*)

The OSACA (1998) architecture is a Control Open System Architecture for Automatic Systems. It appeared in Europe with the ESPRIT III Project 6379 program, being one of the largest projects involving standards for OAC (Open Architecture Control), that includes network connection and applications (Koren et al., 1996a).

The OSACA project began in 1992 in research institutes of France, Germany, Italy, Spain and Switzerland.

The main goal of the OSACA project was the definition of an independent hardware and modularity, that is, to work in modules allowing the addition or removal of numeric control, robot control, Programmable Logical Controllers (PLCs), cells control, etc. To manage these modules, it was created the OSACA phase II project 9115 to establish software modular systems, communication interfaces, operation and open data base systems for new functions and for the use in new digital equipment (Pritschow et al., 1993).

Following the same research line, it was created in Germany the HÜMNOS (Modulate Development for application in object oriented open architecture control system) project. This project development is based on the OSACA results. It had the participation of final users (BMW, Mercedes Benz), machine tool manufacturers (Alfing, Fritz Wener, Grunewald, Heller, Homag, Hüller Hille, Index, Mikromat, Pfauter, Trumpf and Unipo) and the controller manufacturers (Bosch, DASA, Grundig electronics, ISG, SIEMENS), along with of this project several research institutes.

The objective is to exchange information between users and manufacturers, bringing benefits to both. The OSACA architecture allows the assembly of the machine tool control using a user interface, without the need to review the whole software (Altintas, et al., 1996). To reach this goal it is necessary to know the concept of platform.

A platform is composed of hardware and program groups (operating system, communication system) that offer a uniform service for the functional unit (FU) control. The application-programming interface (API) with the FU is based on a well-defined task.

The three main platform areas are:

- Communication System: hardware and software are defined independently of the information exchange interface among different modules of the controller application. The OSACA communication system allows the information exchange in a transparent way between client and server applications.
- Reference Architecture: determines the control FU and specifies the external interface. This is done to enable the use and integration ofexternal units through internal data in a well-defined way. FU examples are Man Machine Interface, Interlock Logical Control, and Axes Movement Control. For each identified FU, an external module using an object oriented communication for data interfacing with application modules is defined. The interface of writing and reading data access is located in the Architecture Oriented Object and this access is available with the use of a Communication Oriented Object.
- System Configuration: Allows a controller dynamic configuration through a combination of different application modules. This does not only allow determining a specific topology of a given functionality, but also the synchronization among the distributed processes.

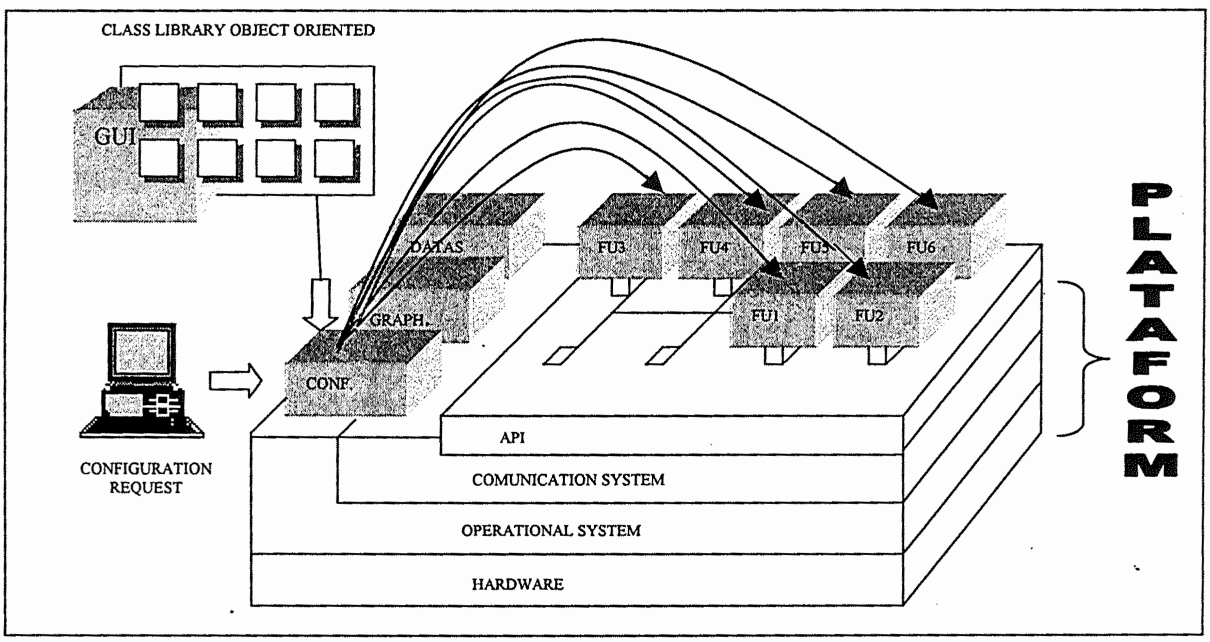

Figure 1. System platform (OSACA, 1998).

Figure 1 describes the platform of the OSACA system, where a configuration request generated by a microcomputer is sent to the system. The reconfiguration uses FU (Function Unite), which works, based on object oriented programs, a class library, with variables and internal data. The OSACA application protocol uses a client/server base mounted on the object orientation principle. All FU functionality will have external access and it is configurable by the communication platform. From the customer's viewpoint, the server can be accessed through shipping and reception of system communication messages.

OMAC Architecture (*Open Modulate Architecture Controllers*)

The OMAC architecture had its beginning in December of 1994 with the publication of "Requirements of Open, Modulate Architecture Controllers for Applications in the Automotive Industry" by Chrysler, Ford and General Motors. This document served as a guide for controllers API in the North American automobile industries.

The OMAC group is composed of open architecture system users, whose objective is to work together, bringing several benefits (Yen, 1998), such as:

- to establish a position of the open architecture controllers based on experience of the software users and machine manufacturers;
- to accelerate the open control use within the industries, with the use of APIs;
- to promote the development of open control among controller manufacturers;
- To develop collective solutions for the development, commercialization and use of open architecture controller technology.

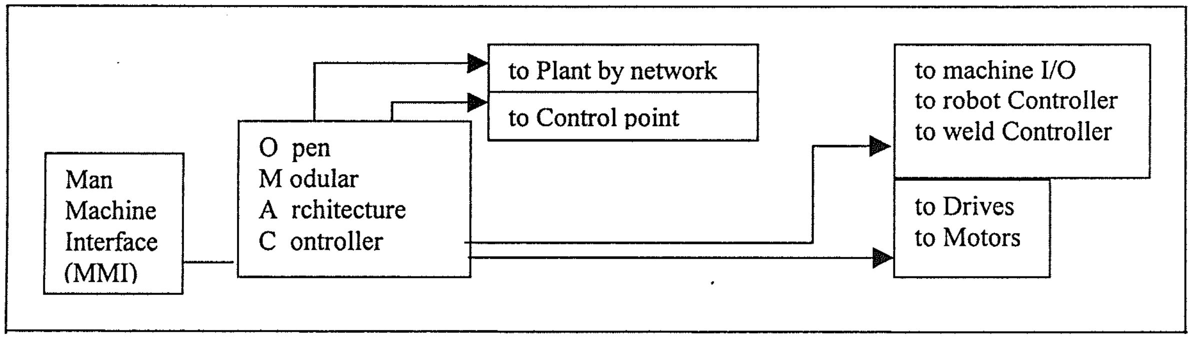

Figure 2. OMAC System simplified plant (Yen, 1998).

HOAM-CNC Architecture (*Hierarchical Open Architecture Multi-processor - CNC*)

The HOAM-CNC architecture – Open System Architecture Hierarchical Multi-processor for CNC machines-acts mainly in the machine hardware, offering the advantages of having two buses, a CNC control bus and another bus to allow the introduction of new components. Some research centers involved in this research line are:

- University of Michigan/Ann Arbor, USA – which studies open architecture controller in real time for machines tools of high performance. They execute the implementation of several different types of hardware control with net communications to study the difference in machine performance depending on the adopted architecture (Koren et al., 1996[a]; (Koren et al., 1996b).
- University British Columbia/Vancouver, Canada - they use this architecture seeking the regulating adaptive control. Modules that detect tool damage and vibration are inserted using acoustic sensors for the control execution. A primary bus is used to execute the machine control process and to monitor the tasks and a secondary bus of higher performance is used to communicate with the CNC (Altintas et. al., 1996) (Yamazaki, 1996).

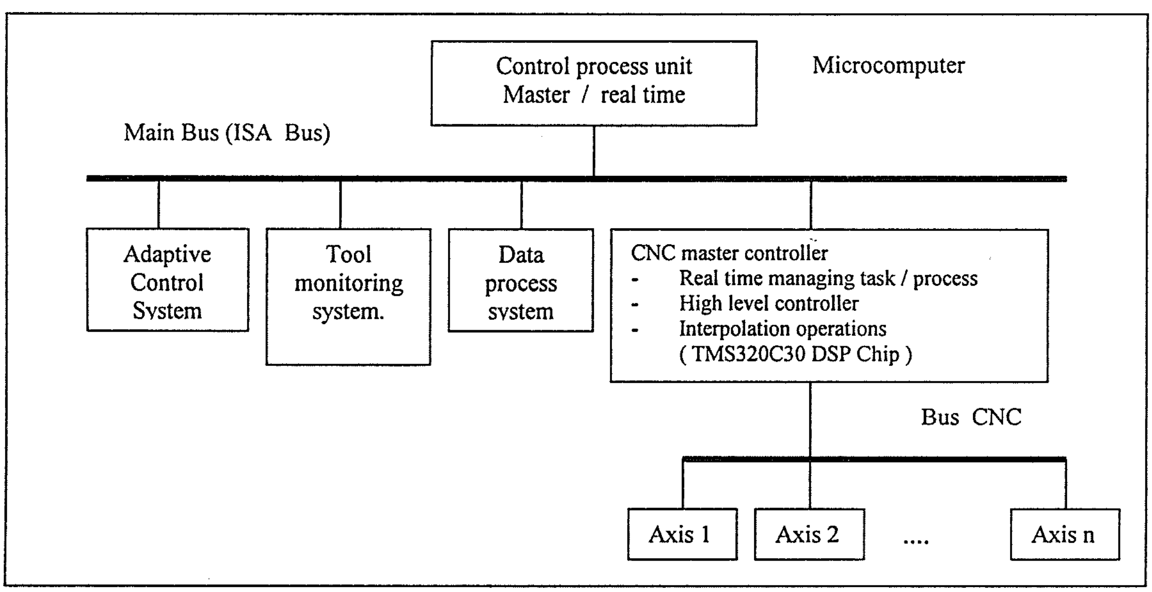

Figure 3. HOAM-CNC Hardware Global Architecture.

Figure 3 illustrates the HOAM-CNC architecture where a microcomputer is used. The standard main bus ISA deals with the monitor activities, data processing, adaptive control and man machine interface (MMI),. The CNC bus deals with the position and speed control of each axis (Altintas et al, 1996), operating the control in real time with a dedicated processor.

The system allows the addition of several processing modules in the primary bus and the interaction of control axes in the secondary bus.

OSEC Architecture (*Open System Environment for Controller*)

Six Japan companies, Toshiba Machine Co., Toyoda Machine Works Ltda., Yamazaki Mazak Co., IBM Japan Ltda., Mitsubishi Electric Co., SML Corporation, composed the OSEC (Open System Environment for Controllers) group, whose objective was to develop a platform of open architecture for numeric control equipment.

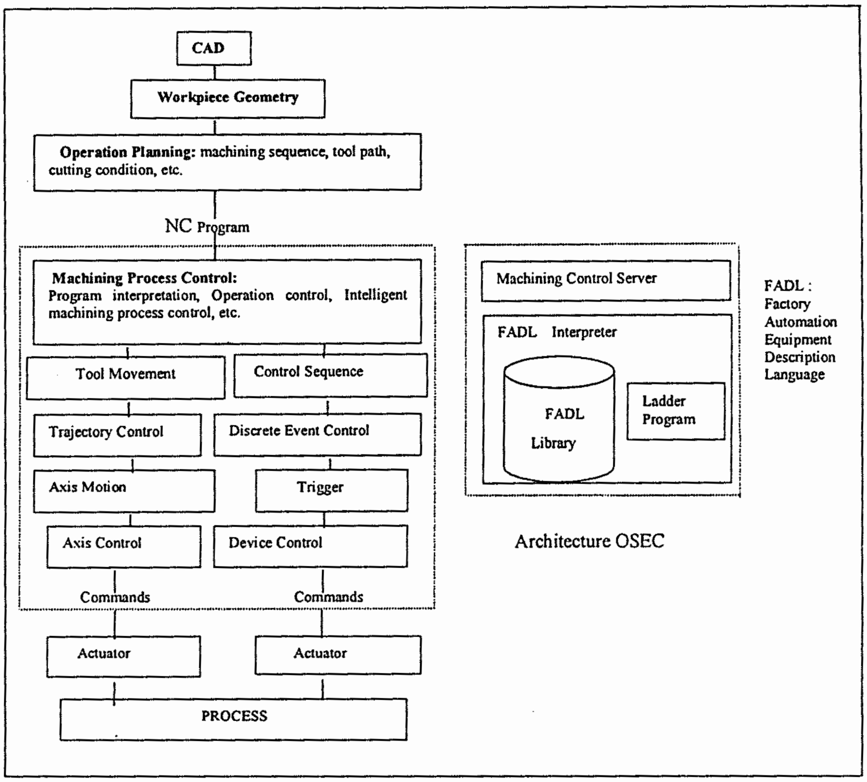

Figure 4. Architecture OSEC.

The purpose of this group is to create an open architecture based on a standard personal microcomputer IBM-PC to control manufacturing equipment, to improve its performance and to facilitate its maintenance. The personal microcomputer besides controlling equipment can also act as an information base system for the factory operation. In other words, pieces of equipment based on this architecture can be elements of an acquisition and logistics support system based on computer - CALS (Computer-aided Acquisition and Logistic Support) (Yamazaki, 1996).

There are many research centers working on this open architecture concept, such as the USA Navy with the enhanced machine controller project - EMC (Enhanced Machine Controller), with the Trade Department support that proposed a five level architecture:

1 - workstation planning;
2 - workstation managing;
3 - plan interpretation;
4 - trajectory generation/ discrete input and output (I/O);
5 - servo controls.

The project includes thermal deformation error compensation and NURBS (Non Uniform Rational B-Spline) interpolation (Yamazaki, 1996).

The USA Energy Department with the TEAM-ICLP (Technologies Enabling Agile Manufacturing - Intelligent Closed Loop Processing) project concentrates its researches on the development of an API oriented to open architecture.

The National Center for Manufacture Science (NCMS) that launched the NGIS (Next Generation Inspection System II) project is seeking the development of a sensor process inspection interface.

Trends

Several projects presented by companies and research centers seek the development of controllers that supply a machine with new technologies to increase. mainly by establishing world hardware and software patterns so that the technological dependence between manufactures and customer ends.

The increase in programming and configuration flexibility due to the open architecture of CNC generates a modular service composed of reused object oriented pieces of software and the electrical-mechanical system controlled by one or more control processors.

The future trend is the use of autonomous CNC, managing and processing all internal (intrinsic to the machine) and external (related with the production planning) elements. For this, it is necessary to develop several sections:

Planning Section: where the product project (CAD - Computer Aided Design model) and the raw material are received. The planning is executed with the available resources;

Internal Analysis Section: verifies the part machining, storing the best results obtained in the knowledge base. After this, an analysis is executed to classify the part machining in according to the operation sequence, the use of tools, and the cutting conditions needs to control section;

Control Section: execute the real CNC control using compensations and simulation forecasts in real time;

Diagnosis and Control of Quality Section: From the analysis section, the final part is verified, and an autonomous measurement process generates the whole measured data. The quality control verifies the process behavior statistics to diagnose the causes of fails.

The sections above mentioned must:

- use the knowledge base to maintain active the machine operation in an automatic way;
- use the information of the data bases to verify and to modernize the resources (new technology) to improve operation performance;
- use the diagnosis and quality control to check automatically the finish part without human intervention;
- after the finish of the operation, analyzes automatically the operation performance.
- analyze in real time the control model based on simulation and to performance the corrections in the control maintaining the machine tool precision and safety.

The open architecture CNC will have the following characteristics (Yamazaki, 1996):

Transparent: the system architecture should be known completely to the machine tool manufacturers as well as to the final users;

Transportable: any part of the control software can be transported to any remote part or to a personal microcomputer;

Transplantable: the control software can be implemented or modernized;

Liveliness: both the software and the hardware when replaced with new system components should allow the machine to operate immediately and without additional costs;

Re-configurable: the controller functions should be possible to be configured by the user;

Evolution: the complete system must be developed (this means that the intelligent functions should receive information continually).

Conclusion

The use of open architecture CNC is considered of great importance since it is a promising technology that acts in the area of industrial automation, allowing the integration of the equipment, a more friendlyr interface in the configuration, machine tool communication and modernization.

The low cost of the electronic components has been motivating the development of new controllers.

There are several types of open architecture being developed in the USA, Europe and Asia, which use the standard IBM-PC computer for control. The OSACA architecture is used mostyin the software area, the architecture OMAC acts mostly in industrial applications and the OSEC architecture acts in automation in every industrial area, logistics and support. The HOAM-CNC architecture acts in the hardware area in terms of new sensors and special module implementation.

All these architectures have integrated equipment of several different manufacturers and to obtain control solutions at a lower cost, maintaining the same performance.

Some benefits of the open architecture controller are:

- The use of the C + + programming in the design of the control software. Software routines can configure and implement new functions to increase the machine tool performance.
- The application possibility of algorithm development of adaptable control for new applications, which uses force sensor, vibration sensor, acoustic sensor, etc.
- The algorithm execution of special servo-control, increasing the machine tool precision.
- The use of the same operator interface for different machines, simplifying user's training and reducing the costs.

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