PRACTICAL DEVELOPMENT OF AN OPEN ARCHITECTURE PERSONAL COMPUTER-BASED NUMERICAL CONTROL (OAPC-NC) SYSTEM

by

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LIST OF ABBREVIATIONS

CNC	Computer Numerical Control
NC	Numerical Control
US	United State
MIT	Massachusetts Institute of Technology
DNC	Direct Numerical Control
CIM	Computer Integrated Manufacturing
IEEE	Institute of Electrical & Electronics Engineers
PC	Personal Computer
OAPC-NC	Open Architecture Personal Computer-Numerical Control
LabVIEW	Laboratory of Virtual Instrument Engineering Workbench
EIA	Electronic Industries Association
MS-DOS	Microsoft-Disk Operating System
PC-NC	Personal Computer-Numerical Control
3D	3 Dimensional
CAD/CAM	Computer Aided Design/Computer Aided Manufacturing
INCS	Integrated Numerical Control System
OSACA	Open System Architecture for Controls within Automation
OMAC	Open Modular Architecture Controller
OSEC	Open System Environment for Controllers
HMI	Human Machine Interface

API	Application Programming Interface
PLC	Programmable Logic Controller
AO	Architecture Object
JOP	Japan Open Systems Promotion Group
FDM	Fused Deposition Modeling
I/O	Input/Output
LAN	Local Area Network
AC	Analogue Current
DC	Direct Current
N-S	North-South
LED	Light Emitting Diode
VI	Virtual Instrument
LSC	Least Squares Reference Circle
OS	Operating System
DAC	Digital to Analogue Converter
PWM	Pulse Width Modulation
EEPROM	Electrically Erasable Programmable Read-Only Memory
SMI	Smart Motor Interface
PID	Proportional Integral Derivative
P+V	Peak + Valley
HTML	Hyper Text Markup Language

ABSTRACT

In this research, an open architecture personal computer-based numerical control (OAPC-NC) system that can generate G-code was developed. This system was implemented on a milling machine. A driver and an interfacing circuit were developed in order to interface between the machine and PC. Then, the possibility of using the developed controller for Internet machining was also demonstrated. The European OSACA (Open System Architecture for Controls within Automation systems) has been chosen as the basis platform for the proposed OAPC-NC system. Beside that, LabVIEW, a graphical programming language, has been used as the application program interface (API) in developing the software module of the proposed system. In order to test the openness of the developed OAPC-NC system, several addition functions have been added into the developed system. These functions include a different method of G-codes programming, additional features for advanced machining and internet access of the developed OAPC-NC system for Internet machining. Finally, a real time machining is carried out as well as the roundness test on the machined path as to test the performance of the developed system. From the roundness test, the results of machined circular profile have shown the efficiency of the machining path is greater than 99%. Beside that, the deviation of the result is less than the promised error of the new reference pulse interpolator.

As a result, an OAPC-NC system that can generate the G-code programming and operate a milling machine has been developed. Beside that, the stepper motor driver circuit board that is developed has been successfully interfaced between the PC and the milling machine. The results of roundness test have shown the effectiveness and the accuracy of the controller. Finally, the demonstration of the Internet communication program has brought out the ability of the Internet machining. The OAPC-NC system can be use by a variety of NC machine. Therefore, this system has performed the ability in factory communication as to combine a number of difference machines.

PEMBANGUNAN PRAKTIKAL SATU SISTEM KAWALAN BERANGKA BERARKITEKTUR TERBUKA BERDASARKAN KOMPUTER PERIBADI

ABSTRAK

Dalam pengajian ini, satu sistem kawalan berarkitektur terbuka berdasarkan komputer perseorangan (OAPC-NC) yang dapat menjalankan kod kawalan berangka telah dicipta. Sistem ini telah diaplikasi pada satu mesin kisar. Satu litar pengemudian dan perantaramukaan akan dibina untuk mengantaramukakan mesin dengan komputar. Selepas itu, kemungkinan pemesinan melalui jaringan dengan sistem kawalan yang dibina akan ditunjukkan. Sistem Eropah OSACA (Open System Architecture for Controls within Automation systems) telah dipilih sebagai pelantar bagi sistem dicadangkan. Selain itu, LabVIEW, sejenis bahasa atucara grafik, telah dipilih sebagai antaramuka aturcara aplikasi dalam pembentukkan modul perisian untuk pangawal dicadangkan. Untuk menguji keterbukaan sistem dicadangkan ini, beberapa fungsi tambahan telah ditambahkan. Fungsi tersebut termasuk cara aturcara kod kawalan berangka yang baru, ciri tambahan untuk pemesinan termaju dan penerbitan sistem OAPC-NC terbina ke atas jaringan untuk pemesinan jaringan. Akhirnya, pemesinan sebenar dan pengujian kebulatan ke atas hasil pemesinan akan dijalankan untuk menguji pelaksanaan sistem yang dibina. Daripada ujian kebulatan, keputusannya dari bentuk

pemesinan telah menunjukkan keberkesanan pemesinan yang lebih daripada 99% dan juga kelarian bentuk kurang daripada kelarian dijangka daripada interpolator yang dibina.

Keputusannya, satu sistem OAPC-NC yang dapat menjalankan pengaturcaraan kod kawalan berangka dan juga mengoperasi satu mesin kisar 3 paksi telah dibina. Selain itu, litar pengemudian motor pelangkah yang dibina telah berjaya mengantaramukakan mesin kisar dengan komputar. Keputusan pengujian kebulatan telah menunjukkan keberkesanan dna kejituan sistem yang dibina. Akhirnya, pertunjukkan aturcara berkomunikasi jaringan juga telah menunjukkan kemungkinan pemesinan jaringan. Sistem OAPC-NC yang dibina dapat digunakan pada pelbagai jenis mesin kawalan berangka. Maka, sistem ini dapat membekalkan kemudahan komunikasi kilang dalam penghubungan di antara beberapa jenis mesin yang berlainan.

CHAPTER 1

INTRODUCTION

1.1 General

The major goal of automation in manufacturing facilities is to integrate various operations in order to improve the productivity, increase the product quality and uniformity, minimize the cycle times and effort, and reduce the labor costs. Since 1940s, automation has accelerated because of the rapid advances in control systems for machines and in computer technology (Kalpakjian, 1995).

1.1.1 Background of Computerized Numerical Control (CNC) system

Numerical Control (NC) of machines is a method of controlling the movement of machine components by direct insertion of coded instructions in the form of numerical data (Kalpakjian, 1995). The basic concept of numerical control was implemented in the early 1800s, when punched holes in sheet metal cards were used to automatically control weaving machines. Sensing the presence or absence of a hole in the card activated needles. This invention was followed by automatic piano players, in which the keys were activated by air flowing through holes punched in a perforated roll of paper.

The principle of numerically controlling the movements of machine tools was raised up and emerged in the middle the twentieth century. It can be traced back to the year of 1947, where John Parson of the Parsons Corporation has began experimenting the idea of using three-axis curvature data to control machine tool motion for the production of aircraft components, on a project for developing equipment that would machine flat templates for inspecting the contour of helicopter blades (Smid, 2000). In 1949, Parsons was awarded a US Air Force contract to build what was to become the first numerical control machine in aircraft components machining with inspection fixtures to closed accuracy on a repeatable basis.

The Massachusetts Institute of Technology (MIT) was subcontracted into this research and development during the period 1949-1951 (Oberg *et. al.*, 2000). Together, the first control system, which could be adapted to a wide range of machine tools, had been developed. It was a vertical-spindle, two-axis copy-milling machine, retrofitted with servomotors, and the machining operations performed consist of end milling and face milling on an aluminum plate. The numerical data to be punched into the paper tapes were generated by a digital computer, which was being developed at the same time as MIT. The experiments successfully machined parts accurately and repeatedly without operator intervention. On the basis of this success, the machine tool industry began building and marketing NC machine tools.

In the further development of numerical control, the control hardware mounted on the NC machine was converted to local computer control with software (Smid, 2000). Two types of computerized systems were developed, which are direct numerical control (DNC) and computer numerical control (CNC). Direct numerical control (DNC) is developed in the 1960s. Several machines are directly controlled step by step by a central mainframe computer. In this system, the operator has access to the central computer through a remote terminal. Thus handling tapes and the need for computers on each machine are eliminated. With DNC, the status of all machines in manufacturing facility can be monitored and assessed from the central computer. However, DNC has the crucial disadvantage that if the computer goes down, all the machines become inoperative.

Kalpakjian (1995) defined computer numerical control (CNC) is a system in which a microprocessor or microcomputer is an integral part of the control of a machine or equipment (onboard computer). The part program may be prepared at a remote site by the programmer, and may incorporate information obtained from drafting software packages and machining simulations to ensure that the part program is bug-free. However, the machine operator can now easily and manually program onboard computers. The operator can modify the programs directly, prepare programs for different parts, and store the programs. Because of the availability of small computers with large memory, microprocessor, and program editing capabilities, CNC systems are widely used today. The importance of the availability of low-cost, programmable controllers toward successful implementation of CNC in manufacturing plants should be recognized.

1.1.2 Open Architecture Personal Computer-based Numerical Controller

Computer technology today has allowed us to integrate virtually all phases of manufacturing operations, which consist of various technical as well as managerial activities. With sophisticated software and hardware, manufacturers are now able to minimize manufacturing costs, improve product quality, reduce product development time, and maintain a competitive edge in the domestic and international marketplace (Kalpakjian 1995). Beginning with computer graphics, the use of computers has been extended to computer-aided design and manufacturing and, ultimately, to computer-integrated manufacturing (CIM) system. CIM system is a broad term describing the computerized integration of all aspects of design, planning, manufacturing, distributions, and management (Teicholz *et*. *al*., 1987).

The effectiveness of CIM depends greatly on the presence of a large-scale, integrated communications system involving computers, machines, and their controls. However, even though most current automation equipment such as robots and NC machine tools used in the manufacturing industries are programmable and may have various functions related to a given task, they are still characterized by their own control scheme. Major problems have arisen in factory communication when a number of difference machines are combined. These situations not only cause the lack of flexibility due to the incompatibility problem but also the waste of resources and the inefficiency due to duplicated peripherals are apparent (Hong *et. al.*, 2001).

As an alternative approach, researchers have focused on developing an open architecture control system, which requires its control environment to conform to an open technology (Wang *et. al*., 2003). As far as integration and interoperability are concerned, this approach does not force all manufacturers to establish a standard for the control systems used in the automation area in order to deal with the incompatibility problem arising. Instead, this approach uses existing resources and realized user-specific functions.

An open architecture system, as defined by Institute of Electrical & Electronics Engineers, IEEE (Pritschow, 1993), provides capabilities that enable properly implemented applications to run on a variety of platforms, inter-operation with other system applications and present a consistent style of interaction with user. Similarly, an open CNC system is a modular, software architecture that exhibits such capabilities as interoperability, interchangeability, scalability and portability (Pritschow, 1993).

Recently, the number of researches, which focus on the open architecture control system implemented on the numerical control system, has been increasing. According to Wang *et al*. (2003), the purpose of developing open-architecture computer numerical control is to establish a kind of software architecture that fits in with a general computer and is independent of hardware. However the open CNC system requires a communication standard among computer hardware, operating system and application software must be built. Using the advantage of open CNC system, users can quickly build an advanced capability controller to posses a characteristic function based on a general computer and operation system.

Presently, CNC technology has achieved a high reliability in the manufacturing site. However, the CNC machines are all equipped with different control. Each different controller has it own unique functions of operation. Hence, user/operator that is trained to operate a machine with one type of controller often cannot operate a similar machine with a different controller (Proctor, 1997). With the open architecture system, a personal computer (PC)-based controller that can be used by a variety of NC machine can be built. This controller will consist of all the functions of the existing CNC machine controller. Therefore, user/operator can operate any CNC machine with single kind of controller.

Beside that, proprietary controls on existing CNC machine are often unspecified 'control boxes' meaning that it is virtually impossible to incorporate different types of control routines. It is usually difficult to incorporate different types of sensor-based control schemes (Ulmer, 1999). However, the open architecture controller permits different types of control like position, velocity, adaptive control, and also the ability of adding of the hardware (e.g. sensors and types of actuators) to the machine.

1.2 Objectives

The main objectives of the research are,

1. To develop an Open Architecture Personal Computer-based Numerical Control (OAPC-NC) controller for a milling machine.
2. To develop software that can generate machine command from G-code.
3. To develop a driver and an interfacing circuit between machine and PC.

1.3 Scope of the research

The followings are the scopes of the research,

1. The controller will be built using LabVIEW, a graphical programming language.
2. The controller will be built based on the basic G-codes, which are G0, G1, G2 and G3.
3. The controller will be built utilizing the reference pulse interpolator, which was developed by Samad and Wan-Yusof (2002).
4. The new controller will be applied to an existing milling machine, which is the EMCO CNC milling machine by replacing the existing controller of the EMCO CNC milling machine.
5. An interfacing circuit board will be built based on the stepper motor in order to interface between the controllers (PC) and the EMCO CNC milling machine.

6 Actual machining will be done in machining a circular profile in order to carry out a roundness test to show the accuracy of the controller.

7 The Internet communication functions will be available for machining through Internet.

1.4 Research approach

Figure 1.1 describes the approaches to be done in order to achieve the objectives.

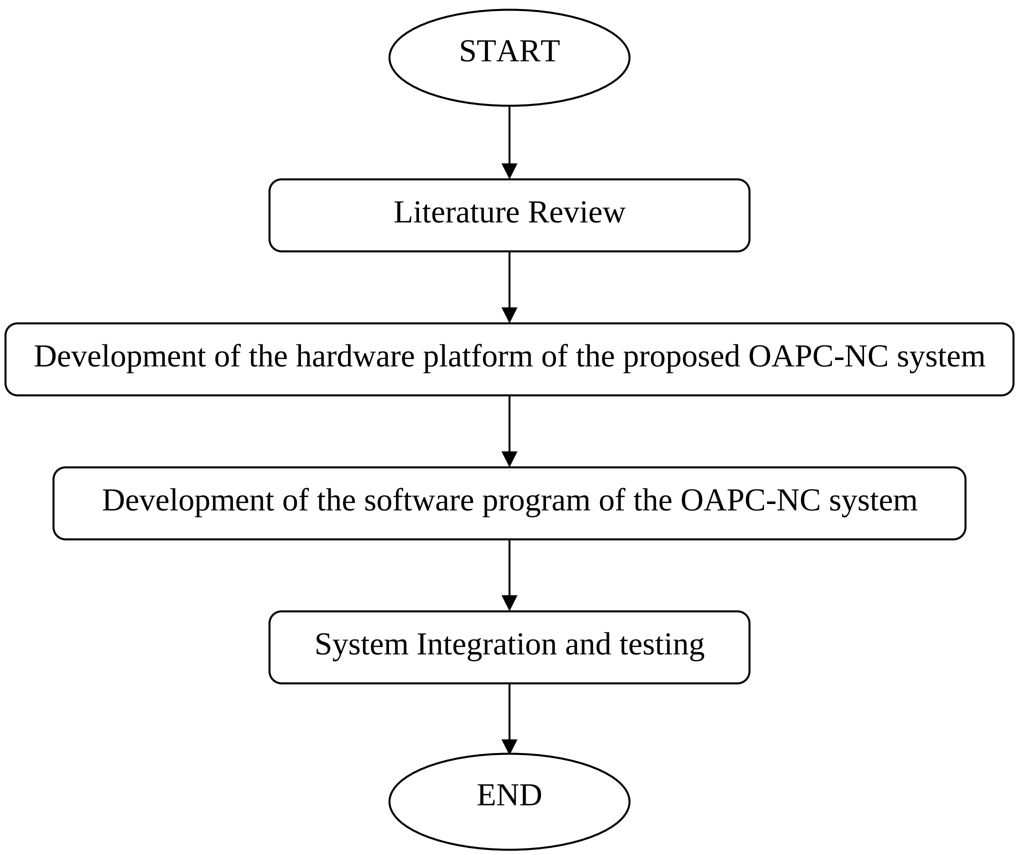

Figure 1.1: Research Approach

Literature will be reviewed on the open architecture personal computer-based numerical control system, and the researches currently done on the specified category. Beside that, literature review will also include the programming software and hardware platform that will be applied in this research.

Secondly, the hardware platform and the structure of the proposed OAPC-NC system will be developed and discussed. Beside that, the interfaces circuit that linking between the PC and the hardware will be constructed.

Thirdly, the software program of the proposed OAPC-NC system will be developed and discussed. The flow of the software program and the user interface of the proposed system will be shown and discussed.

Finally, the real time machine setup will be shown. The OAPC-NC system will be set using an existing 3-axis milling machine. The developed stepper motor driver circuit will be used to interface between the PC and the milling machine. Beside that, the experimental setup for roundness test will also be shown and discussed. A real time machining will be carried out and to get the samples for roundness test. In order to test the openness of the proposed system, several addition functions have been added into the controller. These functions include a new method of G-codes programming and web publishing of the system.

1.5 Thesis outline

The thesis is presented in seven chapters including introduction, literature review, hardware platform development, software program development, system integration and testing, result and discussion, and conclusion. The introduction chapter, which is Chapter One, will describe the background for the idea of open architecture personal computer numerical control (OAPC-NC). The project objectives and scopes have also been declared in this chapter.

Chapter Two covers the literature review on the researches currently done on the OAPC-NC. Some literature review on LabVIEW, graphical programming language that used in building the controller and the working principle of the stepper motor will also be carried out in this chapter.

The methodology of the project is described in Chapter Three and Four. Chapter Three will cover the development of the hardware platform of the open architecture Personal Computer-based Numerical Control (OAPC-NC) controller for three axis milling machine. Then the development of the software program of the OAPC-NC controller will be covered in Chapter Four.

Chapter Five shows the system integration, methodology of the roundness test and the methodology to test the openness of the OAPC-NC controller. In this chapter, a new method of programming interface will be introduced and the web publishing of developed program interface will be demonstrated.

Chapter Six consists of the results and discussion of the project. Finally, the thesis will end with the conclusion. Appendices present to support the thesis for further understanding.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this chapter, literature review is done on the current CNC machine in general. Then, the open architecture personal computer-based numerical control (OAPC-NC) system, and the researches currently done on the specified category are also been reviewed. Beside that, literature review is also done on the EMCO F1-CNC milling machine. This machine has been used in the experiment of the proposed OAPC-NC system.

2.2 Review of the Numerical Control (NC)

The Electronic Industries Association (EIA) defines numerical control as "a system in which actions are controlled by the direct insertion of numerical data as some point." (Kalpakjian, 1995). More specifically, numerical control, or NC as it will be called here, involves machines controlled by electronic systems designed to accept numerical data and other instructions, usually in a coded form. These instructions may come directly from some source such as a punched tape, a floppy disk, directly from computer, or from an operator.

The key to the success of numerical control lies in its flexibility, (Smid, 2000). To machine a different part, it is only necessary to “play” a different tape. NC machines are more productive than conventional equipment and consequently produce parts as less cost even when the higher investment is considered. NC machines also are more accurate and produce far less scrap then their conventional counterparts.

2.2.1 Principles of NC machines

The basic elements and operation of a typical NC machine in numerical control and the components basically involved of data input, data processing and data output, (Kalpakjian, 1995). For data input, numerical information is read and stored in the tape reader or in computer memory. In data processing, the programs are read into machine control unit for processing. For data output, this information is translated into commands, typically pulsed commands to the motor. The motor moves the table on which the work piece is placed to specified positions, through linear or rotary movements, by the motors, ball screw, and others devices.

A NC machine can be controlled through two types of circuits, which is open loop and closed loop, (Oberg *et al*, 2000). In the open loop system, the signals are given to the motor by the processor, but the movements and final destinations of the worktable are not accurate. Although the open loop system cannot machine accurately, but it still can produce the shape that is required. The closed loop system is equipped with various transducers, sensors, and counters that measure the position of the table accurately. Through feedback control, the position of the worktable is compared against the signal. Table movements terminate when the proper coordinates are reached. For the close loop system normally servomotor is utilized. For open loop system normally the stepper motor is utilized. The closed loop system is more complicated and more expensive than the open loop.

There are two basic types of control systems in numerical control, point-to-point and contouring. In point-to-point system, also called positioning, each axis of the machine is driven separately by ball screw, depending on the type of operation, at different velocities, (Kalpakjian, 1995). The machine moves initially at maximum velocity in order to reduce nonproductive time, but decelerates as the tool reaches its numerically defined position. Thus in an operation such as drilling or punching, the positioning and cutting take place sequentially. The time required in the operation is minimized for efficiency. Point-to-point systems are used mainly in drilling, punching, and straight milling operations.

In the contouring system, also known as the continuous path system, positioning and cutting operations are both along controlled paths but at different velocities, (Kalpakjian, 1995). Because the tool cuts as it travels along the path, accurate control and synchronization of velocities and movements are important. The contouring system is used on lathes, milling machines, grinders, welding machinery and machining centers. Movements along path, or interpolation, occur incrementally, by one of several basic methods, (Smid, 2000). In all interpolations, the path controlled is that of the center of rotation of the tool. Compensation for different tools, different diameter tools, or tool wear during machining can be made in the NC program.

2.2.2 Programming for Numerical Control

A NC program is a list of instructions (commands) that completely describes, in sequence, every operation to be carried out by a machine (Peter, 2000). When a program is run, each instruction is interpreted by the machine controller, which causes an action such as starting or stopping of a spindle or coolant, changing of spindle speed or rotation, or moving a table or slide a specified direction, distance, or speed. The form that program instructions can take, and how programs are stored and/or loaded into the machine, depends on the individual machine control system. However, program instructions must be in a form (language) that the machine controller can understand.

A programming language is a system of symbols, codes, and rules that describe the manner in which program instructions can be written (Peter, 2000). One of the earliest and most widely recognized numerical control programming languages is based on the Standard EIA RS-274-D-1980. The standard defines a recommended data and codes for sending instructions to machine controllers. Although adherence to the standard is not mandatory, most controller manufacturers support it and most NC machine controllers (especially controllers on older NC machines using tape input) can accept data in format that conforms, at least in part, to the recommended codes described in the standard. Most of the new controllers also accept instructions written in proprietary formats offered (specified) by the controller's manufacturer.

Therefore, in developing the proposed OAPC-NC controller, the functions should be compatible with the existing NC machines. Beside that, the controller should follow the working principles of the NC machines.

2.3 Review of OAPC-NC system

In recent years, the amount of research done on the PC-based open architecture controller has been increasing dramatically (Rober and Shin, 1995). This controller has been introduced widely in machine control, industrial robot and even in medical surgery. The progress of computer technology has resulted in extremely sophisticated machine tool controllers. However, there are still a many of issues related to practical applications of these controllers due to the lack of openness in most of the controllers used today (Ulmer and Kurfess, 1998). A machine tool user is commonly confronted with closed, unspecified (proprietary) control panel. It is virtually impossible to incorporate different types of control routines. It is equally difficult to incorporate different types of sensor based control schemes. Considerable interest in the area of open architecture controllers in industry and academia is forcing machine tool builders to consider incorporating such controllers in their machines (Ulmer and Kurfess, 1998).

Rober and Shin (1995) have introduced the PC-based open architecture numerical controller (CNC) to a milling machine. The controller was designed using commercially available MS-DOS-based software and analog/digital boards. Lab Windows (programming language) was used to develop the user graphical interface and the system control code in BASIC programming language. The controller was designed only to allow the operation of the introduced controlling system. Therefore, the control is built without the function of NC programming.

The controller is implemented on two systems. The first system is a single-axis high speed milling machine using analog control signal where the PC-based controller assumes all CNC function. This application involved a high-speed mill, where the controller was used to control the axis and spindle motors directly with feedback signals. The second system is a three-axis milling machine controlled by digital signals where the existing CNC continues to monitor peripheral functions but the PC-based system generates the reference commands for the axes and spindle. This system application involves interfacing to a MAZAK CNC machining center, with the objective to reduce the position and contour error of a two-dimensional milled profile. Rober and Shin (1995) has concluded that implementation of new algorithms for machine control is made possible through the use of PC-based controller.

Older machine tools are often mechanically sound but their proprietary controls are outdated and can be economically upgraded to modern open architecture control. Ulmer and Kurfess (1998) have presented a procedure for integrating these flexible control architectures into machine tools, which is the integration of an open architecture controller and a diamond turning machine. This required a significant retrofit of an existing diamond turning machine where the original controller was completely removed in favor of adding this type of control to the machine. The open architecture control permits research into various types of control such as position, velocity, force, and adaptive control.

To incorporate an open architecture controller into an existing diamond turning machine requires the identification, integration and installation of many components. After installing these components, the machine was calibrated to improve its performance. The most important aspect in improving the overall performance of the machine was correcting its vibration characteristics. Spindle imbalance, the spindle shaft coupler and the table and slide amplifiers were found to play a significant role in producing vibration. Under Ulmer and Kurfess research, the goal of incorporating an open architecture controller into an existing diamond turning machine was successfully completed. Many components had to be located, purchased and installed in place of the proprietary and worn components. The integration of hardware was straightforward although tedious. This work differs from most typical retrofits in that the open architecture control was installed in an older machine tool rather than a new machine. Unfortunately, older machine components do not operate with peak performance, requiring significant effort to improve various capabilities and aspects. For instance, a new machine's spindle would have been balanced and the X and Z-axis gear reducers would have functioned properly.

Thus, with a new diamond turning machine, it would have only been necessary to interface controller with the already installed components.

Increasing demands on precision machining have necessitated that the tool moves not only with a position error as small as possible, but also with smoothly varying feed rates. In the research of Yang and Hong (2000), a three-axis personal computer – numerical control (PC-NC) milling system, which is capable of synchronized simultaneous three-dimensional (3D) machining, is developed. To achieve the synchronous 3D linear and circular motions, new interpolation algorithms based on the intersection criteria are presented. A real-time reference-pulse 3D linear and circular interpolation is developed using a PC to implement the framework of the PC-NC milling machine reconfigured in his research. In order to evaluate the performance of the proposed 3D interpolation algorithm and the developed real time 3-axis PC-NC milling system, several experiments were carried out. Firstly a simulation was performed to evaluate the interpolation error. Then, the maximum feed rate, which can be achieved by the developed system, was evaluated. Thirdly, the developed system is evaluated by comparing of the number of the move commands required for the same circular paths. Finally, the PC-NC milling system was evaluated by programming the tool to move along a 3D circle on arbitrary planes. The performance test via computer simulation and actual machining has shown that the developed PC-NC milling system is useful for the machining of arbitrary lines and circles in 3D space.

Beside that, the personal computer – based open architecture system is widely applied on the computer aided design/computer aided manufacturing (CAD/CAM) system also. As an alternative for enhancing the capability of the existing NC machines economically, Suh *et al*. (1994) has presented a PC-based retrofitting for the manufacture of free surface with built-in CAD/CAM feature. The retrofitting scheme is based on an integrated NC system (INCS) structure comprising modules for CAD, CAM, and CNC. The INCS takes modular structure for the execution and maintenance of the CAD/CAM and CNC functions. By this, the user can perform the whole NC procedure from part design through machine control in a unified fashion. With the maintenance interface, the user can access the inside of the system. These are useful features for NC retrofitting in which the customization and maintenance of the CAD/CAM and CNC is often required.

The INCS scheme is implemented on a two-axis NC milling machine by developing integrated software and reconfiguring the existing hardware. The developed INCS software includes modules for surface design, tool path generation, and machine control, and hence a truly integrated CAD/CAM/CNC system. The retrofitted system allows users to perform the whole NC procedure including certain parameters. These parameters are geometric modeling of free surface, graphic simulation, and direct machine control (without Graphical-code conversion). The performance methodology together with software and hardware development is given with adequate illustrations. The INCS, however, is still a prototype system, which is by no means complete. The main emphasis of the system is to integrate the CAD/CAM function and the execution hardware through CNC module. By reconfiguring an existing NC machine, the INCS is implemented and tested. The results showed the effectiveness of the developed system, and convinced us that the INCS scheme together with its implementation details can be retrofitted for NC machining of free surfaces with built-in CAD/CAM feature. The presented scheme can be used as an economical upgrading method for small to medium industries.

From the review of the researches done recently, the open architecture system is developed due to the fact of flexibility, improved of system delivery time and the quality assurance. In this research, an open architecture personal computer-based numerical control (OAPC-NC) system will be built based on these particular factors. Additionally, the OAPC-NC system should also allow the easy integration and reuse of hardware and software.

2.4 Review of the Open architecture Controller standard

Since the late 80s there is a growing need of the machine tool builders and the end users to have open architecture controllers (Nacsa, 2001). Different levels of openness can be defined by analyzing the available research results and products. The main initiatives leading the current research in these efforts are the European Open System Architecture for Controls within Automation System (OSACA), the American Open Modular Architecture Controller (OMAC) and the Open System Environment for Controllers (OSEC) from Japan. In the following section, some different ways of open architecture systems researches and the complex comparison of these projects and their goals and achievements will be discussed. Nacsa (2001) has indicated that in their present form it is not possible to merge easily the three results to get a unified and potentially worldwide-accepted open architecture controller standard.

Basically, there are three different ways of openness in controller architecture (see Figure 2.1).

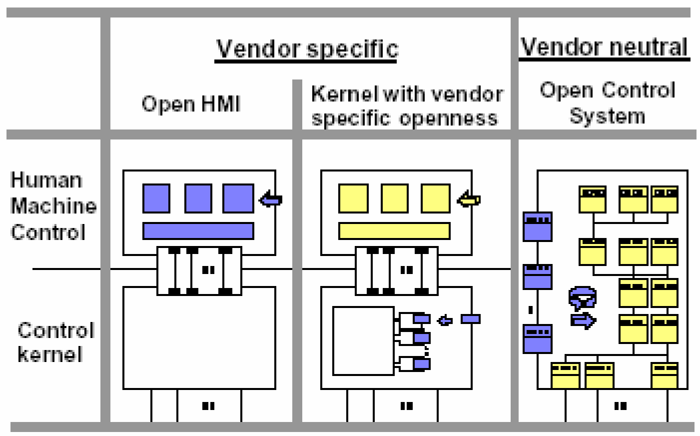

Figure 2.1: Different types of open controller architecture (Nacsa, 2001)

The first architecture means an open human machine interface (HMI). These features are most applied using a PC/Windows based environment coupled to the NC kernel which solves the motion control tasks in real-time. The second type of open architecture interface is also offer to the NC kernel or -at least – to insert user specific filters. Many users have PC based 'open' solutions where an add-on digital signal-processing card makes the motion control. Others run a real time operating system parallel to the Microsoft (MS) Windows on the same single processor. In both cases users have an application programming interfaces (API) to build their applications based on the vendor specific open platform. The third type of open architecture is vendor neutral. In this case a sort of joint consortium defines all the interfaces of the different controller modules including the real time parts (e.g. motion control, axis control, programmable logical control functions). The three most important vendor neutral initiatives are shortly introduced in the following section.

2.4.1 OSACA system

The first vendor neutral project that will be discussed is the OSACA (Open System Architecture for Controls within Automation Systems). In the OSACA project the different partners (universities, control vendors and machine tool builders) wanted to develop a vendor neutral open architecture controller (Sperling and Lutz, 1997). The final result has two basic elements. The first element is a general application-programming interface (the upper layer in Figure 2.2), which is independent from the information infrastructure (hardware, operating system and communication channel), where the so-called OSACA platform is available. Currently about 6-8 different OSACA platforms are available. This API has further sub layers and manages different types of items (events, variables, actions) to communicate with.

The second element is a reference architecture that defines the basic OSACA modules (the little boxes in Figure 2.2) with their function specific items. In OSACA the NC kernel functions were developed very precisely (motion control, axis control, spindle control, motion management control), while the others (e.g. PLC like logical functions) are still undefined.

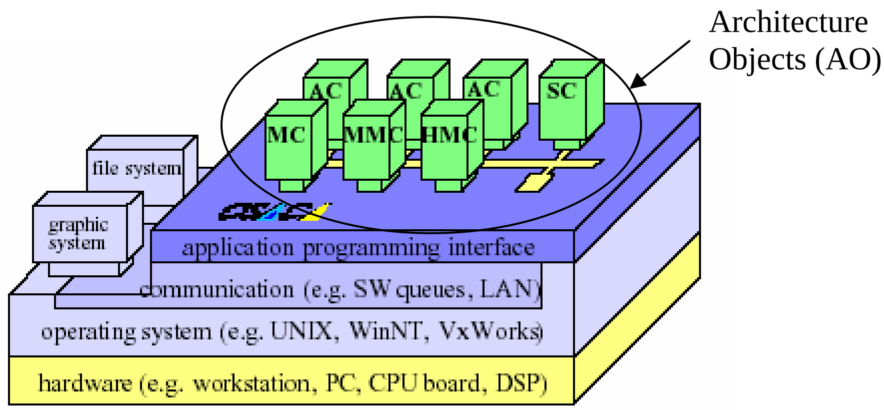

Figure 2.2: OSACA platforms with the basic application objects (Nacsa 2001)

There are three basic elements found in a system platform for open control system. These elements are the operating system, communication system and configuration system. The operating system guarantees an independent, quasi-parallel execution of modules and ensures independence from the specific hardware. The communication system ensures the co-operation of modules in a standardized way. The configuration system serves to build up a software topology of the set of available modules by instantiating and connecting the different modules. These three elements, integrated into the system platform, are accessible through a common application program interface (API). The API also allows manufacturers to choose optimized solutions for their systems without violating the criteria for open systems. The API has to be vendor-neutral to allow the portability of application modules onto systems of different vendors. Because of their