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OPEN ARCHITECTURE PC-BASED CNC CONTROLLER

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Abstract

The objectives of this project are two: developing CNC controller and developing a prototype machine to implement the controller. The developed CNC controller is an Open Architecture PC based type controller. Besides having all normal controller functions, the developed controller also permit upgradeable and interchangeable controller functions. Because of the open architecture characteristic, different interpolator algorithms are able to be executed for different manufacturing applications. Furthermore, the controller function is located inside a PC. The prototype machine is a general purpose three-axis machine flexible enough to execute different manufacturing processes ranging from pen-plotting, sheet metal processing and engraving applications just by changing the tool application. The CNC controller and the prototype machine is successfully developed, integrated and tested for two types of applications: wood engraving and pen-plotting. The result is that the developed machine is capable of tracing any 2D drawing, letters and Arabic scripts. As a testing application, custom wood engraving application was carried out and sold to the public with positive feedback. By having the controller and the prototype machine, KUKTEM now has platform to further research into CNC technology. With the knowledge of the CNC controller, CNC machines can be locally engineered thus reducing future imports of CNC machines.

Abstrak

Projek ini bermatlamatkan dua perkara; membina pengawal CNC dan membina mesin prototaip untuk melaksanakan pengawal. Pengawal CNC yang dibina, berasaskan arkitektur terbuka keatas komputer peribadi. Selain dari mempunyai fungsi pengawal yang umum, pengawal yang dibina juga mempunyai fungsi-fungsi yang boleh dilakukan penambahbaikan serta kebolehtukaran. Disebabkan sifat arkitektur terbuka ini, algoritma interpolasi yang berlainan boleh digunakan untuk aplikasi pembuatan yang berlainan. Tambahan pula, fungsi pengawal ini terletak di dalam komputer peribadi. Mesin prototaip yang dibina adalah prototaip umum, bercirikan 3 paksi, cukup umum untuk melaksanakan proses pembuatan yang berlainan seperti lakaran pen, proses kepingan logam dan aplikasi ukiran kayu iaitu dengan hanya menukar alat pemotongan. Pengawal CNC dan mesin prototaip ini telah dibina, diintegrasi dan diuji dengan jayanya keatas dua aplikasi; lakaran pen dan ukiran kayu. Hasilnya, pembinaan mesin ini, telah berjaya melakarkan sebarang gambar 2-D, huruf dan skrip arab. Sebagai aplikasi ujian, ukiran kayu secara tempahan telah dilaksanakan dan dijual kepada masyarakat umum serta mendapat maklum balas yang positif. Dengan adanya pengawal dan mesin prototaip, KUKTEM sekarang telah mempunyai landasan untuk memajukan penyelidikan didalam bidang teknologi CNC. Dengan ilmu pengetahuan mengenai pengawal CNC, mesin CNC boleh dibina di dalam negara yang mana akan mengurangkan aktiviti pengimpotan mesin CNC dimasa hadapan.

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List of Acronyms

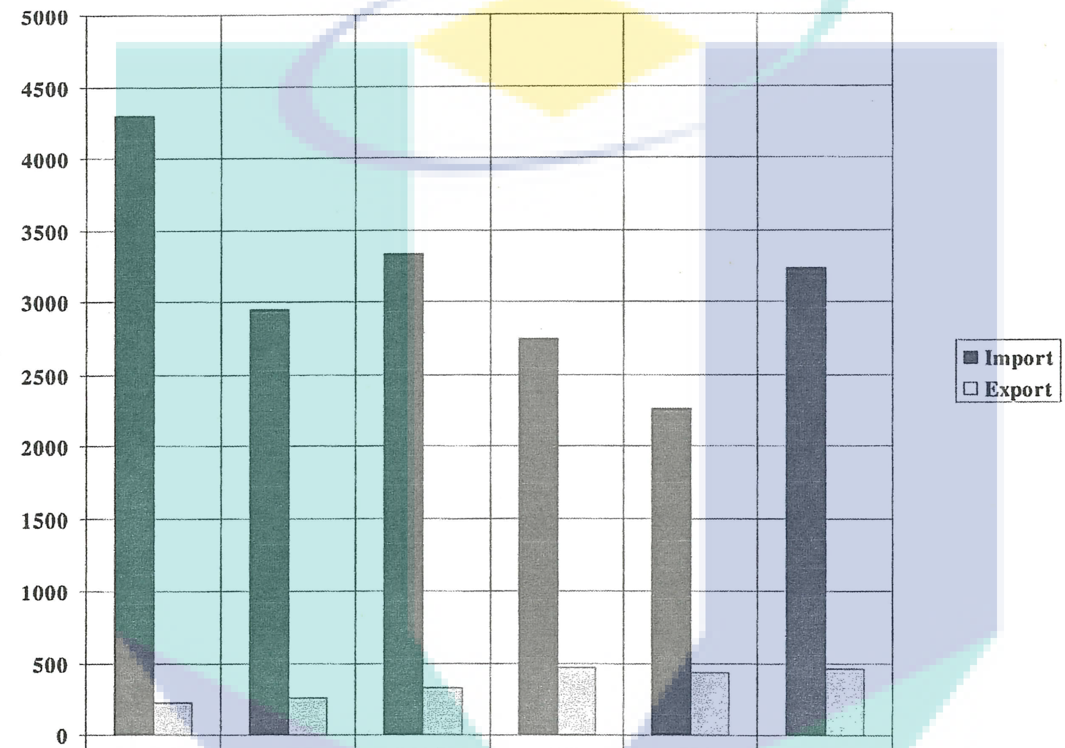
2D:	Two-dimensional
3D:	Three-dimensional
AGV:	Automated Guided Vehicle
BLU:	Basic-Length-Unit
CAD/CAM:	Computer-Aided Design and Computer-Aided Manufacturing
CAD:	Computer-Aided Design
CAM:	Computer-Aided Manufacturing
CNC:	Computer Numerical-Control
I/O:	Input-Output
NC:	Numerical Controller
NURBS:	Non-Uniform Rational B-Spline
OAC:	Open Architecture Controller
OAPC-NC:	Open Architecture Personal Computer–Numerical Controller
PC:	Personal Computer
PID:	Proportional-Integral-Derivative
PLC:	Programmable Logic Controller

CHAPTER 1

INTRODUCTION

1.1 PROJECT MOTIVATION

Machine tools are tools that are capable of producing dimensionally accurate parts in large quantities. They are indispensable innovations that had realized mass production of interchangeable parts (The New Penguin Encyclopedia 2003). Most functions of modern machine tools are computer controlled such as computer numerical-control (CNC) machine tools (Thyer 1991). With computer controlled, CNC machine tools have improved manufacturing industry in many aspects: higher flexibility, increased productivity, consistent quality, reduced scrap rate, reliable operation, reduced non-productive time, reduced manpower, shorter cycle time, higher accuracy, reduced lead time, lesser floor space, increased operational safety and capability of machining advanced materials (Ramanuja 1999, Krar et. al 1998). Malaysia, as a manufacturing-driven country, is massively dependent on machine tools. As an indicator, Malaysia imports for metalworking machinery in the year 2000 are RM 3,232 millions while exports are only RM 460 millions. These huge trade imbalances from the year 1995 through 2000 are presented in Figure 1-1 (Malaysia Statistic Department 1996-2001)1. The figures reflect the state of metalworking machinery industry and technology in



	1995	1996	1997	1998	1999	2000
Import	4298,625	2951,047	3333,832	2743,867	2257,117	3232,541
Export	226,119	257,803	326,489	472,124	436,219	460,864

Figure 0-1: Malaysia Import and Export Values for Metal Working Machinery[2]

Malaysia. The high import values imply that machine tools are critical to Malaysian

[1] In general, the statistic for a particular year is published one year after that year. For instance, statistic for 1995 is published in June 1996.
[2] All figures are in RM million. Sources are from Malaysia Statistic Department, Tables of Summaries, Division Code 73, External Trade Statistics (1996 – 2001)

manufacturing industries. At the same time, the low export values mean that local industries lack the necessary technology to build machine tools.

For that reason, researching on machine tools technology is relevant. Mastering the technologies enables Malaysian manufacturers to pay for cheaper state-of-the-arts machine tools that will lower manufacturing investment. Simultaneously, imports of machine tools are reduced with possibilities of exports. This research concerns with the technology of machine tools.

1.2 PROBLEM STATEMENT

Performance of machine tools is based upon accuracy, repeatability, reliability and machining rates of the produced part. These performances depend on the advances of controller used by the machine tools. Currently, there are three types of machine tool controller: programmable logic controller (PLC), Computer Numerical Control (CNC) and PC-based systems. In 1970s, CNC has replaced the Numerical Controller (NC) and the PLC. Among CNC features are; dedicated computer as controller, program input is through software, memory size is bigger and management information not related to actual machining is available. With CNC, machine tool for unconventional machining (laser, water-jet, plasma-arc etc.) is appearing. Despite major improvements created by CNC, advanced commercial CNC controllers such as those of Siemens, Allen Bradley, Fanuc, and Mitsubishi, is a closed-architecture controller; the terms use to indicate that all of the controller functions are proprietary of the manufacturers. As such, users and third party vendors cannot incorporate newly invented functions or control schemes into the controller.

1.3 PROJECT OBJECTIVES

The objectives of the project are two:

- To develop Open Architecture PC-Based CNC controller. The controller will host the interpolator and servo control loop algorithms. By having open architecture controller, further research and enhancement to he controller are easily integrated.

- To apply OAPC-based CNC controller on prototype CNC machine. The prototype machine is based on three-axis general purpose machine so that different manufacturing processes which require different controller functions can be applied.

CHAPTER 2

LITERATURE REVIEW

2.1 Machine Tool Controller

Performance of machine tools is based upon accuracy, repeatability, reliability and machining rates of the produced part. These performances depend on the advances of controller used by the machine tools (Krar et. Al 1998).

Regardless of conventional or unconventional machining, machine tool controller involves three major functions: control of cutting speed, control of feed speed and control of miscellaneous functions (HMT Press Limited 2000).

Control of cutting speed. The relative motion between the cutting edge of the tool and the work is called the cutting speed. Precise control of cutting speed (also called spindle speed) ensures constant material removal rates, which controls the finishing of the produced part.

Control of feed velocity. The speed in which uncut material is brought into contact with the tool is called the feed velocity. The feed velocity depends on the axes velocities, which control not only the material removal rate but also the shape of the produced part. Precise control of axes velocities ensures précised part.

Control of miscellaneous functions. The machine tool controller also provides controls of miscellaneous functions such as the coolant on/off, safety functions and on a modern controller the automatic tool-changer.

According to Koren in his review paper Control of Machine Tools (Koren 1997), the modern construction of CNC machine tool controller can be divided into several levels as indicated in Figure 1 (on the next page).

Level 1: Servo control and spindle control loop

Servo control loop implements the controls of multi-axes velocities and positions for precise feed control. Taking reference positions and velocities provided by interpolator, servo control loop implements the required motion using designated control schemes provided. Among the major control schemes utilized are PID, fuzzy logic, feed-forward and cross-coupling controllers. This level is sometimes called command realization or command tracking (Chou and Yang 1992a). On the other hand, spindle control loop implements the control of spindle speed using control scheme provided by the adaptive control function. Among the major control schemes used are adaptive control optimization (ACO) and adaptive control constraints (ACC) (Koren 1997).

Level 2: Interpolator

The role of interpolator is to provide reference axes positions and velocities such that the precise shape of the produced part is realized by the servo control loop. Sometimes, the interpolator is also termed as command generation (Chou and Yang 1992a).

Level 3: Adaptive control and error compensation

At this higher level, measured various errors such as by induced thermal and geometrical inaccuracies are compensated as well as intelligent adaptive control algorithm for tool conditioning and monitoring are implemented.

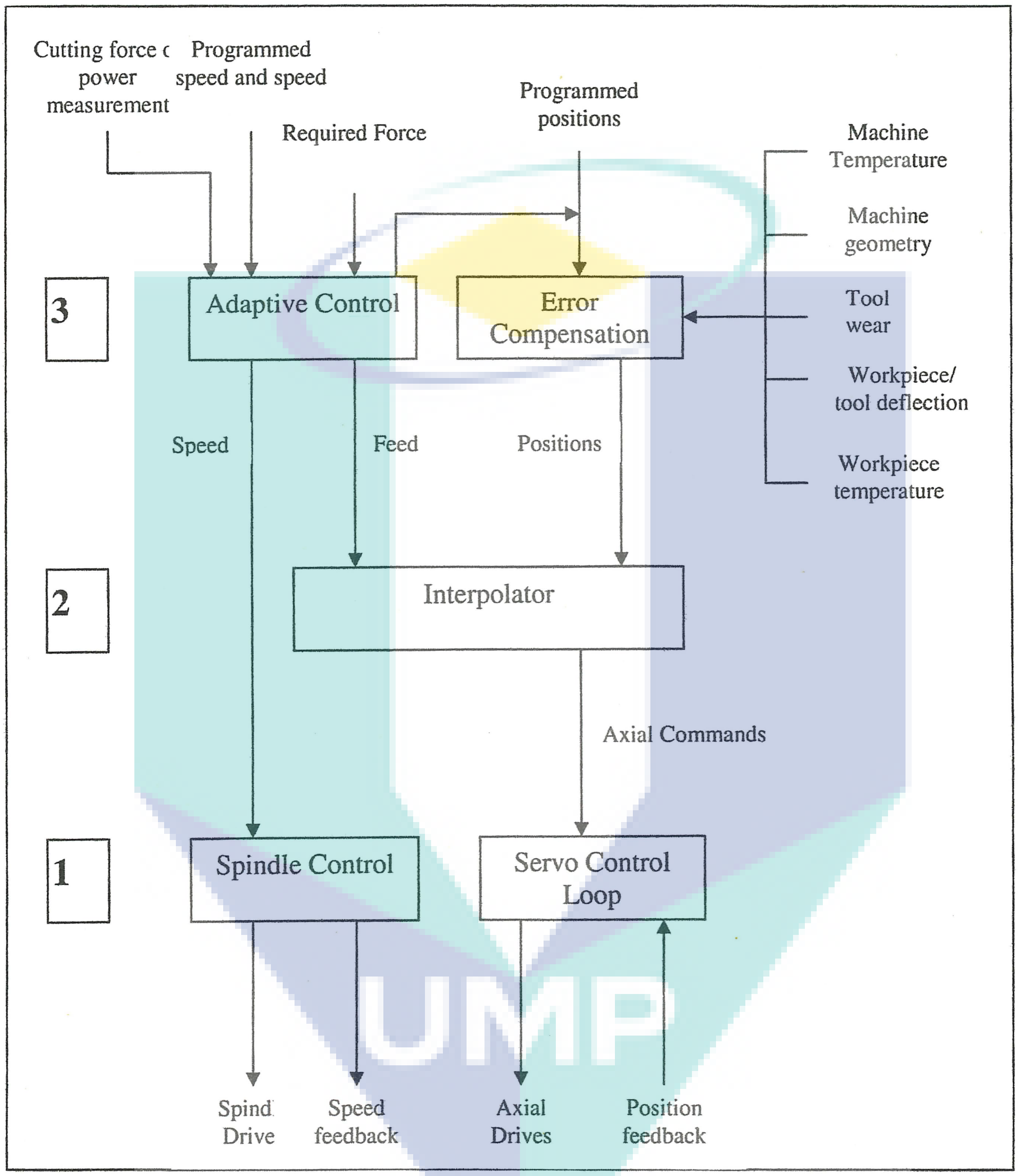


Figure 2.1: Hierarchical levels in CNC controllers

2.2 Historical Development of Machine Tool Controller

According to Thyer (1991), historically, machine tool controllers had passed through seven levels of controls based upon control technology utilized. The descriptions are briefly given below:

Zero level of control

In the beginning, machine tools are controlled manually. The power for material removal and the positioning of cutting tool is completely manual.

First level of control

The availability of power source through water wheel, steam engine and electric motor allows the implementation of ON-OFF control. Different cutting tool speed is possible through the used of pulleys and gears.

Second level of control

Around 1792, the development of Muadley's screw cutting lathe marks the beginning of the synchronization of movements between the cutting tool and the work piece. However, the relative position between the tool and the work piece as well as the selection of cutting speed and feed are still dependent on manual expertise.

Third level of control

The relative movement between the cutting tool and the workpiece is now controlled by fixed-cycle of mechanical movements such as cam-controlled and tracer-controlled, which are driven by electric motors. This allows production of large quantities of similar parts.

Fourth level of control

Sensors and transducers are used to measure the feed and the cutting tool motions. The measured feed position and velocity as well as spindle speed is then controlled using ON–OFF control scheme.

Fifth level of control

The information for controlling the machine such as the shape, the required tools, spindle speed, feedrate and the miscellaneous functions are input to control unit as symbolic numerical values famously known as the G/M-Code. The machine tool controller is called numerical-control (NC) controller. The first developed NC controller is by researchers at Massachusetts Institute of Technology (MIT) for Parsons Aircraft Corporation during 1947 – 1952 (Thyer 1991). NC controller has further matured into three generations: the first generation of NC, the second generation of NC and the generation of CNC and DNC.

First generation of numerical control (NC)

The numerical control features are only for the relative movement between the cutting tool and the work piece. Selections of tool type, cutting speed and the feed speed are still carried out manually.

Second generation of numerical control (NC)

The numerical control features include not only the relative movement between the cutting tool and the work piece but also include the selection of tool type, cutting speed and the feed speed.

Computer Numerical Control (CNC) and Direct Numerical Control (DNC)

In 1970s, Computer Numerical Control (CNC) has replaced the NC. Among the features are; dedicated computer as controller, program input is through software, memory size is bigger and management information not related to actual machining (such as number of components completed, machining time, fault diagnosis, maximum load during machining etc.) is available. With CNC, machine tool for unconventional machining (laser, water-jet, plasma-arc etc.) is appearing. Moreover, CNC had allowed combinational machining of machine tools such as machining center, turning center, and mill-turning center. DNC is a system containing a number of CNC machines controlled by supervisory computer usually a mainframe computer.

Sixth level of control

Intelligent or adaptive controls are used. Temperature, force and geometrical sensors are mounted on cutting tools, drive shafts and the machine structures itself. Information is analyzed and cutting parameters are adjusted and optimized using control intelligent algorithm such as fuzzy-control, neural network and genetic algorithm. The modified parameters are fed to interpolator, servo control loop and spindle control loop in real time.

Despite major improvements created by CNC, advanced commercial CNC controllers such as those of Siemens, Allen Bradley, Fanuc, and Mitsubishi, is a closed-architecture controller; the terms use to indicate that all of the controller functions in Figure 2-1 are a proprietary of the manufacturers. As such, users and third part vendors cannot incorporate newly developed functions or control schemes into the controller (Rober and Shin 1995). For instance, given the linear/circular interpolator algorithm and the PID servo control algorithm in the proprietary CNC controller, users have no access to implement newly developed general curve interpolator or a cross-coupling servo control algorithm.

2.3 Open Architecture Machine Tool Controller

By 1990s, the concept of open architecture controller (OAC) of machine tools surfaced to address the problem. The phrase "Open Architecture Controller" is actually taken from the computer workstation community particularly from Sun Microsystems who promotes "open system" computing platform (Schofield and Wright 1998). Since OAC is a relatively new area, there are many definitions (versions) of OAC and most of them are overlapping (Altintas and Erol 1998). Three of the definitions are described below:

1. Schofield and Wright (1998) defines open architecture controller as controller that is flexible, integrative and standardized. Flexibility means allowing hardware changes to its basic configuration and software changes at all levels of control thus enabled the use of advanced monitoring and control technique. Integrative features allow CNC controller to be coordinated at peer level (machine tool, robotics, PLC, material handling devices etc.) and at the higher system level (CAD/CAM, process planning, etc.). Standardized means that the controller allows third party vendors to develop new hardware and software thus creating larger development base for new technology.

2. TRUE-CNC controller. The word "TRUE" is an acronym in which T is for "Transparent", "Transportable" and "Transplantable". R is for "Revivable". U is for "User Re-configurable" while E stands for "Evolving" (Yamazaki *et. al* 1997). "Transparent" means that the control software is accessible to machine tool builders, outside vendors and end users; "Transportable" means that control

software is portable; "Transplantable" means that the control software is upgrade-compatible. "Revivable" means that the software and hardware are replaceable to newly emerging technology. "User re-configurable" means that the controller elements are customizable. Lastly, the term "Evolving" indicates that the controller is update able.

3. According to Proctor and Albus (1997), OAC for machine tool consists of the following four features: extensibility, interoperability, portability and scalability. Extensibility means the easiness of third party vendor to add capabilities to software and hardware. Interoperability, on the other hand, means the ability of two or more controllers to exchange and use information. Portability feature allows control software to operate in different environment. Finally, scalability means the easiness with which an existing system's performance is increased or decreased according to application demand.

According to Schofield and Wright (1998), the first conceptual introduction of OAC is proposed by (Greenfeld *et. al* 1989). Since then, both the academic institutions and industries have initiated many OAC projects. Some of the previous OAC researches by the industries are given in Table 1.

Table 1: Some open-architecture controllers by industries in USA.

Source: National Institute of Standards and Technology (NIST).

Table reproduced from Proctor and Albus (1997).

Vendor	Product	Computer(s)	Operating system
Advanced Technology & Research Corp.	RCS	Dual PCs	Windows NT for GUI Real-time kernel for control
Bridgeport Machines Inc.	DX-32	Dual computers	PC/DOS for GUI Motorola 64K/real-time kernel for control
Cimetrix Inc.	CX-3000	Single PC	Windows NT of Lynx05 VMEbus
Delta Tau data systems Inc.	PMAC-NC	Single PC	Windows 95
GE Fanuc Inc.	MMC-4 HSSB	PC front-end	
Hewlett-Packard Co.	OAC 500	Dual PCs	Windows NT for GUI LynxOS for control
ICON Industrial Controls Corp.	MOS	Single PC	Windows 95 Real-time kernel
Indramat (Div. Of Rexroth Corp.)	MTC 200	CNC coprocessor	PC bus
Manufacturing data systems Inc.	Open CNC	Single PC	QNX real-time Unix
Siemens AG	Sinumerik 840D	Dual PCs	PC/DOS for Windows for GUI RISC or PC with real-time kernel for control

Controller Hardware Types

Currently, there are three types of machine tool controller: programmable logic controller (PLC), CNC and PC-based systems (Mitchell 2000a). Accordingly, PC-Based controller has penetrated the CNC systems. Among the advantages of PC-Based systems are (Mintchell 2000a, Mintchell 2000b, Mintchell 1999, Petrone and Stackhouse 1998, Kaufman 2000):

- Open platform
- Information handling for improved analysis of manufacturing systems
- Built-in communication
- Improved programming
- Integration into enterprise systems for "e-manufacturing" implementation

As a result, there are many advantages associated with PC-Based OAC. In terms of machine tool controller as in Figure 1, three of the main advantages are listed below:

Control improvement

All control functions in Figure 1at all level can be modified, improved and added. At level 1, control scheme for servo control loop and the adaptive control of spindle speed are opened to improvement not only to machine tool users but also more importantly to outside vendors who specialize in the respective area. Likewise, the interpolator, and the error compensations routines are "opened" to improvement (Proctor and Albus 1997). For example, according to Tsai (2000), his newly developed Pythagorean Hodograph variable feedrate interpolator is implemented successfully in an OAC milling machine.

Process improvement and innovation

Machining process is improving. New ways are found in many processes. Unconventional machining processes such as laser cutting or even rapid prototyping systems are always changing. In addition, all future machine tools, such as micro-mechanical machine tools, bio-mechanical machine tools require customized controller, which is currently available only to proprietary machine tool builders.

Integration

Communication between various peer equipments such as PLCs, Robotics and automated-guided vehicles (AGVs) is seamless even though all the devices including machine tools themselves are constantly changing. Likewise, integration with higher-level activities such as design in CAD\CAM, computer-aided process planning (CAPP), MRP/ERP and the Internet are possible (Altintas and Erol 1998, Mitchell 2000a).

CHAPTER 3

METHODOLOGY

The project activities are divided into three major activities: mechanical system, electrical system and software. The three general activities are executed simultaneously involving 5 researchers. Followings are brief descriptions of the project activities.

3.1 Mechanical System

Mechanical system involves fabrication of prototype machines. Generally, the system is build based on the following four main activities.

Design of prototype machine

Figure 3.1 shows the design of the machine structure prototype. The design was carried out using 3D CAD software. The machine is designed to process 4 x 8 feet of raw materials such as sheet metal and plywood which are standard material size used in the industry. This type of machine structure is called "gantry" type because it is the tool that moves instead of the materials. Many manufacturing applications can be implemented with this type of machine structures. Manufacturing applications such as engraving, tracing, measuring, inspection, pick and place are such examples.

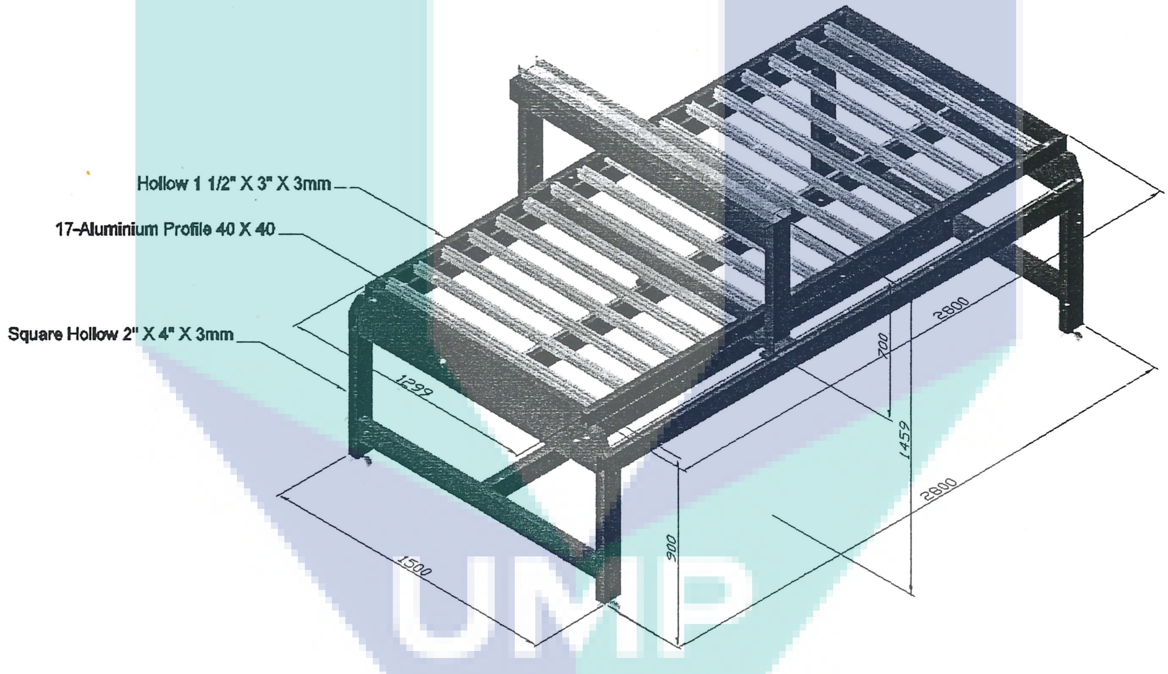


Figure 3-1: The Machine Prototype Design

Because of the relatively long size, the mechanical components such as ball screws are selected for rigidity and minimal deflection based on advices from component suppliers. The big size is needed for processing sheet metal or large engraving requirements.

Procurement of mechanical components

Building prototype machines are based upon available off-the-shelf automation components. The basic mechanical components for the prototype machines are listed below:

Mechanical Components	Descriptions
Balls crews	Diameter 32 mm with the longest axis is 9 feet.
Carriers	The carriers are linkage between the load and the ball screws
Aluminum profiles	The structure is build around interchangeable aluminum profile for easy sizing.
Motor gearbox	Each axis motor are fixed to gear box with the torque ratio is one to five
Linear guides	To maintain rigidity and straight line motion, linear guides are used instead of shaft. This ensures that long axis motion is not deflected.
Coupling	This links motor to the ball screw.

Figure 3-2: Coupling (left) and gear box (right)

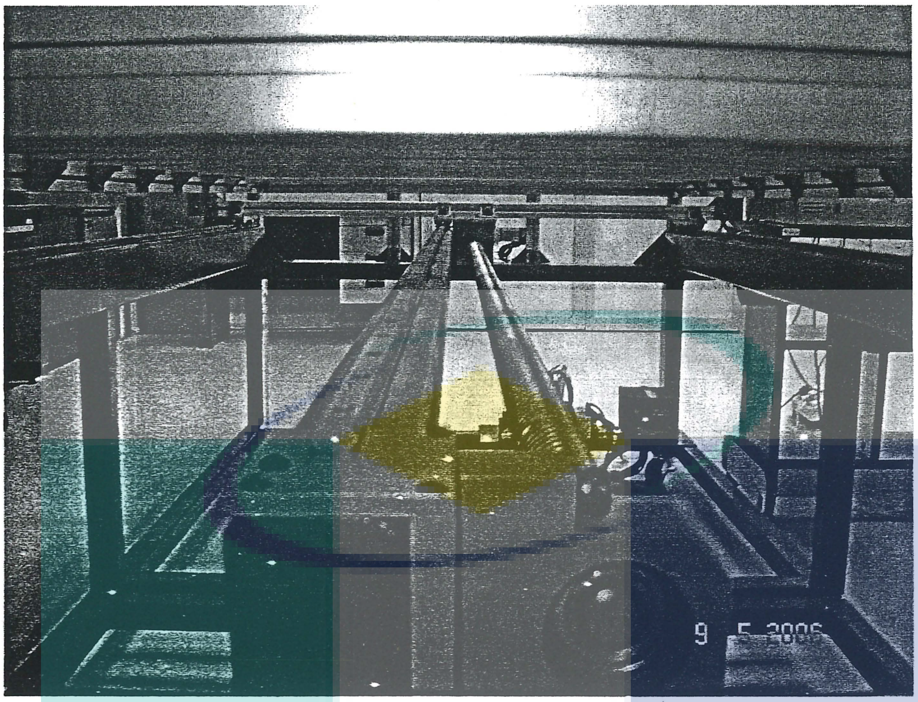


Figure 3-3: Ball Screw along with Linear Guides

Components are off-the-shelf and majority of them are imported through local agents such as coupling and gear box system as shown in Figure 3-2. However, since one of the ball screws is nine feet long as shown in Figure 3-3, it is specially purchased from Japan.

Assembly of mechanical components

Once components and the structure are available, they are assembled and adjusted for straight alignment, orthogonal and flatness. The machine balancing is leveled using the four support adjuster at the bottom of the machine as shown in Figure 3-4.

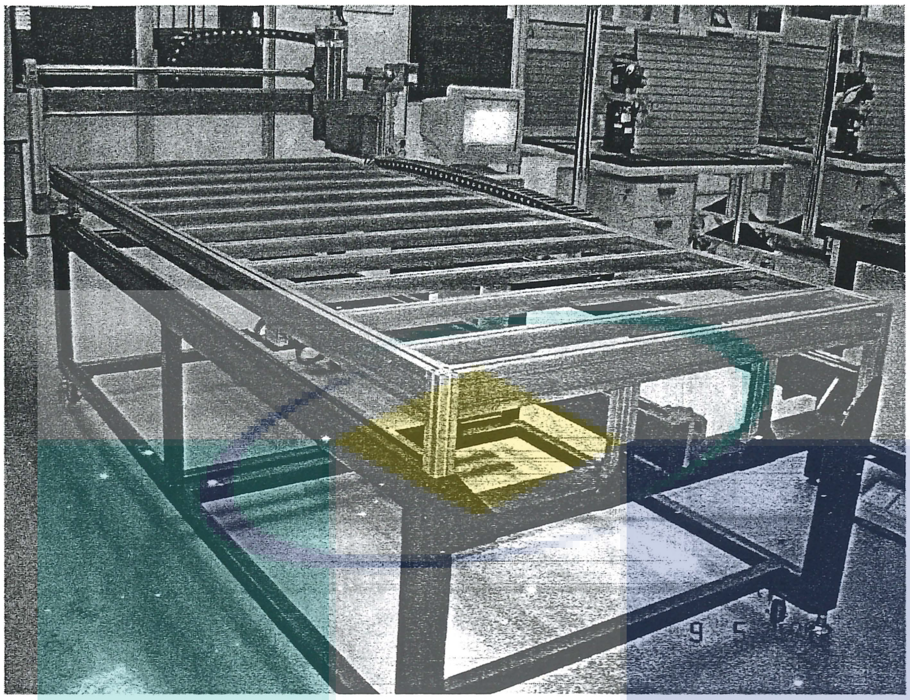


Figure 3-4: Assembled Machine Structure

Testing of mechanical structure and components

The machine structure is then tested with trial run under various speeds in order to observe the vibrations and maximum load carrying capability. Finally, some lubrication was added to the gear boxes and ball screw assembly for reducing friction loss.

3.2 Electrical System

The electrical systems for the prototype machines are feed drive systems and spindle system.

Spindle system

The spindle system is based upon cutting requirement. In this project, router cutting system is utilized as shown in Figure 3-5. The cutting speed is controlled via speed controller as illustrated in Figure 3-6 which varies the speed from 0 to 30,000 rpm.

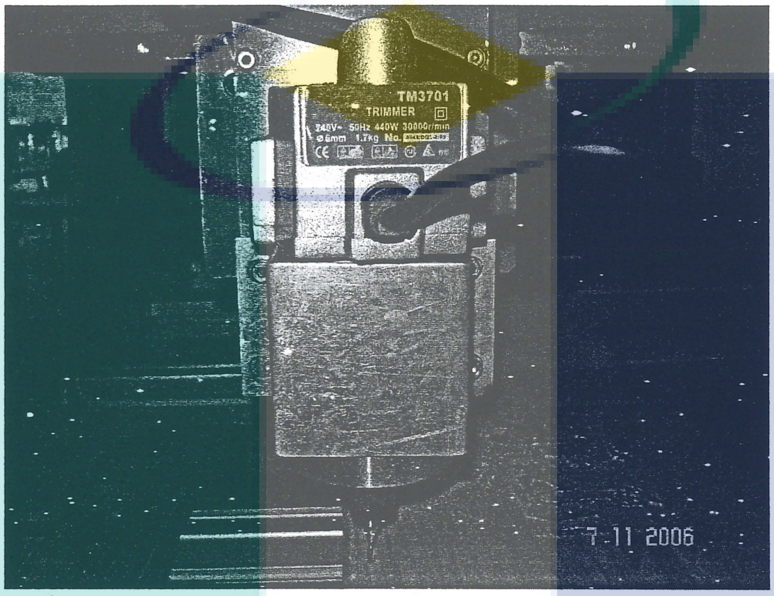


Figure 3-5: The cutting tool used for wood engraving

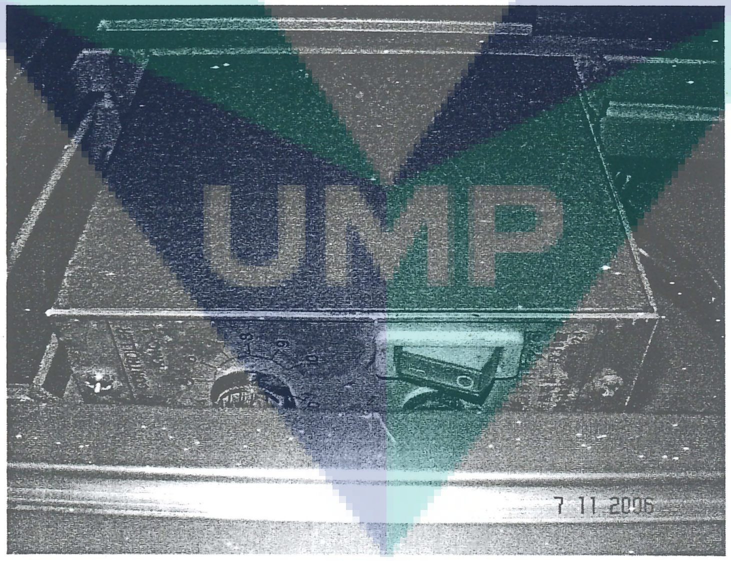


Figure 3-6: The speed controller for the cutting tool

Feed drive system

The feed drive system as shown in Figure 3-7, Figure 3-8 and Figure 3-9 are constructed in order to drive the machine motion based on servo motor performance. A 240 V, single phase power supply is utilized to drive completely three axis movements without of short circuit.

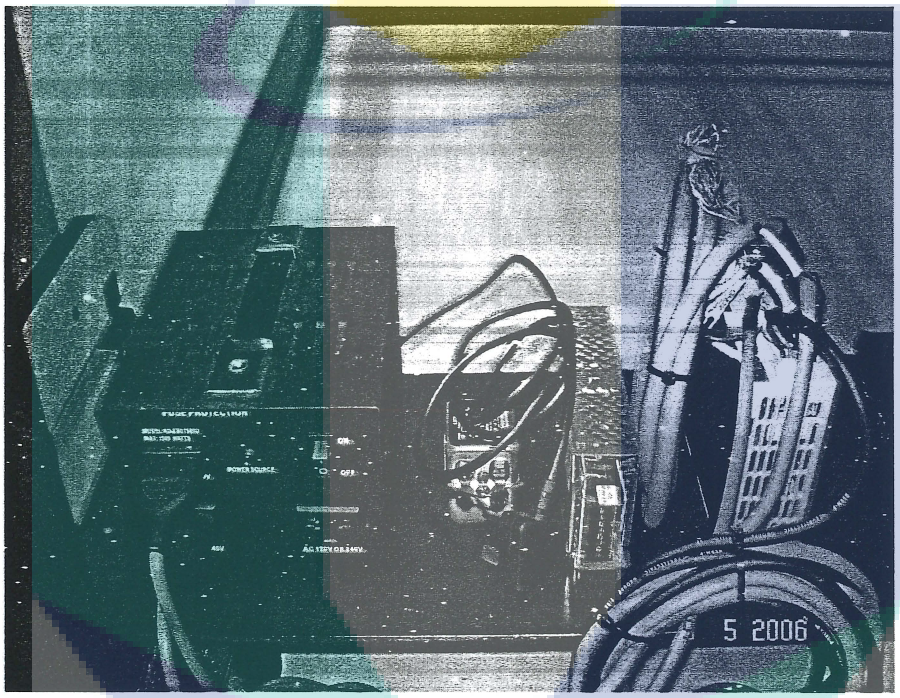


Figure 3-7: Driver system complete with power supply

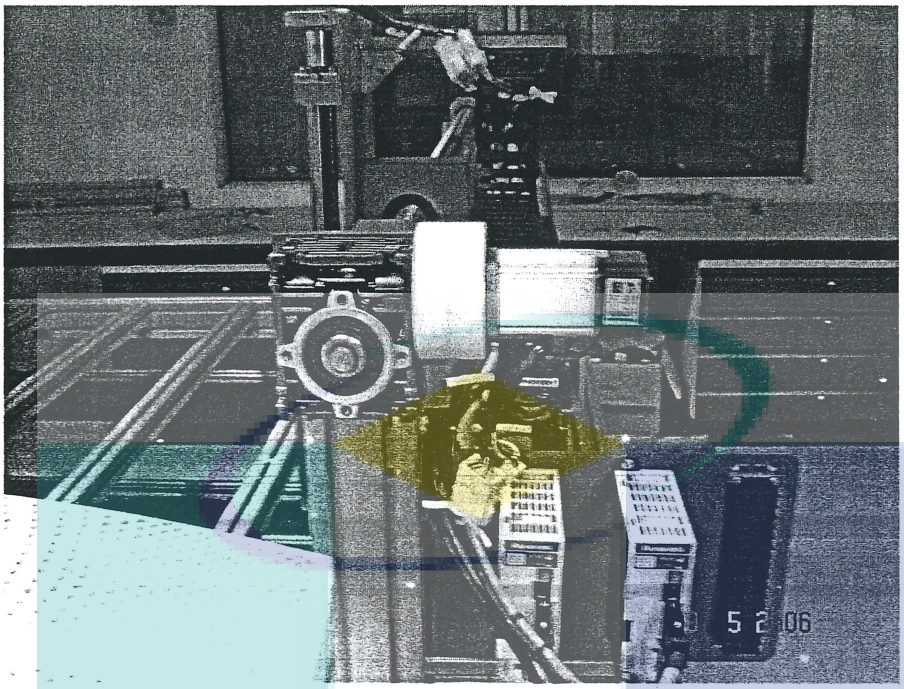


Figure 3-8: Driver system attached for servo motor controller

Figure 3-9: Panasonic drive system

3.3 Software

Software system is divided by pre-processor and post-processor activities. Pre-processor is involved of computer aided design (CAD) and computer aided manufacturing (CAM) while post-processor is developed by using visual C++ software.

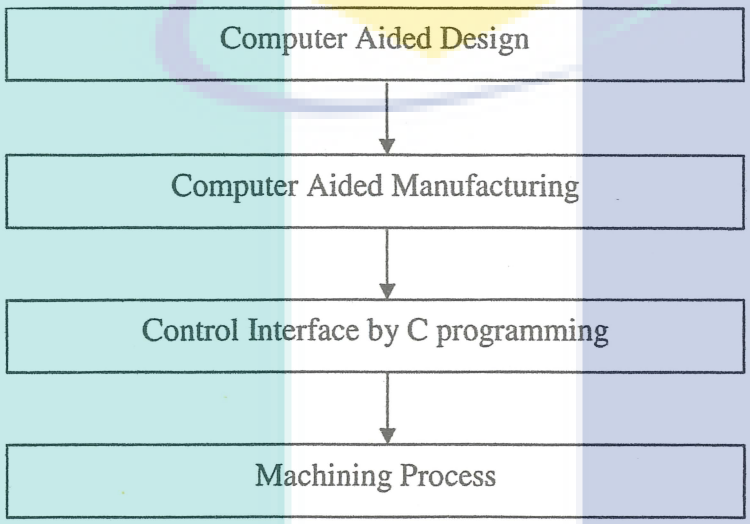


Figure 3.10: Flow chart of software methodology

Pre-processor: Computer aided design and computer aided manufacturing

The fabrication process started with a design in CAD software. The design could be two or three dimension and must be vector form. The design is exported to CAM software. The CAM software is used to define the machining properties such as the tool path operation which is a machining strategy for machining areas based on the currently selected vector boundaries. Environment of the CAM software is illustrated in Figure 3-

11. Machining properties also include cutting tool chosen from the tool library or user defined tool. The geometry properties in term of the thickness and origin of the material need to be specified in this stage. Simulation of the tool path can be performed in CAM stage in order to avoid the error and collision during the actual running stage.

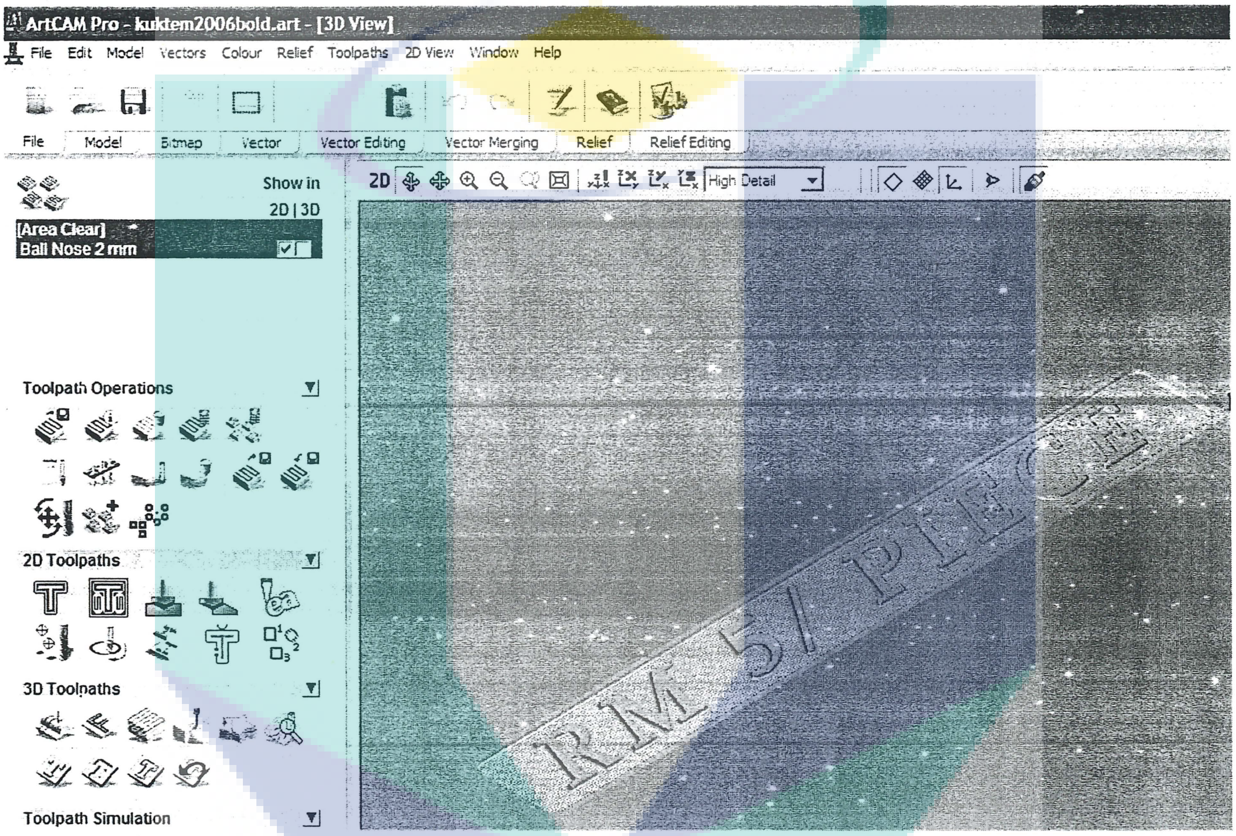


Figure 3-11: CAM environment of the wood engraving

Post-processor: Visual C++ program

A Pentium III PC using Windows 98 operating system is utilized beside the whole control program which is located in the PC. The developed software consists of the user interface path input, path simulations, real-time interpolator and the web-based remote machining. Servo control loop for the three-axis is implemented through the integrated of Panasonic servo motor.

As a machine interface for the instruction that had been defined in CAM, an algorithm is developed using C program. The program used to control the machine speed is by pulse signal control from the PC. By using the algorithm, the machining process can be run automatically which is fully controlled by PC as shown in Figure 3-12.

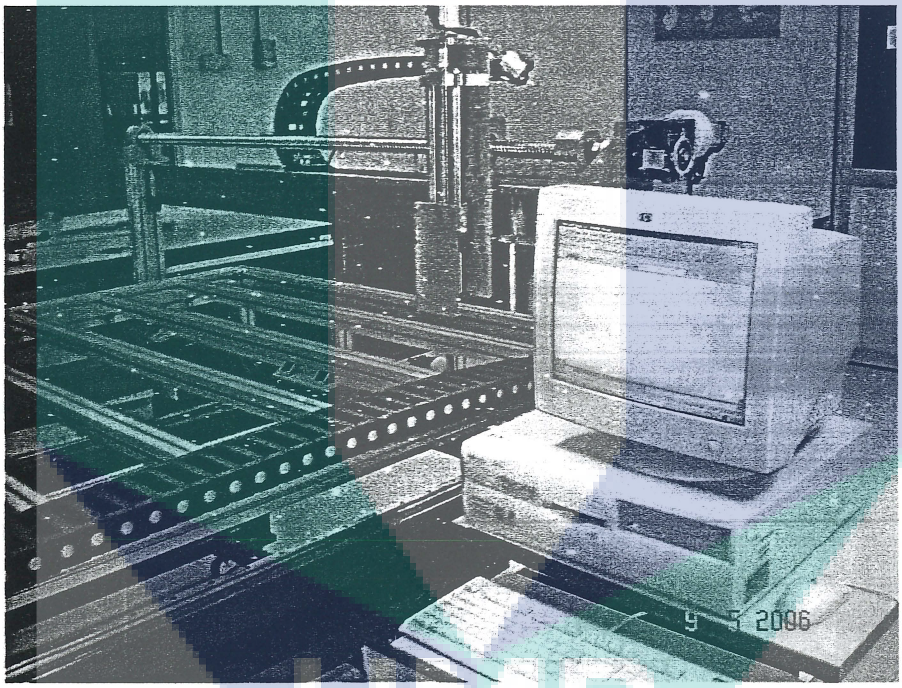


Figure 3-12: Machine motion controlled by PC

The C programming strategy is utilized through PC parallel port by supplying a 5 V voltage through it. The 5V voltage is set as input and 0 V as no input.

After the three major activities are completed, integration of all components and systems into products will be carried out. Next, the CNC machines are put into operations at exposition for rigorous and real world feedback. Using feedback from industry, the machines will be modified and ready for commercialization.

CHAPTER 4

RESULTS AND DISCUSSIONS

To implement the developed controller, two processes were applied: pen-plotting and wood engraving. The pen-plotting process measure the controller ability to trace 2D contour profiles without heavy load while the wood engraving process involves cutting load between the tools and the materials.

4.1 Pen Plotting

The pen-plotting process was implemented successfully for various contour profiles.

Among the tested profiles are the roman letters, Arabic letters, AutoCAD drawings and free-hand figures. Figure 4-1 and Figure 4-2 below illustrate the pen plotting capability.

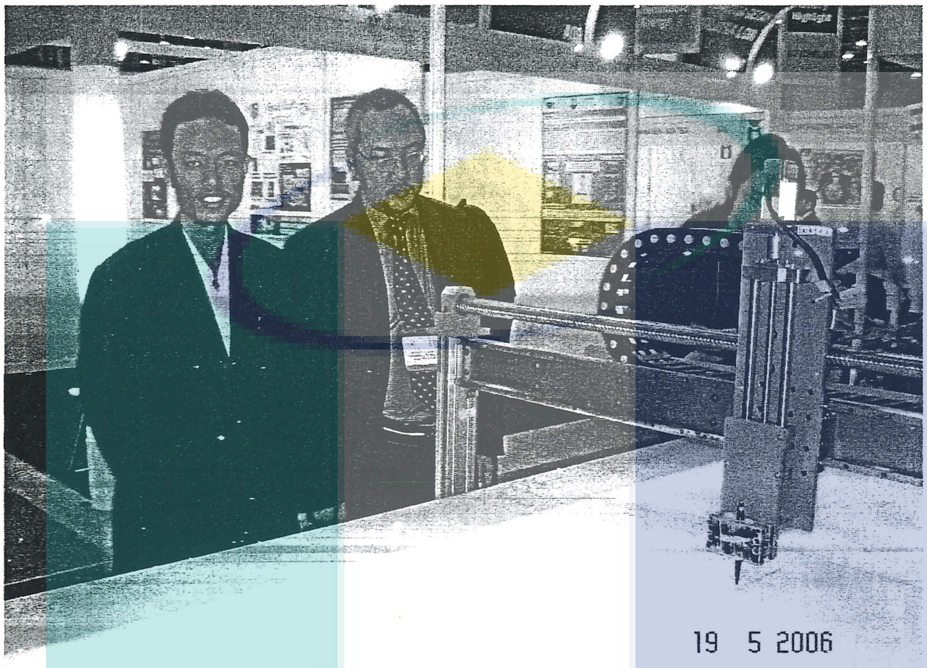


Figure 4-1: The pen-plotting process

The repeatability test is carried out by tracing the same profile location and the test indicates acceptable results. The repeatability performance of the pen-plotting process is found to be accurate.

Pen-plotting is a low torque application in which the load between pen and paper is small. These applications extend to "batik" making, optical inspection, laser cutting, glue dispensing and soldering.

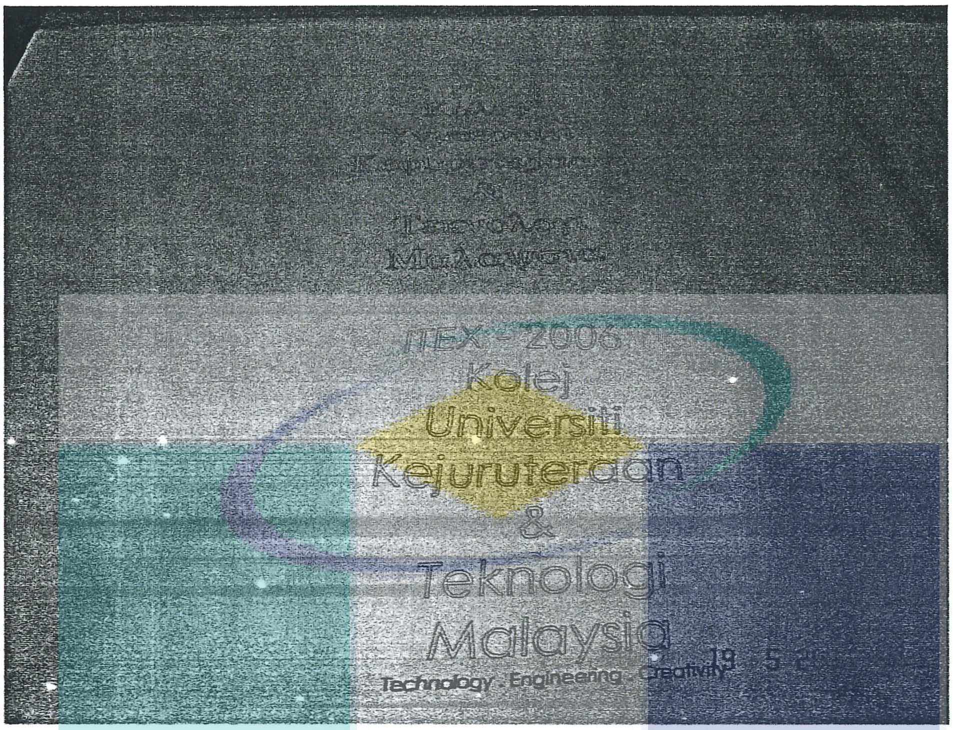


Figure 4-2: Sample of plotting results

4.2 Wood Engraving

The second tested application is applied for wood engraving. The difficulty of wood engraving is on the cutting task which involves friction between the cutting tool and work piece. "Nyatoh" wood is chosen for the souvenir product.

Jig and Clamping Setup

The jig and clamping apparatus is needed during the wood engraving process. It is very important due to the requirement to fit the work piece at the original place until the end of the process. The clamping kids set used are illustrated in Figure 4-3. The clamping is supported by parallel bar in order to prevent of high stress applied directly to the wood or work piece.

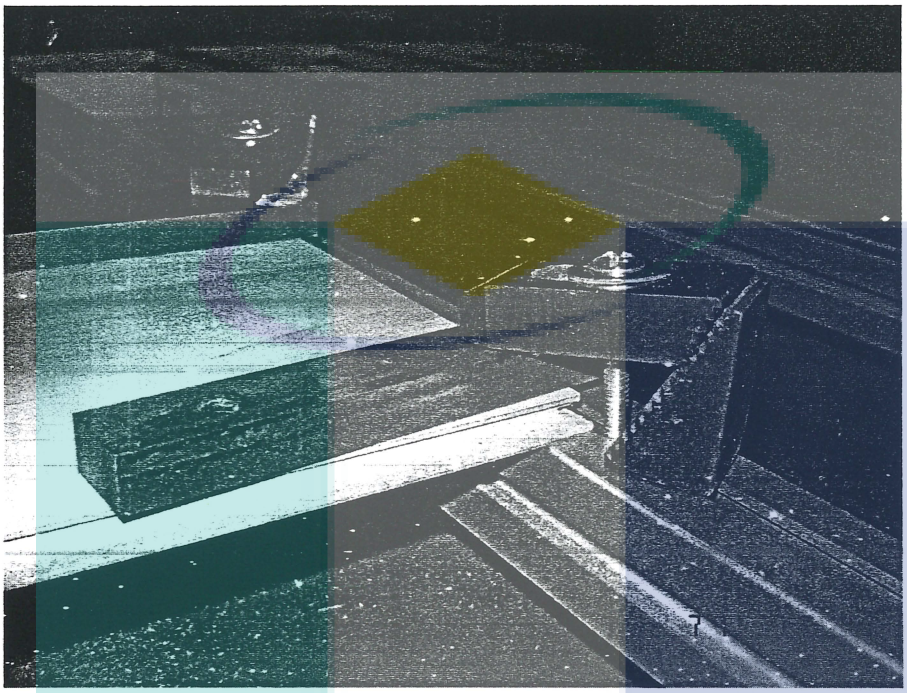


Figure 4-3: Clamping kids' setup

Tool Clearance Strategy

Because of the wood structure is in a unilateral form as shown in Figure 4-4, the suitable cutting tool clearance strategy for the wood engraving need to be considered. The engraving work is conducted in two method; raster and offset strategy. The option that is suitable for the wood engraving is raster which is parallel with the wood structure. By this clearance strategy, the finishing edge of end product is better compare to offset method.

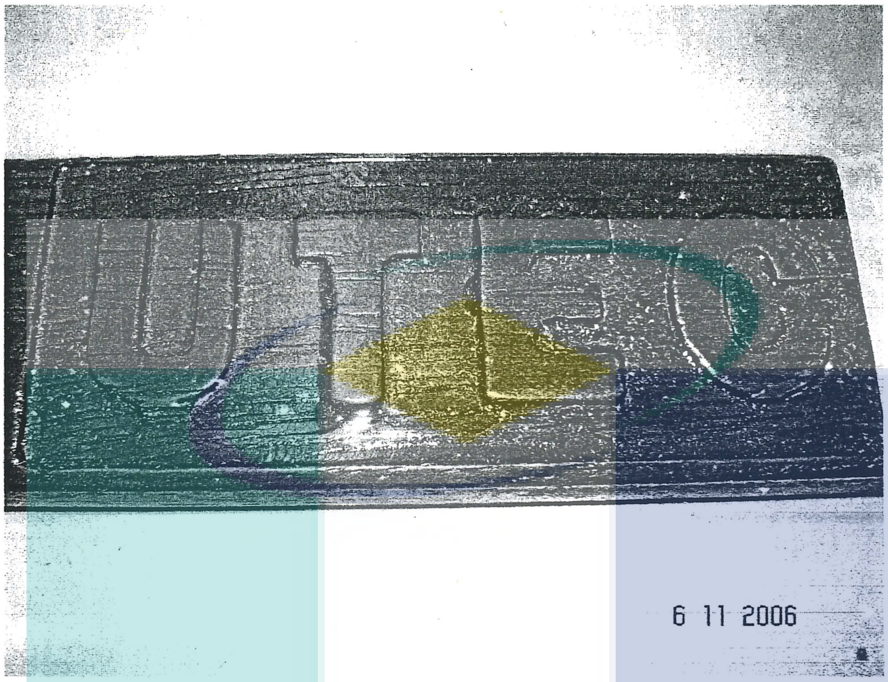


Figure 4-4: Wood structure which is a combination of unilateral form

Cutting tool

Option for the cutting tool is between the end-mill and ball-nose type. After conducting a test, end-mill type is the best for the wood engraving. It provides a flat surface and acceptable quality for the souvenir standard.

Cutting parameter

Cutting parameters for the wood engraving involve of cutting speed and feed rate. The test is conducted by engraving a straight line along x and y axis. The best cutting speed for the Nyatoh wood is 5000 rpm. Over this value, it will destroy the wood because of overheating during the engraving work. The feed rate is set 1.5 mm/s based on the pulse/length test conducted at the beginning of the internal test.

Wood engraving product

Example of successfully end product is shown in Figure 4-5 and was sold to the customer during the KUKTEM ExpoKonvo 2006 at Berjaya Megamall. The product is custom fabricated base on order by the customer.

Parameters	Description
Work Piece dimensions	300 mm x 60 mm x 10 mm
Engraving Time	30 minutes
Font Type	Sylfaen Baltic 30

The detail of the wood engraving process is shown in Table above. Overall, the quality of the product is acceptable by the customer and got a high demand.

In general, the controller and the prototype machine were successfully integrated and tested over two different applications. In fact, the wood engraving product is already commercialized.

CHAPTER 5

CONCLUSION

In summary, this project/product development attempts to develop:

1. PC-Based CNC Controller
2. Open architecture CNC controller
3. Prototype machine as platform to implement the developed controller

Significant contributions from the research:

1. The PC OAC platform will become the basis for the development of other computer-controlled machines such as robots and AGV in manufacturing focus area.
2. Any newly invented CNC sub-system (invention in a very specialized area in

CNC technology such as newly developed manufacturing process) can immediately be implemented. Confirmed success of the sub-system can immediately be commercialized.

3. Indirectly, the research project supports national drive towards less dependency on foreign technology in particular machine tool technology.

Future research in CNC controller

There is a lot of future research that can be continued. The potential areas that can be considered are list below.

Development of real-time operating system

The controller is based on Windows operating system. It is not suitable for machine control. Using Windows OS, the execution of program is not in real-time meaning there is always interruption from servicing utility program such as anti virus and file checking. This interruption effects the deterministic of program execution. Future research shall move towards Open Source OS which allows full control over program running.

5-Axis Controller

The controller can be expended to control 5-axis movement application. It is suitable for milling and cutting processes that involved of 3-D profile such as propeller and turbine blades. Since the controller is open architecture, the integration of 5-axis control functions can easily carried out.

Retrofitting

Since the developed controller is open-architecture, the controller can be integrated with conventional machines such as milling and turning. This is a viable alternative for SMI company upgrading from conventional to CNC.

Cryptology

Beside that, the security system for the real-time operating system need to be developed to make sure the safety of the program, crash prevention as well as virus protection. It is also very important due to the user safety during operations.

Machine Structure

Proper stress analysis was not carried out during the design of this machine. The fabrication is based on industry advisor by their experience. Future works may include stress analysis during the design of the machine considering dead load, thermal and vibrations.

Development of CAD/CAM interface system

CAD/CAM interface system has a good potential and can be developed based on specific process. The environment can be creating more users friendly and specific to the custom process.

Applying incremental forming process

Incremental forming process involves of minimum 3-axis application. So the prototype machine can be a good platform to have a study on it. The changing is only at tool selection and the jig setup.

Applying laser cutting process

Laser cutting is an expensive process but have a wide application on it. The prototype machine that had been fabricated also can be a platform to start the study on laser cutting process.

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