DEVELOPMENT OF MICROCONTROLLER CONTROLLED COMPUTER NUMERICAL CONTROL (CNC) ROUTER MACHINE WITH GRAPHICAL USER INTERFACE (GUI)

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By

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LIST OF ABBREVIATIONS

NC   Numerical Control

CNC   Computer Numerical Control

CAD   Computer-Aided Drawing

CAM   Computer-Aided Manufacturing

3-D   Three-Dimentional

USB   Universal Serial Bus

MCU   Machine Control Unit

DC   Direct Current

AC   Alternating Current

PCB   Printed Circuit Board

GUI   Graphic User Interface

EEPROM   Electrically Erasable Programmable Read-Only Memory

I/O   Input/Output

EOL   End of Line

EMC   Enhance Machine Controller

PEMBANGUNAN MESIN PEMOTONG KOMPUTER KAWALAN BERANGKA (CNC) KAWALAN PENGAWAL MIKRO BESERTA ANTARAMUKA PENGGUNA GRAFIK (GUI)

ABSTRAK

Kajian ini adalah berkenaan pembangunan mesin pemotong Komputer Kawalan Berangka (CNC) kawalan pengawal mikro beserta Antaramuka Pengguna Grafik (GUI). Pengawal mikro mampu berfungsi sebagai pengawal perisian untuk pemantauan operasi mesin dengan melalui proses 'flashing' Grbl – sebuah pengawal CNC dan pengurai G-code berprestasi tinggi serta terbuka ke pengawal mikro. GUI berperanan sebagai cara perhubungan dan antaramuka antara komputer dengan pengawal mikro. Mesin pemotong CNC boleh melaksanakan koordinasi 3-D menggunakan ketiga-tiga paksinya. Untuk penentuan kedudukan dan kawalan pergerakan paksi, motor pelangkah digabungkan dengan pemandu motor pelangkah dan pengawal mikro. Komputer digunakan untuk menulis pengaturcaraan G-code dimana ianya adalah piawaian industri untuk kod pemesinan. Alat peranti lain seperti suis pembatas disepadukan bersama pengawal micro AVR untuk penentuan titik rujukan sifar mesin dan juga untuk melaksanakan fungsi had batasan. Cabaran pertama adalah membina GUI yang berfungsi untuk antara muka mesin menggunakan bahasa pengaturcaraan Microsoft Visual Basic 2010 Express dan yang keduanya adalah untuk menggabungkan semua komponen ini bersama dengan pengawal mikro AVR. Dengan tindakan penambahbaikan terhadap mesin pemotongan CNC berupaya mengurangkan kejadian ralat kesalahan dari 60% ke 5%, GUI yang dibina berupaya berfungsi 100% seperti yang diingini, dan ketepatan mesin CNC dengan ralat kurang dari 1%, objektif kajian ini tercapai. Penambahbaikan yang dapat dilakukan adalah memperkembangkan lagi sistem Grbl, GUI dan sistem perkakasan untuk meningkatkan prestasi mesin pemotong CNC.

DEVELOPMENT OF MICROCONTROLLER CONTROLLED COMPUTER NUMERICAL CONTROL (CNC) ROUTER MACHINE WITH GRAPHICAL USER INTERFACE (GUI)

ABSTRACT

This research is about developing a microcontroller controlled Computer Numerical Control (CNC) router machine with Graphical User Interface (GUI). The microcontroller able to work as control software for machining operation monitoring by flashing Grbl - an open source, high performance G-code-parser and CNC milling controller to the microcontroller. The GUI's role as a mean of communication between computer and the microcontroller. The CNC router machine able to perform 3-D coordination using its three axes. For positioning and axes motion control, stepper motors are incorporated with stepping motor drivers and AVR microcontroller. The computer is used to create G-code programming which is a standard industry machining code. Other peripheral devices such as limit switches are integrated with AVR microcontroller for machine's zero reference point calibration as well to perform hard limit function. The first challenge is to build a working GUI for machine interface using Microsoft Visual Basic 2010 Express programming language and secondly is to interface all these components together with the AVR microcontroller. With the improvement implementation of the CNC router machine able to reduce fault error occurrence from 60% to 5%, the built GUI able to function 100% as intended to, and the accuracy of the CNC router machine with less than 1% error, the objective of this research is achieved. Improvements that can be done on the system are to further developing the Grbl system, the GUI and the hardware system to improve the performance of the CNC router machine.

CHAPTER 1

INTRODUCTION

1.1 Overview

CNC or Computer Numerical Control machines are computer controlled machining tools used widely in manufacturing industries as such machines are precise, reliable and able to speed up the manufacturing process without sacrificing the product's quality. CNC used coded instructions which are then sent to controller, guiding the machine movement or action as per instruction, thus allowing the fabrication of precise part. One of the type of coded instructions used is G-code which focus on machine's positioning. Other example of coded instructions are F-code that controls the feed of the tool and S-code addresses the feed of the tools. All three of the coded instructions are part of Numerical Control (NC) programming language. There are many variants of CNC machines. CNC router machine is one of the examples. CNC router are mostly used in carpentry works such as creating pattern or cut-outs out of wood. The CNC router able to do 3-D coordination motion control using Cartesian coordination system on three axes (x, y and z axes). Nowadays, with the help of Computer-Aided Drawing (CAD) and Computer-Aided Manufacturing (CAM) software, user are able to generates the NC programming without the need to manually constructing using G-codes. CAD is graphical process of drafting drawing object with vectors. Usually CAD is use in tandem to CAM software. This is because CAM is able to accept vector-based graphical input file created by CAD. The user then gives the needed information to allow CAM to create an output file in G-code format with all the cutting tool paths, feed rates necessary instruction in it (Overby, 2011). Mach3 and EMC (Enhance Machine Controller) are the most powerful and

popular controllers available in the market. However due to its pricey price tag, a cheap alternative is needed for this project. AVR microcontroller is used because it is not only cheap, the microcontroller is also supported by Grbl. Grbl is an open source, high performance G-code parser. Microcontroller is used to interfacing and controlling hardware, in this case the CNC router. For interfacing between computer and CNC router, serial communication method is used which can be establish by the use of Graphical User Interface (GUI) on the computer. In this project, a new GUI is built. GUI is use to feed G-code to microcontroller line-by-line via USB cable and then the G-code parser produces set of pulses to the driver to drive up stepper motors. Calculated positioning status info and other feedback data then being send from Grbl to GUI to be sorted and display accordingly to layout window on GUI panel.

1.2 Problem Statement

Aside from reliable and precise nature of CNC machines, the ability to do repetitive movement or task without losing its accuracy is why CNC machines continue to be used in manufacturing sector. The automation of CNC machine can reduce cost of the product by speeding up production lines, reduce the manpower, and ease the job in fabricating complex products. Since the AVR microcontroller is not compatible with the industry standard G-code, Grbl which is a G-code interpreter and parser are used to interpret and process the G-code. A GUI is needed as mean for computer to interface with Grbl system in the microcontroller. A good GUI will increase productivity and lowering the learning curve needed to control the CNC. GUI also act as a data sorter and display.

1.3 Objective of Research

The main objective in this research is to develop AVR controlled CNC router machine complete with its own Graphical User Interface (GUI).

There are two minor objectives to support main objective during the development. The first objective is to implement hardware improvement on the AVR controlled CNC router machine for ensuring system stability during experiments. Stability of the system is determine by the number of successful CNC run without the occurrence of fault error.

The second objective is to incorporate the GUI and AVR microcontroller together with computer, stepping motor drivers and other peripheral devices for running experiments on CNC router for performance evaluation of the machine.

1.4 Scope of Research

In this research, the CNC router machine allowable operating area is limited within 40cm x 30cm. The positioning of router and table are limited by limit switches that are placed at the both end of the x, y and z axes. Work piece size, weight and thickness allowable on the gantry or working area are restricted to a certain amount. Maximum allowable thickness is set to 2.0cm.

In this research, due to router stand limitation on supported weight up to 500g, no router is installed on the hardware system as all available router at hand weight over than 500g. Before suitable router is purchased, as replacement a pen is use to

illustrate the router point. In other word, the pen is used to verify axes coordination by drawing object or product's cutting path. The objective is still achievable with this replacement.

Not all NC codes are supported by the Grbl system. These codes are seldom used in general cutting process thus their functions are not included in the system. However mostly basic functions for router machine are supported by the Grbl system. In this research, the existing Grbl system capable to fulfill objective requirements.

For building a new graphical user interface (GUI) as mean for sending the G-code to microcontroller, Microsoft Visual Basic 2010 Express integrated development environment (IDE) is used. IDE is a software application that provides comprehensive facilities to computer programmers for software development. This IDE is chosen for its low learning curve and user friendly interface, as well as it is freely available from the internet. GUI need to at least fulfill few requirements such as able to establish connection with AVR microcontroller, able to send codes and instructions (i.e. G-code), able to receive feedback data from AVR microcontroller, and able to display position and respond from Grbl.

For designing parts, the G-code is manually programmed. Due to no access to high level software such as CAD/CAM, the designer need to manually write in the G-code. In order to work with CNC router, the designer need to have certain understanding or knowledge on G-code programming.

1.5 Outline of Thesis

In overall, this thesis comprises of five chapters. First chapter starts with an explanation on research background, followed by problem statements, objectives, scope of research and finally end with thesis's outline.

In chapter 2, the literature review and background studies on CNC machine, embedded system, and GUI is presented. This chapter also discuss the basic description of software and hardware parts of CNC machine, together with simple explanations on GUI, Grbl and G-code. Lastly, reviews summary is presented.

Chapter 3 will focusing on the approaches of developing the GUI and the possible improvement on CNC router machine hardware. Explanation on how the microcontroller's integration and interfacing with computer and other peripheral devices are done in this chapter. The newly built GUI overall functions as per source code is describes with the use of flow charts. Furthermore, experiments to check CNC machine accuracy are explained.

Chapter 4 presents all of experiments and tests result as well as discussion of the results. Some of the CNC products are presented at the end of the chapter.

Chapter 5 as the last chapter will conclude research and future development for further enhancement of the research.

CHAPTER 2

LITERATURE REVIEW AND

BACKGROUND STUDIES

2.1 CNC machine

Computer Numerical Control (CNC) machine uses Numerical control (NC) technology. NC technology is an automatic control technology in which the parameters such as position, speed or angle on production and processing are controlled by digital quantity in form of coded instructions (Li & Zhang, 2014). The coded instruction comprise of letters of symbols, numbers and alphabets can be read by the machine control unit (MCU). These letters referred to specific motions, positions, distances, or functions of the machine tools which are converted into electrical pulses of current sent to machine's electrical motors moving according to electrical pulses of current (Krar, Gill & Smid, 2001). The birth of NC technology is credited to John T. Parsons, a machinist and salesman of machining company, Parsons Corp.

John T. Parsons and MIT (Massachusetts Institute of Technology) collaboration develop the Numerical control (NC) between end of 1940s and early 1950s. Parsons was involved in the manufacture of helicopter propellers that required the perfect blend of complex shapes leading to discoveries that by using an IBM computer, more accurate contour profiles can be obtained using calculations and models (Albert, 2011). The program of the NC machines at that time was stored in tape and was edited and programmed by using only basic computers. For controller to read the

program, a tape reader was required to read the program, and then store the program in the controller's memory (*The CNC controller History past to Present*, 2011). By the early 1960s, the price and complexity of automated device tools had reduced to the point where they were introduced in other industries (Iliescu, Deaconu, Fartinescu, Deaconu, & Chirila, 2015). The invention of more modern computers on early 70's paved ways for Computer Numerical Control (CNC) implementation (*Training Material for CNC*, 2007). By using microcontrollers and computer systems, the NC controller can communicated directly to a computer (*The CNC controller History past to Present*, 2011).

Nowadays, most computerized numerical control (CNC) systems can be subdivided into two main groups. The first group contains standalone controllers which use dedicated embedded solutions such as microcontrollers, field-programmable gate arrays (FPGAs), and others. The other groups utilize general-purpose PCs. The CNC controllers implemented on the PC usually utilize some form of dedicated hardware to achieve machining capability (Erwinski, Paprocki, Grzesiak, Karwowski, & Wawrzak, 2013). CNC machines are usually used in carpentry or machinery with materials such as metal and wood. The machining mostly involves drilling, milling, cutting and contouring which are done with servo mechanism controlled by computer and specific tools. The servo mechanism can be separated into two fashion, an open-loop or close-loop fashion. Stepper motor is an open close servo control mechanism which is suitable for small loads while close-loop fashion is using servo control driving AC/DC motor or linear motor. As close-loop fashion, linear servo systems have the advantages of high velocity, precise, and excellent stability which can be used as high-performance system for CNC machine tools (Xu, Li, Lin,

& He, 2011). But such setting requires multiple sensors thus total cost are high. By using Kalman Filter to estimate the angular speed by measuring noisy current of DC motor, Khalid and Nawaz was able to create sensor less CNC machine (Khalid, & Nawaz, 2014). Motion controller is the core part of a CNC system, thus the development of open architecture motion controller is needed in developing further the open CNC system (Yuan, Yong-zhang, & Hong-ya, 2008). Since the implementation of the open architecture platform, CNC system's systematic functions becomes more flexible to integrate, modify, and expand systematic functions in order to fulfill different demands (Weidong, & Zhanbiao, 2010). Capabilities of CNC machine are well reflected in CNC router.

A CNC router is a cutting machine controlled by computer used for cutting various hard materials, such as wood, composites, aluminium, steel, plastics, and foams. Depending on machining tools, software controller and machine design and hardware, CNC routers can perform the tasks of many carpentry shop machines such as the panel saw and spindle moulder. With CNC router, instead of routing by hand, the machine takes control of the tool paths. A CNC router can produces high-quality work and consistent products as well improves factory productivity. Unlike a jig router, due to the accuracy and precision of the CNC router, it can produce a one-off as effectively as repeated identical production. The main benefit of CNC router are automation and precision. Generally CNC routers are available in 3-axis. Higher number of axis in CNC machines are called multi-axis coordination. Comparing to 3-axis machines, multi-axis machines perform more efficient and accurate machining. It is believed that multi-axis CNC machine is the best tools in sculptured surfaces machining (Yang, Shengmin, & Ping, 2011). With rapid technologies development,

even wireless control CNC machine is possible. Rong, Kerong, and Zhisen was successful in developing CNC system that able to be use with wireless Bluetooth technologies where part of the original CNC system functions is transferred to PDA or smartphones (Rong, Kerong, & Zhisen, 2012).

2.2 Embedded system

An embedded system is compromise of hardware and software parts. Hardware in the system refers to the electronic or electrical components as well as mechanical parts or any other physical device. The software is the programs or GUI that are designed for particular functions. The heart of embedded system is the processor which is either microcontrollers or digital signal processors. Many gadgets available nowadays are examples of embedded system such as cellular phones and cameras. Even automobiles are packed with embedded system to the point checking faulty in cars can be done just by connecting to main car board system.

Software

For CNC router, the software mainly must be develop to be able to send commands, able to display positioning of the axes, and user friendly. Interface is very important to the system in order to transfer commands from a computer to CNC controllers, and displaying the system operating data and results (Lu, Jia & Wang, 2010). LabView had been proposed as a user-computer interface (Weidong, & Zhanbiao, 2010). However, in this research Visual Basic 2010 Express had been used due to its easy learning curve and freely available to create the CNC machine's GUI,

AVR G-code Sender. Aside from GUI, CNC control software also needed to build a working CNC router. Controller software function as the CNC controller.

Some CNC control software are design to works specifically with certain hardware while some other are standalone software that support a wide range of hardware. The two most popular software available nowadays are Mach3 and EMC which use industry standard such as G-codes. The Mach3 software can operates up to 6 axes simultaneously while EMC operates up to 9 axes. The Mach3 software runs in Microsoft Windows while EMC only support Linux operating system. EMC is an open source and free controller which supports PLC programming with ladder diagrams. PLC programming is widely used in the industry. Despite being widely use and highly accurate, these systems are designed for nonprofessional use. Industry uses Heidenhain (*Heidenhain*, 2013) or Siemens Sinumerik (*Control systems SINUMERIK. SIEMENS*, 2013) which are special systems based on programmable automatic machines and industrial PCs (Mejdr, & Beran, 2015). Apart from these control software, microcontroller is another choice of CNC controller software. For controller software to work, instruction code is needed. Instruction code for complex design can be produce by the use of CAD/CAM software.

CAD (computer-aided design) and CAM (computer-aided manufacturing) are computer software that used for design and manufacture products by generating coordinates or paths for tool processing. Combination use of both software are widely uses in CNC scenes commercially as these software able support complex tool paths (Wang, Qi, Cai, Zeng, & Wang, 2011). For NC programming, the technologies used is still mainly based on M-codes and G-codes. CAD is mainly use to designs parts

(i.e. shape) and CAM use the design to create paths or coordinates in codes instruction for CNC machine. CAD stores graphics data in DWG and DXF format. DWG is binary format file, which mainly consists of five parts: head, entity part, table part, block entity part and emergency entity head. The entity part keeps all graphic entities, including point, line, arc, circle, size, and others (He, Wu, Dai, Chen L., & Chen C., 2011). DXF contains graphic information such as line types, base surface height, thickness, and other relevant geometric data (Laijie, Qiangbo, Lijuan, Ruiwen, & Jing, 2011). In current market, CAD software such as ORCAD or PowerPCB has been widely used in designing printed circuit boards (Haiming, Yueming, Peng, & Jiaxiang, 2013).

There are 4 stages in process flow of CNC router software parts. There are design, convert, interpret and interface. In design stage, parts to be machine is design by using CAD software, producing CAD drawings. In the next stage, the CAD drawings then are convert to G-codes via CAM software. These G-codes then being interpret by CNC control software for controlling the motor on each axis, producing motion or path for tools create the design part. The last stage is where GUI is use to send and receive data from CNC control software to check position and machine status. GUI also act as message display.

Hardware

Basic hardware component of CNC routers are a controller, servo motors, servo drivers, power supplies, workspaces table, and depending on setting, lead screw rod-nut or belt-gear combination parts. In this research, the developed CNC router machine consists one microcontroller, 3 stepper motors, 3 stepper motor drivers, 3

power supplies, lead screw rods and nuts for each axis, frame to hold all the parts and workspace to accommodate the CNC router machines. The dedicated controller is the Arduino AVR microcontroller.

Arduino AVR microcontroller is an open-source platform where software/hardware is easily to access, customized and support a lot of other peripheral devices through offering a variety of digital and analog inputs, SPI, serial interface, digital and PWM outputs. Arduino also easy to use and can connects to computer via USB, communicates using standard serial protocol, and widely supported in various OS such as Window or Linux whereby EMC only can run on Linux (Overby, 2011). Arduino also is cheap compare to other controller. Since Arduino also back up by online community where a lot of open source libraries are available for references in design using G-code. However, users can not program microcontroller directly by itself without external personal computer is the downside of Arduino (Krushinitskiy, & Sziebig, 2013). Arduino, together with computer and motor driver, control the stepper motor.

In CNC setup, stepper motor provide the motion necessary in the machining process by turning the electrical pulses into mechanical forms. When electrical pulses are applied in proper sequence, the stepper motor rotates its shaft in clockwise or counterclockwise direction. If the motor shaft connected to the lead screw rods, this in turn rotates the lead screw rods thus controlling motion on the axis. The motor shaft rotation speed is controlled by manipulating input pulses frequency. Higher input pulse frequency contribute to higher shaft rotation speed. Since stepper motor is an open loop operation, no sensor is required as there is no feedback system. This can

cause incorrect display of positioning data if stepper motor are to miss its step. In this research, the CNC router machine use two stepper motor model. The RS 440-442 stepper motor and the Vexta PH 268-21 stepper motor.

In order for stepper motor to work, stepper motor driver is needed to supply the input pulse. In this research, EasyDriver v4.4 is use as the stepper motor driver. EasyDriver v4.4 designed with two input lines: step and direction, and capable to drive bi-polar stepper motors. EasyDriver v4.4 support up to 30V output voltage and ±750mA range of output current per coil. Resolution of the driver can be set by manipulating MS1 and MS2 value. In the developed CNC, EasyDriver is set to fullstep (2 phase). The main component of EasyDriver v4.4 is the A3967 IC. A3967 IC is integrated with built in translator, pulse-width modulated (PWM) control circuitry, and DACs. PWM mainly controls the current supplied to stepper motor depending on stepper motor phases. DAC or Digital Analog Converter convert the step command on STEP pin to current level sequence and current polarity. Current level sequences and current polarities for step modes is tabulated in Table A.1 in Appendix A.

2.3 Graphical User Interface (GUI) for CNC

Graphical user interface is a platform for user to interact between electronic devices using a combination of technologies and devices for the tasks of gathering and producing information. Nowadays, GUI are in a wide range used in programs and they are considered as the main media between the user and the computer. GUI is the front-end of a software where the user interacts with the software (Ahmed, 2014).

GUI can be develop using programming language or integrated development environment (IDE) such as Visual Basic, LabView, and MatLab. In developing GUI, there are key areas need to be focus on in ensuring a good GUI building. Those are the functions detail, defining the user interface (UI) element such as input and output type, and placement rules that controls the UI (Khaddam, Mezhoudi, & Vanderdonckt, 2015). Detailed functions explain how a task is carried such as system functions (carried out by the system), input functions (require input from the end user), and output functions such as display information on the screen. The UI of input and output type can be either visible such as button, label, text box or non-visible such as mouse click. The placement rules here refer to placement of such button or label on the GUI.

In this research, the built GUI must act as a platform for AVR microcontroller interfaces with the computer. GUI send data such as G-code and Grbl commands to microcontroller line-by-line from the computer. Other GUI functions are to connect computer to microcontroller via serial communication upon setting up the serial port and baud rate, and to report the status of the Grbl system and axes positioning.

Grbl system

Grbl is an open source, free high performance CNC router controller. Grbl need to be flash to Arduino board for it to run. It accepts standard G-code and support most of the basic motions like linear and circle. However Grbl only support 3 axes with no rotation axes. When a G-code text file is stream to microcontroller via GUI that act as G-code sender, Grbl interprets the G-code command before converting them into pulse signal which is sent to stepper drivers thus producing motion on stepper motor.

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Grbl mainly consist of two parts, the interpreter and interpolator. For the interpreter part to work, these four components are needed. There are the parser, the executor, the path generator and the error handler. Parser main function is to interpret the input code line by line while the executor executes the function as per interpreted code from parser. The function of path generator is to generate position data based on input code. If there is an error in part of the program, the error handler generates warning notifications as is main function. The interpolator main function is to generate axis movement data as per data generated by the interpreter (Voon, 2013). For building the GUI, the basic understanding of Grbl's program flow is needed. By analyzing Grbl program flows, the GUI requirement for controlling the CNC can be establish. The Grbl programs flow is shown in Appendix B.

G-code

G-code is simple programming language, mainly because in its original form it does not have decisions, variables or loops (Aciu, & Ciocarlie, 2014). G-code comprise of two part, an address and a set of two digit number. An address is to differentiate between what kind of code is being use especially between G-code and M-code. The set of two digit number is to identify particular program to run in CNC. For CNC to run, at least a word complete with address and two digit number is needed. These variables of G-code command can be combine together in text file creating a set of instruction or program that can be send to CNC to perform certain tasks. For Grbl system, G-code and M-code are supported. G-code mostly use for tool movement while the M-code is for controlling the on/off functions in machine tools (Suh, Kang, Chung, & Stroud, 2008). Some of the examples of G-code and M-code is shown in Table 2.1.

Table 2.1: Examples of G-code and M-code (Desai & Patel, 2015)

Programming Code	Routines
G00	Rapid Linear Travel
G01	Linear Interpolation
G02	Clockwise Circular Interpolation
G03	Anticlockwise Circular Interpolation
M30	Machine tool Stop

2.4 Summary

The technologies in CNC sector are increasing rapidly. The introduction of wireless CNC and sensor less close loop CNC system is the proof of that. More CNC system are becoming accessible to common user due to software and hardware for CNC costing lesser and lesser. Arduino AVR microcontroller as software controller cost significantly lower than Mach3 or EMC with wider support since can run on both Windows and Linux. As a free high performance CNC router machine controller, Grbl is preferable as it's also support Arduino. However Grbl only able to support up to only 3 axes compare to much more costly Mach3 or EMC. The programming language chosen for developing GUI is Visual Basic Express 2010 as it's easy to implement due to less learning curve.

CHAPTER 3

METHODOLOGY

3.1   Overview

In this chapter, the methodology of developing Grbl flashed AVR controlled CNC router machine with its own Graphical User Interface (GUI) is discussed. Methodology process flow is shown in Figure 3.1. The developed CNC router machine rig setting is reviewed. Further improvements are implemented on the CNC router machine hardware. The Grbl program is written in C language and being compiled by AVR Studio 4 to the AVR microcontroller (Voon, 2013). The GUI is built using Microsoft Visual Basic 2010 Express. Functional tests are conducted to confirm GUI usability. Further tests are done to confirm microcontroller interfacing with other peripheral devices, specifically motor drivers and stepper motors. Experiments are carried out for CNC router machine workability.

3.2   CNC router machine

The block diagram for CNC router machine for one axis configuration is shown in Figure 3.2. The actual setting of the CNC rig is shown in Figure A.1 in Appendix A. This CNC machine setting originally developed by Voon (2013). This CNC machine setting is chosen due to low cost, easily obtainable hardware and support factors. Since the main program on the microcontroller is the widely used Grbl program, commonly in private setting, the use for GUI is needed. The CNC router machine able to perform 3-D coordination using its three axes. For positioning and

axes motion control, stepper motors are incorporated with stepping motor drivers and AVR microcontroller. The computer is used to create G-code programming which is a standard industry machining code. Other peripheral devices such as limit switches are integrated with AVR microcontroller for machine's zero reference point calibration as well to perform hard limit function.

The x, y, and z axes motions are controlled by three stepping motors via turning the screw rods. The RS 440-442 stepping motors with the lower torque is use for y and z axes motion. The higher torque Vexta PH 268-21 stepper motor is needed to control x axis, the longest axis where the table work for carrying work piece is set. A certain parameter need to be define for Grbl system to work correctly. For this CNC machine, the setting parameter is shown in Figure 3.3. By using the selected setting parameter of steps/mm, Grbl system can generate necessary step pulses to stepper motor which then rotates the screw rods, moving in 1 mm distance .There are 6 limit switches installed on the CNC machine. 2 limit switches on each axis. Limit switches are needed in homing cycle to locate zero reference positioning. Once homing cycle started, stepper motors will rotates each axis until limit switches is triggered. Hard reset button also set to reset pin on Arduino.

3.2.1   Input/Output (I/O) of AVR microcontroller

The assignment of AVR microcontroller I/O pin is shown in Figure 3.4. To reduce noise some resistor were added between input pins and VCC. Since only one LIMIT input pin available for each axis, two limit switches are wired in parallel to LIMIT pin to allow hard limit function to perform on both ends on the axis.
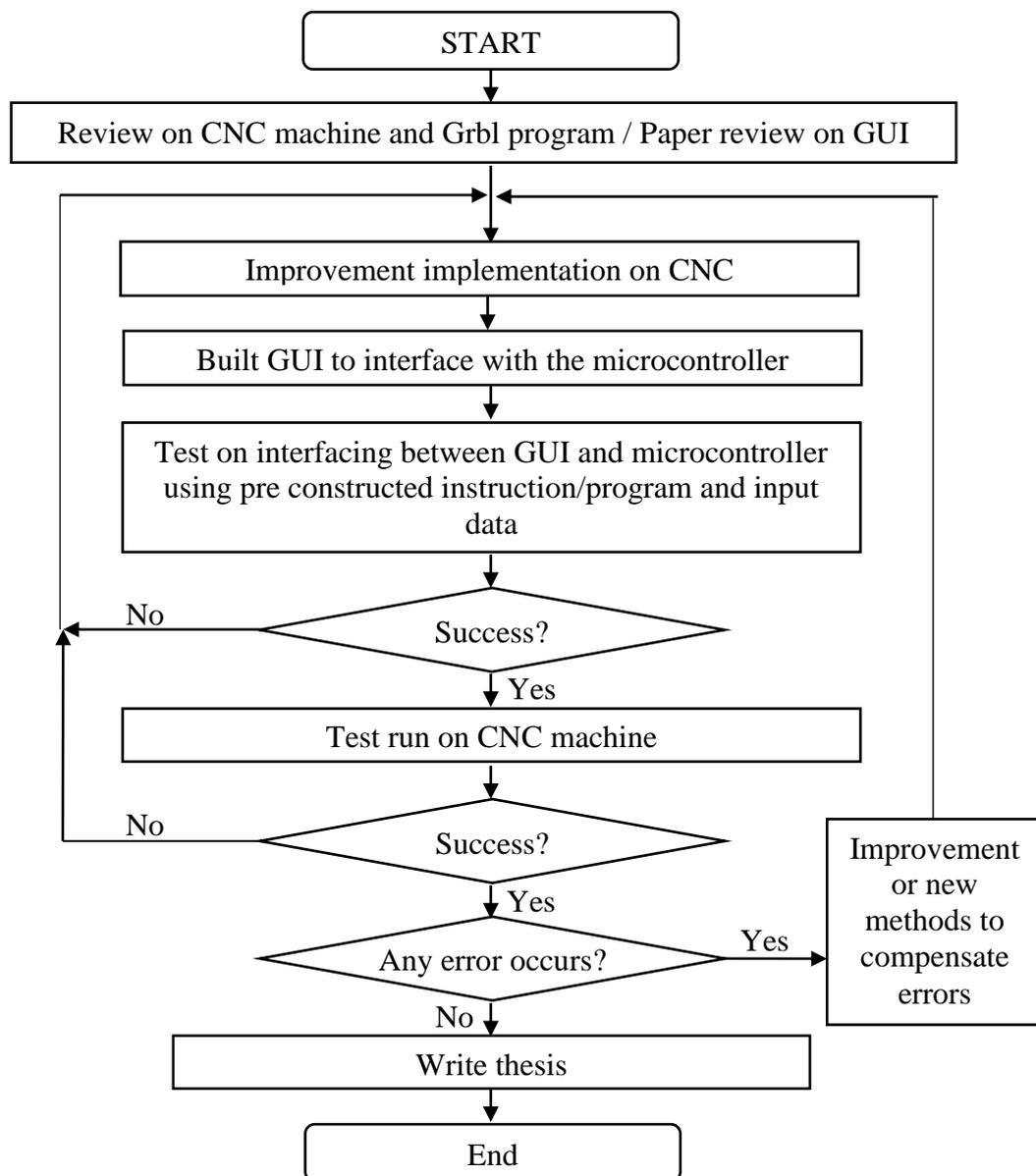
Figure 3.1 : Flow chart of the process flow of developing the AVR controlled CNC router machine complete with Graphical User Interface (GUI)
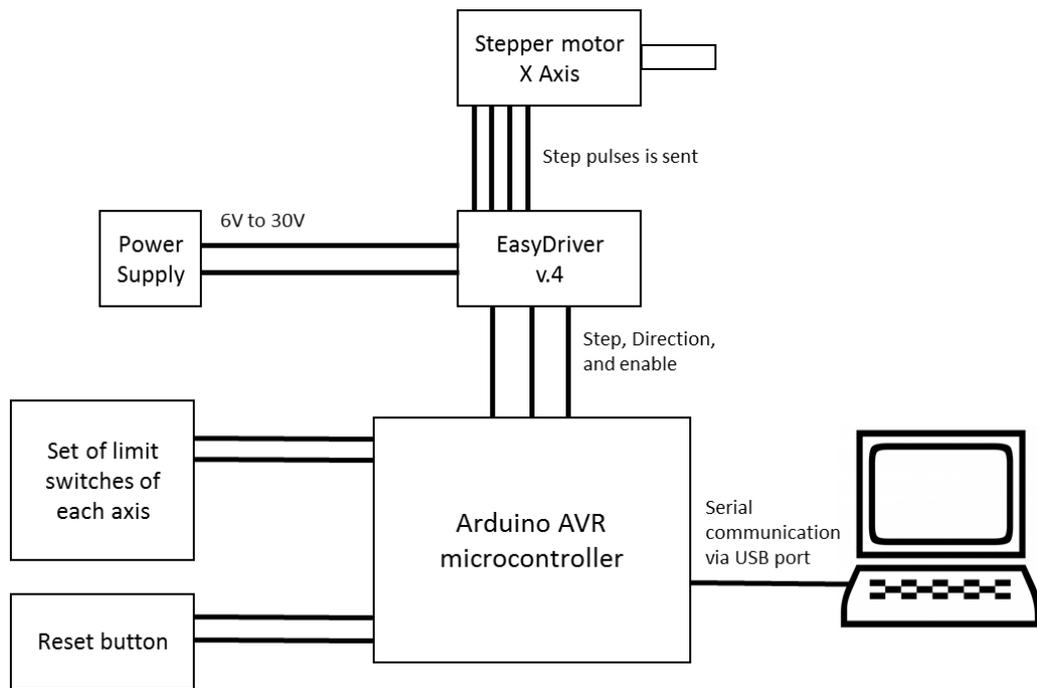
Figure 3.2 : Block diagram for CNC router machine on one axis configuration


```
Grbl 0.8c ['$' for help]
['$H'|'$X' to unlock]
>>>$X
[Caution: Unlocked]
>>>$$
$0=1063.000 (x, step/mm)
$1=1250.000 (y, step/mm)
$2=1034.000 (z, step/mm)
$3=10 (step pulse, usec)
$4=100.000 (default feed, mm/min)
$5=200.000 (default seek, mm/min)
$6=160 (step port invert mask, int:10100000)
$7=25 (step idle delay, msec)
$8=10.000 (acceleration, mm/sec^2)
$9=0.050 (junction deviation, mm)
$10=0.100 (arc, mm/segment)
$11=25 (n-arc correction, int)
$12=3 (n-decimals, int)
$13=0 (report inches, bool)
$14=1 (auto start, bool)
$15=0 (invert step enable, bool)
$16=0 (hard limits, bool)
$17=1 (homing cycle, bool)
$18=224 (homing dir invert mask, int:11100000)
$19=60.000 (homing feed, mm/min)
$20=180.000 (homing seek, mm/min)
$21=100 (homing debounce, msec)
$22=2.500 (homing pull-off, mm)
```

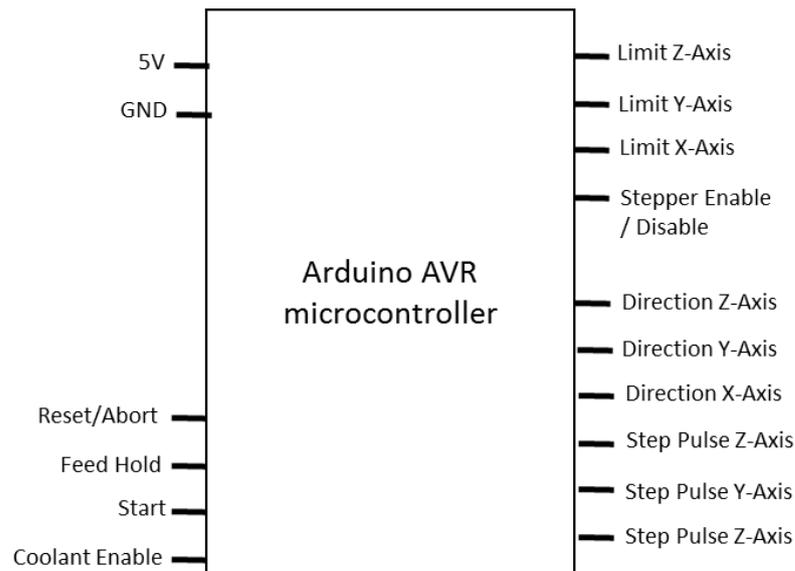Figure 3.3 : Grbl setting parameter of the CNC router machine

Figure 3.4 : Block diagram of Arduino UNO ATmega 328p microcontroller

3.2.2 Stepper Motors

In the developed CNC router machine, three stepper motors are being implemented. Two of the stepper motors are RS 440-442 hybrid stepping motors while the other one is Vexta PH 268-21 stepping motor. Each stepper motor model specifications are listed in Table 3.1. The rated current is the maximum amount of currents can be allowed to flows through the coil without damaging the motor.

Both model have stepping angle of 1.8 degree but RS 440-442 have 8 wires while Vexta PH 268-21 only have 6 wires. The setting configuration of both model to a controller and power supply is shown in Figure 3.5 and Figure 3.6. To obtain full step drive mode, both motors are configured as 2-phases motors by wiring only four wires of the motors. For RS 440-442, the remaining 4 wires are connect in short circuit but for Vexta PH 268-21, the remaining 2 wires are leave unconnected. Table

21

3.2 and Table 3.3 shows that the sequence of energize and de-energize of coil A and B can control the direction of motor shaft spin.

Table 3.1 : Specifications of RS 440-442 Hybrid and Vexta PH 268-21 stepper motors

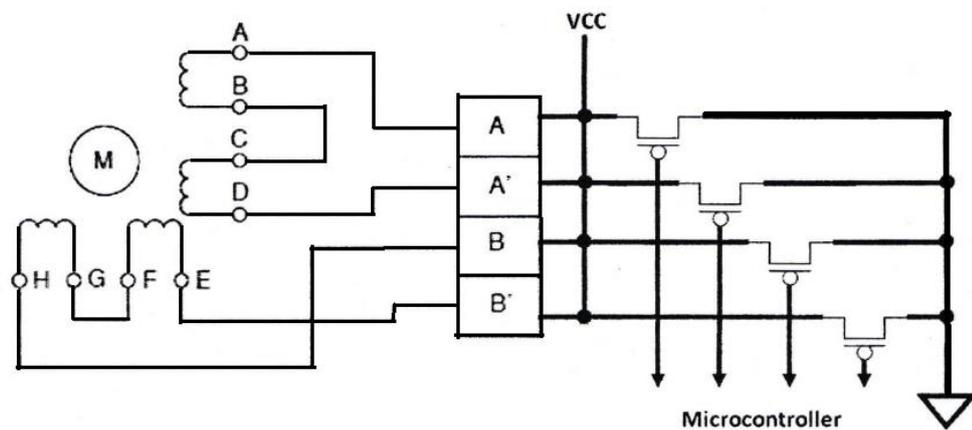| Specification of stepping motor		
Model:	RS 440-442 Hybrid	Vexta PH 268-21
Rated Current:	1 A	1.5 A
Rated Voltage:	5.1 Vdc	5.4 Vdc
Holding Torque:	500m Nm	883m Nm
Step Angle:	1.8 degree	1.8 degree
No. of wires:	8	6

Figure 3.5 : 8 wires stepper motor configuration with transistors and microcontroller
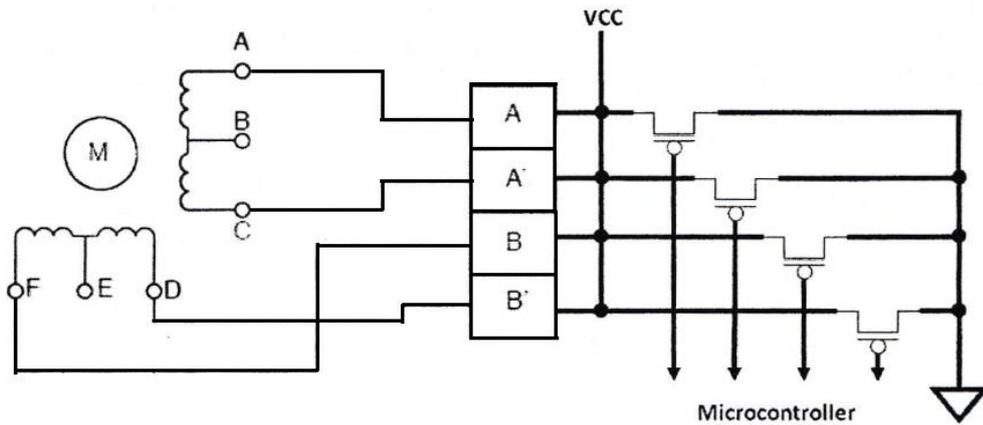
Figure 3.6 : 6 wires stepper motor configuration with transistors and microcontroller

Table 3.2 : Step for energize and de-energized port A, B, A', and B'
for clockwise direction.

Step	A	B	A'	B'
1	ON	ON		
2		ON	ON	
3			ON	ON
4	ON			ON

Table 3.3 : Step for energize and de-energized port A, B, A', and B'
for counter clockwise direction.

Step	A	B	A'	B'
1	ON			ON
2			ON	ON
3		ON	ON	
4	ON	ON		

3.2.3 EasyDriver v4.4 stepping motor driver

EasyDriver v4.4 stepping motor driver which can provides a maximum of 750mA output current for each phase of stepping motor below than rated current of both stepper motor and compatible with 4,6 and 8 wires stepper motor configuration of any voltages, is used in the CNC router machine . Since the driver can easily get heated up upon running, heat sinks is added onto the top of the driver's IC chip to counter this disadvantage as well to protect the IC chip. If the maximum thermal protection is reach, the IC chip may be damaged. The driver's specification is tabulated in Table 3.4. The driver pin out is shown in Figure 3.7.

Table 3.4 : Specifications of EasyDriver v4.4 stepping motor driver

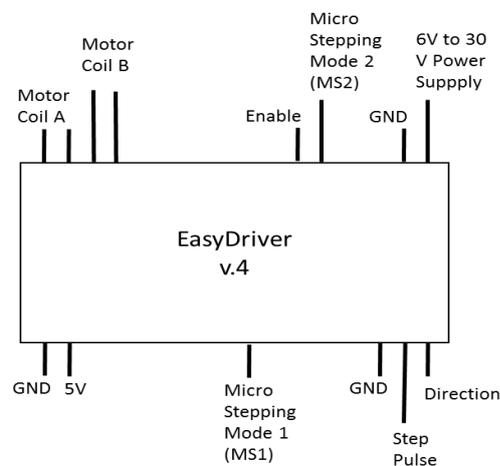| Specification of EasyDriver v4.4 stepping motor driver	
Power supply:	6V to 30V
Output Current:	150mA/phase to 750mA/phase
Output Voltage:	≤5V
Motor type:	Bi-polar stepping motor
Microstepping resolution:	Full-,Half-,Quarter-, and Eight-step modes
Maximum thermal protection:	165 degree Celsius

Figure 3.7 : Block diagram of the EasyDriver v4.4 stepping motor driver