ARDUINO COMPUTER NUMERICAL CONTROL DRAWING MACHINE

NEOH HOCK EE

A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Engineering (Hons) Electronic Engineering

Faculty of Engineering and Green Technology
Universiti Tunku Abdul Rahman

May 2019

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature : ____________________________

Name : ____________________________

ID No. : ____________________________

Date : ____________________________

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"ARDUINO COMPUTER NUMERICAL CONTROL DRAWING MACHINE"** was prepared by **NEOH HOCK EE** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons) Electronic Engineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : _________________________

Supervisor : _________________________

Date : _________________________

Specially dedicated to

my beloved grandmother, mother and father

ACKNOWLEDGEMENTS

I would like to thank everyone who had contributed to the successful completion of this project. I would like to express my gratitude to my research supervisor, Dr. Loh Siu Hong for his invaluable advice, guidance and his enormous patience throughout the development of the research.

In addition, I would also like to express my gratitude to my loving parent and friends who had helped and given me encouragement and support to complete this project.

ARDUINO COMPUTER NUMERICAL CONTROL DRAWING MACHINE

ABSTRACT

Computer Numerical Control, CNC machine is one of the most common machines that widely used in the industries nowadays. Many works that involve in movement or action that keep repeating everyday were substituted by the CNC machine from human as the human concentration becomes lower when times goes on while the product quality and quantity fabricated by machine will be maintain when times move. However, the cost of CNC machine use in industries is very high which causes the machine is not affordable in the small businesses and family use. This project is works to design a low cost Arduino based CNC machine that can perform drawing according to the given scale set by the user. The low price CNC machine is build for the small business company and family use. In this project, some types of CNC machine have been reviewed and discussed. The methodology of the hardware build, the required software and the operation flow of the machine have discussed in this project. The designs of the 3D printed components for the CNC drawing machine have been show in the result. Two types of images which are the input image and the import image have been tested. The scale of the original image and the drawn image have been compared and discussed. Two users have been invited to review on the CNC drawing machine. Future enhancements and recommendation such as the software development and the additional axis add to perform three dimensional printing have been discussed on this project.

TABLE OF CONTENTS

DECLARATION		**ii**
APPROVAL FOR SUBMISSION		**iii**
ACKNOWLEDGEMENTS		**vi**
ABSTRACT		**vii**
TABLE OF CONTENTS		**viii**
LIST OF TABLES		**xi**
LIST OF FIGURES		**xii**
LIST OF SYMBOLS / ABBREVIATIONS		**xvi**
LIST OF APPENDICES		**xvii**

CHAPTER

1	**INTRODUCTION**	**1**
	1.1 Background	1
	1.2 Project Statements	2
	1.3 Project Objective	2
	1.4 Project Scope	3
	1.5 Summary of Entire Project	3
2	**LETERATURE REVIEW**	**5**
	2.1 Background Study	5
	2.2 Types of CNC machine	5
	2.2.1 CNC Pick and Place Machine	6
	2.2.2 CNC Laser Cutting Machine	6
	2.2.3 CNC Milling Machine	8

		2.2.4 CNC 3D Printer	9
	2.3	Hardware System Overview	10
		2.3.1 Arduino Uno Microcontroller	10
		2.3.2 CNC Shield V3	10
		2.3.3 Motor Driver	11
		2.3.4 Motor	12
	2.4	Universal Gcode Sender Software	13
3	**METHODOLOGY**		**14**
	3.1	Introduction	14
	3.2	Project Flow	14
	3.3	Material Selection	15
		3.3.1 Motor Selection	15
		3.3.2 Arduino Uno Microcontroller	16
		3.3.3 CNC Shield V3	16
		3.3.4 A4988 Stepper Motor Driver	17
		3.3.5 2020 Model Aluminium	18
		3.3.6 PLA Filament	18
		3.3.7 12 V 20 A Power Supply	19
		3.3.8 SG92R Servo Motor	19
		3.3.9 Limit Switch	20
	3.4	Setup of Arduino IDE Software	20
	3.5	Setup of Inkscape Software	21
		3.5.1 Document Properties Setting	22
		3.5.2 Drawing Image	23
		3.5.3 Original Import Image	23
		3.5.4 Trace Bitmap of the Image	24
		3.5.5 Export Image as Gcode Format	25
	3.6	Universal Gcode Sender Software	27
	3.7	Setup of FreeCAD Software	29
	3.8	Setup of ideaMaker Software	30
	3.9	Hardware Building Stage	31
	3.10	Stepper Motor Calibration	34

3.11 Operation Process 35
3.12 Equipment and Cost Analysis 36
3.7 Project Milestone 38

4 RESULTS AND DISCUSSIONS 40
4.1 Results 40
4.1.1 Printed Design Hardware Components 40
4.1.1.1 Linear Bearing Holder 41
4.1.1.2 Stepper Motor Holder 43
4.1.1.3 X-axis Plane 45
4.1.1.4 Pen Holder 46
4.1.1.5 Holder Extension 47
4.1.2 Overall Look of the CNC Drawing Machine 49
4.1.3 Operation between the Hardware and Software of the CNC Machine 49
4.1.4 Homing System 50
4.1.5 Results of Drawing Image by CNC Machine 51
4.1.5.1 Original Import Image 51
4.1.5.2 Drawing Input Image 54
4.1.6 User Testing 57
4.2 Discussions 61
4.2.1 Components Used to Build CNC Machine 62
4.2.2 Accuracy of Stepper Motor in X-axis and Y-axis 62

5 CONCLUSIN AND RECOMMENDATIONS 64
5.1 Conclusion 64
5.2 Future Work and Enhancement 65
5.2.1 Three Dimension Printing 65
5.2.2 Software Development 65

REFERENCES 66

APPENDICES 68

LIST OF TABLES

TABLE	TITLE	PAGE
3.1	Command for Function of Universal Gcode Sender	27
3.2	Grbl Settings of CNC Machine	28
3.3	Cost Analysis for each Components and Equipment	36
3.4	Gantt Chart for FYP 1	38
3.5	Gantt Chart for FYP 2	39
4.1	Results of Image (Square)	52
4.2	Results of Image (Dolphin)	54
4.3	Results of Image (EE)	55
4.4	Results of Image (Spiral)	57
4.5	Results of Image (Robin)	59
4.6	Results of Image (Terry + Star)	61

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Linear CNC Pick and Place Machine	6
2.2	CNC Laser Cutting Machine	6
2.3	CNC Laser Cutting Machine Working Principle	7
2.4	CNC Milling Machine	8
2.5	Working Principle of Milling Process	8
2.6	CNC 3D Printer	9
2.7	CNC 3D Print House	9
2.8	Arduino Uno Microcontroller	10
2.9	CNC Shield V3	10
2.10	A4988 Stepper Motor Driver	11
2.11	L293D Motor Driver	11
2.12	Nema 17 Stepper Motor	12
2.13	DC Motor	12
2.14	Universal Gcode Sender Software	13
2.15	CNC Drawing Machine with Image Processing Method (Rupanagudi, et al., 2015)	13
3.1	Project Flow for Arduino CNC Drawing Machine	14
3.2	Dimension of Nema 17 Stepper Motor	15
3.3	Arduino Uno Microcontroller	16

3.4	CNC Shield V3	17
3.5	A4988 Stepper Motor Driver with Heat Sink	17
3.6	2020 Model Aluminium	18
3.7	PLA Filament	18
3.8	12 V 20 A Power Supply	19
3.9	SG92R Servo Motor	19
3.10	Limit Switch	20
3.11	Arduino IDE Software	20
3.12	grbl Library File Location	21
3.13	Inkscape Software Version 0.48.0	21
3.14	MakerBot Unicorn Gcode Extension File	22
3.15	Document Properties Window Setting	22
3.16	Spiral Shape Drawing Image	23
3.17	Original Import Image	24
3.18	Trace Bitmap Setting	24
3.19	Bitmap Traced Image and Original Colour Image	25
3.20	Stroke to Path Image	25
3.21	Location of Gcode Exporrt File	26
3.22	Export Gcode File Setting	26
3.23	Universal Gcode Sender Software	27
3.24	FreeCAD Software	29
3.25	Sample Hardware Component Design using FreeCAD Software	29
3.26	ideaMaker Software	30
3.27	Print Preview of the Component	30
3.28	Body Frame for the CNC Machine	31

3.29	Arduino Uno + CNC Shield V3 + A4988 Stepper Motor Driver + Heat Sink	31
3.30	Wiring of Stepper Motors, Power Supply, Limit Switches and Servo Motor on CNC shield	32
3.31	Connection of Stepper Motor and Lead Screw	32
3.32	Voltage Checking oon Power Supply	33
3.33	X-axis Stepper Motor Results before and after Calibration	34
3.34	Y-axis Stepper Motor Result before and after Calibration	34
3.35	Operation Process of the CNC Drawing Machine	35
4.1	X-axis Linear Bearing Holder Design	41
4.2	Printed X-axis Linear Bearing Holder	41
4.3	Y-axis Linear Bearing Holder Design	42
4.4	Printed Y-axis Linear Bearing Holder	42
4.5	X-axis Stepper Motor Holder Design	43
4.6	Printed X-axis Stepper Motor Holder	43
4.7	Y-axis Stepper Motor Holder Design	44
4.8	Printed Y-axis Stepper Motor Holder	44
4.9	X-axis Plane Design	45
4.10	Printed X-axis Plane	45
4.11	Upper Pen Holder Design	46
4.12	Lower Pen Holder Design	46
4.13	Printed Pen Holder Left to Right (Upper Pen Holder, Lower Pen Holder)	46
4.14	Cylinder Rod Holder Extension Design	47
4.15	Printed Cylinder Rod Holder Extension	47
4.16	Lead Screw Holder Extension Design	48

4.17	Printed Lead Screw Holder Extension	48
4.18	CNC Drawing Machine Hardware with Software	49
4.19	Random Position	50
4.20	Homing Position	50
4.21	Original Import Image (Square)	51
4.22	gcode File Image (Square)	51
4.23	Drawn Image (Square)	52
4.24	Original Import Image (Dolphin)	53
4.25	gcode File Image (Dolphin)	53
4.26	Drawn Image (Dolphin)	53
4.27	Text Input Image (EE)	54
4.28	gcode File Image (EE)	55
4.29	Drawn Image (EE)	55
4.30	Shape Input Image (Spiral)	56
4.31	gcode File Image (Spiral)	56
4.32	Drawn Image (Spiral)	56
4.33	First User test to use the CNC Machine	57
4.34	Image create by First User (Robin)	58
4.35	gcode File Image (Robin)	58
4.36	Drawn Image (Robin)	58
4.37	Second User test use the CNC Machine	59
4.38	Image create by Second User (Terry + Star)	60
4.39	gcode File Image (Terry + Star)	60
4.40	Drawn Image (Terry + Star)	60

LIST OF SYMBOLS / ABBREVIATIONS

A	Ampere
V	Volt
°	Degree
%	Percentage
AC	Alternating Current
CNC	Computer Numerical Control
DC	Direct Current
FYP	Final Year project
GUI	Graphical User Interface
IDE	Integrated Development Environment
I/O	Input / Output
PLA	Polylactic Acid
PWM	Pulse Width modulation
USB	Universal Serial Bus

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	CNC Shield V3 Schematic Diagram	68
B	CNC Shield V3 Layout	69
C	Dimension for 2020 Model Aluminium	70
D	Nema 17 Stepper Motor Datasheet	71
E	Servo Motor SG92R Datasheet	72

CHAPTER 1

INTRODUCTION

1.1 Background

The technology in the world has been speed up in this century. Works that involve movement or action keep repeating all the time has been substitute by machine from human as human concentration become lower when time goes on. For the machine, the performance in accuracy and precision can maintain when the time moves on. Computer Numerical Control, CNC machine is a machine that been widely used in the industry nowadays.

There are many types of CNC machine being used in the industry such as CNC milling machine, CNC routers, circuit drawing and the others. CNC milling machine is a machine that automatically cut the provided material by follow the instructions given by the computer. For the CNC routers, it is used to make cuts, as well as computer programmable 3D printing and also turret punch purpose. The CNC machine can be used in different cutter including laser, water and plasma as well. G-code is the code use to program the CNC machine. The instruction or drawing input by the user will convert into G-code and transfer to the machine to carry out the given task. G-code is a low level language which can only be understands by the machine. CNC machine plays an important role to fabricate the part of product quickly and accurately. With the CNC machine, the industries can speed up their production quality and also quantity.

1.2 Project Statements

Generally, CNC machine had been widely used in the industries. With the invention of CNC machine, many work can be replace by the machine instead of using men power. CNC machine boosts the productivity of the industries as well as the accuracy. However, the cost of a CNC machine used in industry is very high which is not affordable for small businesses and family use. Besides, CNC machine used in the industries nowadays only have a single function. In this project, a simple low cost Arduino based CNC machine had been built to perform simple drawing in X-axis and Y-axis according to the given image scale. This low cost CNC machine is built for the family use and small businesses as the price is cheaper compared to the industries CNC machine. This project is constructed to study the working principle of the machine and to learn on the hardware and software used for the machine.

1.3 Project Objective

The objectives of this project are shown below:

i. To build a low cost Arduino based CNC machine for small businesses and family use.
ii. To build CNC machine hardware which able to communicate with software.
iii. To run the CNC machine in both X-axis and Y-axis for simple drawing.
iv. To transfer gcode file from software to hardware to perform simple drawing.
v. To perform simple drawing according to the given scale.

1.4 Project Scope

The project consists of the CNC machine hardware designing, hardware building, calibration of the stepper motor for synchronise drawing and the communication between the hardware and software. Some of the addition features are added in the project such as additional function like limit switch homing function was added on the CNC machine. The project has been complete by April 2019 with some improvement to make the project more attractive and user friendly.

1.5 Summary of Entire Project

This project consists of five chapters for the body test. The first chapter of the project discuss about the introductory of the entire project and some background study of the CNC machine. In this chapter, it also mentions about problems faced and how these problems been solved as well as the project statements, objectives and project scopes.

Next, the research works of the project are elaborated in the second chapter of the body text. In this chapter, the history of CNC machine was briefly discussed. The types of CNC machine, functionality as well as the 2-axis and 3-axis CNC machine are discussed in this chapter. Some projects built with different based CNC machine also have review in this chapter.

For the following chapter, which is chapter three, the methodology, project flow and operating process of this project have been discussed. The selection of the materials and software used to run the CNC machine are shown in this chapter. The equipment and cost analysis and the project milestone are shown in the last section in this chapter as well.

The drawing results of the CNC machine built are compared with the original image and discussed in chapter four. Some hardware components design will be shown and discussed in this chapter. The problems that encountered in the project as well as the solutions for the problems have been discussed in the last section of this chapter. Finally, the chapter five is the last chapter for this project. This chapter concludes overall project and the future improvements of this project have listed on this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Background Study

Automation is defined as work done with the control system such as the computer numerical control. The birth of CNC was given in America in year of 1959 (Dey, Mondal, Barik, 2016). CNC machines then lead the industries toward an evolution. CNC machine is a machine that controlled by computer with input command data, code numbers, letters or symbols. CNC machine had been widely used as the automation control in industrial. By operating product using the CNC machine, the precision of product made can be guaranteed up to 1/1000 mm (microns) workmanship mass product (Sutarman, EdiHermawan, Sarmidi, 2017). Thus, the need of human intervention can be reduced as the mechanization can assists operators in the muscular requirement of work as well as decrease the involvement for human mental and sensory requirement (Modi, Prof. Patel, 2015). CNC machine can work semi-automatically or fully automatic according to the programme set by user. Many research studies are done to lower the cost of the CNC machine and trying to apply the CNC machine in different work areas.

2.2 Types of CNC machine

In this section, different types of CNC machines have been review for study purpose.

2.2.1 CNC Pick and Place Machine

CNC pick and place machine is machine which picks up the objects and places the object on the present destination. According to the researchers, CNC pick and place machine can reduce time development required for trial and error process, boost productivity and reduce men-power requirement (Modi, Prof. Patel, 2015).

Figure 2.1: Linear CNC Pick and Place Machine

The pick and place machine can be classified into major two types of machine which are the linear pick and place machine and rotation pick and place machine. Linear pick and place machine pick the object vertically or horizontally while for the rotation pick and place machine pick and place the object by rotating at the stationary point instead of moving along the horizontal axis and vertical axis.

2.2.2 CNC Laser Cutting Machine

Figure 2.2: CNC Laser Cutting Machine

CNC laser cutting machine is a machine that normally use CO_2 and Nd:YAG to cut materials by focusing the laser beam direct on the material surface that want to cut. There are few methods of cutting such as the vaporization cutting (focus beam heat on the material surface to create hole), melt and blow (use gas jet to blow the molten material away) and reactive cutting which is use to cut thick carbon steel with little laser power. CNC Nd:YAG laser robot able to cutting and soldering sheet metal components made of steel, stainless steel and aluminium (Radovanovic, 2002).

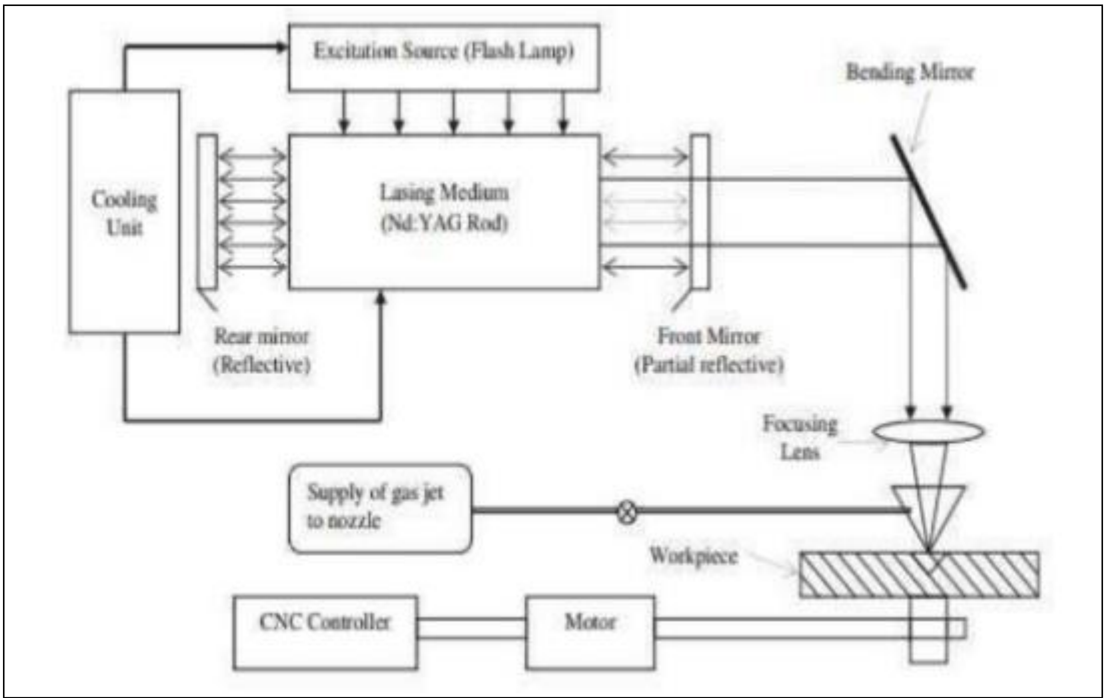


Figure 2.3: CNC Laser Cutting Machine Working Principle

Besides using laser for cutting purpose, laser beam also can be used for welding purpose. Laser welding is a process that joining the two metals together by applying brazing material and shoot the material using laser beams. Once the brazing material solidified, both metals will join together.

2.2.3 CNC Milling Machine

Figure 2.4: CNC Milling Machine

CNC milling machine is a machine that uses rotary cutters to remove or reshape material such as the wood or metal from surface of the work piece. The starting point of the CNC milling machine was using the placement of cutting tool as the reference while the milling part of the machine, the two side junction of the work piece are used as the reference point (Sutarman, EdiHermawan and Sarmidi, 2017).

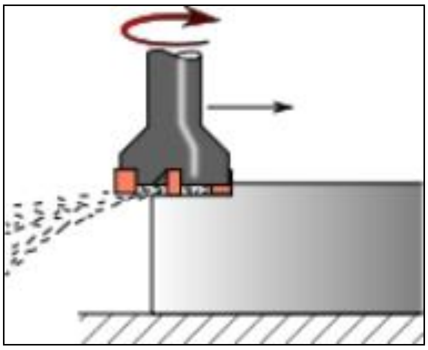


Figure 2.5: Working Principle of Milling Process

For the milling process, the rotary cutter rotates on its spindle and the work piece will move toward for milling where the milling process depends on the user input data.

2.2.4 CNC 3D Printer

CNC 3D printer is an evolution from the 2D printer. 3D printer can print out a 3 dimensional object after receive the G-code from the computer. The material use for printing is the thermoplastics, which is a plastic that will become semi-liquid above the specific heat and will return to solid again when cool down.

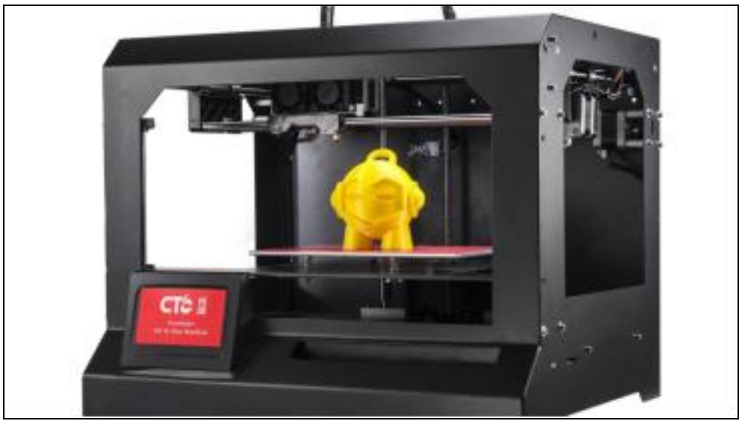


Figure 2.6: CNC 3D Printer

According to Nematollahi, Ming and Sanjayan (2017), architecture using the 3D printer concept to construct a house by created a largest 3D printer in world that uses sand and chemical binding agent to create stone-like material. With this construction method, it successfully reduces the construction time compared to old construction method. It also helps in saving cost as well as reducing men power in construction.

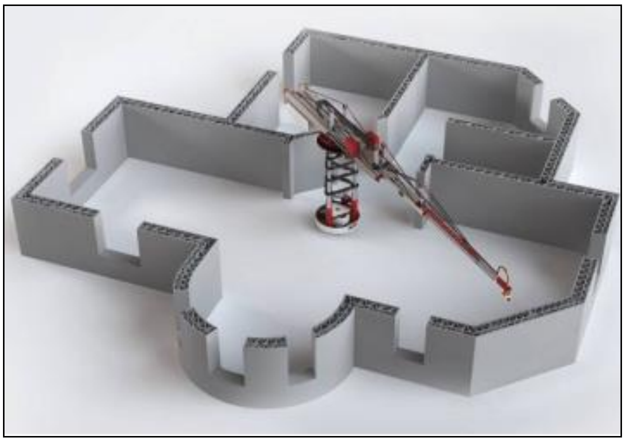


Figure 2.7: CNC 3D Print House

2.3 Hardware System Overview

This section will give the overview on the hardware that been used for this project.

2.3.1 Arduino Uno Microcontroller

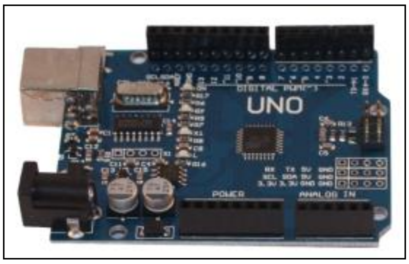


Figure 2.8: Arduino Uno Microcontroller

Arduino Uno is a microcontroller that provides easy way for student or professional to create own devices in cheaper way. Arduino is an open source microcontroller that runs under C and C++ language programme. The coding written to Arduino board can be overwritten any time when you wish to do another project. With help of CNC Shield V3, it will be able to control the stepper motor in the easiest way. Shivakumar and Selvajyothi (2016) used the Arduino Uno board as a signal generator to direct importing the CAD file into system without compromising on the performance of the system.

2.3.2 CNC Shield V3

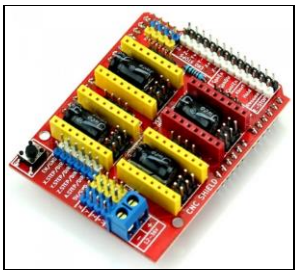


Figure 2.9: CNC Shield V3

CNC Shield basically is a stepper motor driver board that receives signal from Arduino Uno microcontroller and requires external power source to deliver to the stepper motors (Dey, Mondal, Barik, 2016). CNC Shield is a shield that helps to set up CNC machine in easier way. With the CNC Shield V3, it able to control up to 4 stepper motors by using the A4988 motor driver. With this shield and Arduino Uno microcontroller, the CNC machine such as pick and place machine, CNC router, engraving machine and also 3D printer project can be done.

2.3.3 Motor Driver

Figure 2.10: A4988 Stepper Motor Driver

The A4988 is a micro-stepping motor driver with built-in translator which allows easy implementation of A4988. This driver designs to operate the bipolar stepper motor in full, quarter, eighth and sixteenth step mode.

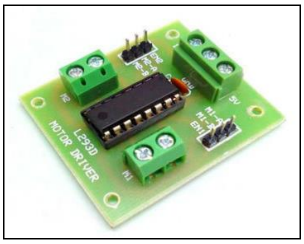


Figure 2.11: L293D Motor Driver

Rupanagudi, et al. (2015) uses the L293D motor driver to driver the DC motor to move along the axis in his project.

2.3.4 Motor

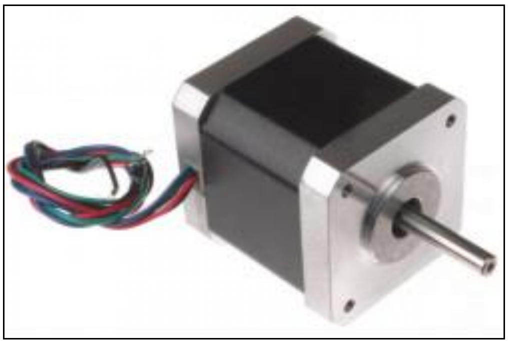


Figure 2.12: Nema 17 Stepper Motor

Nema 17 Stepper motor is a four phase, unipolar, permanent magnet stepper motor. It consists of 200-steps-per-revolution. Each step of the stepper motor turns the shaft in 1.8 degree for full step and 0.9 degree for half step. The CNC shield V3 and A4988 motor drivers have been used in the project to drive the stepper motor.

Figure 2.13: DC Motor

Rupanagudi, et al. (2015) using a DC motor for the CNC drawing project instead of using the stepper motor. Stepper motor has been chosen to use in this project as it will not overload easily compare to the DC motor.

2.4 Universal Gcode Sender Software

Universal Gcode sender software is software that receives the imported gcode file and sends instructions to the machine to perform drawing. The Gcode sender software is open source software that can be used as an interface for the CNC controller like the GRBL and TinyG.

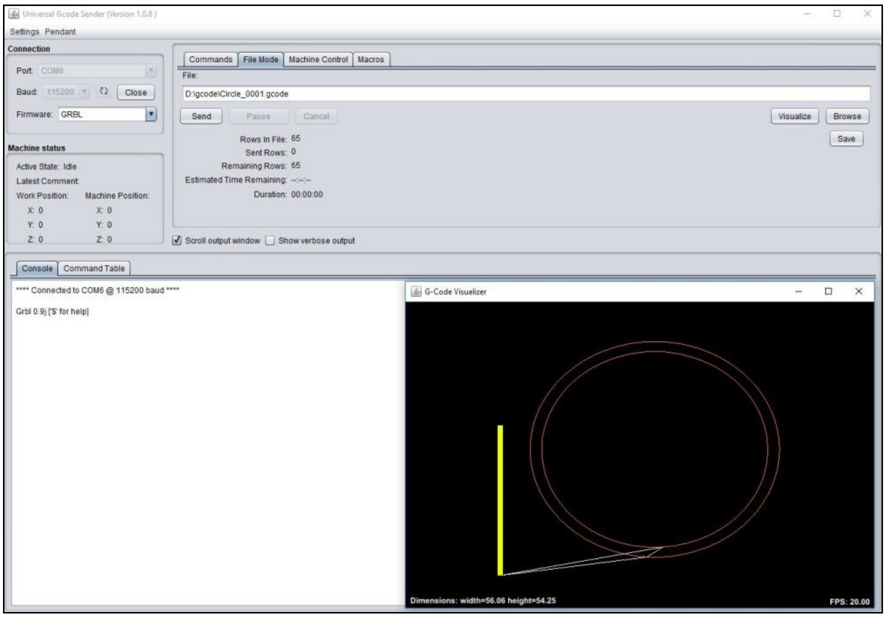


Figure 2.14: Universal Gcode Sender Software

Besides of using the gcode file for drawing the image, Rupanagudi, et al. (2015) using an image processing method through Matlab to perform simple drawing.

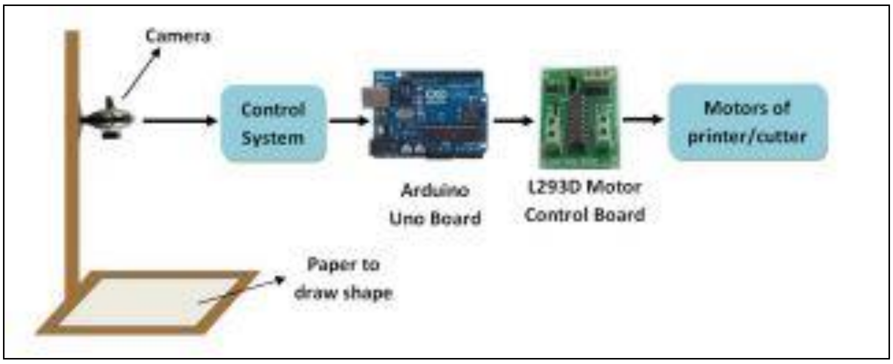


Figure 2.15: CNC Drawing Machine with Image Processing Method (Rupanagudi, et al., 2015)

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter illustrates the software use for the CNC machine, the idea and the component used in the hardware system design of the CNC machine. The process and system flow of the machine are mentioned in this chapter to give a clear illustration on the system design.

3.2 Project Flow

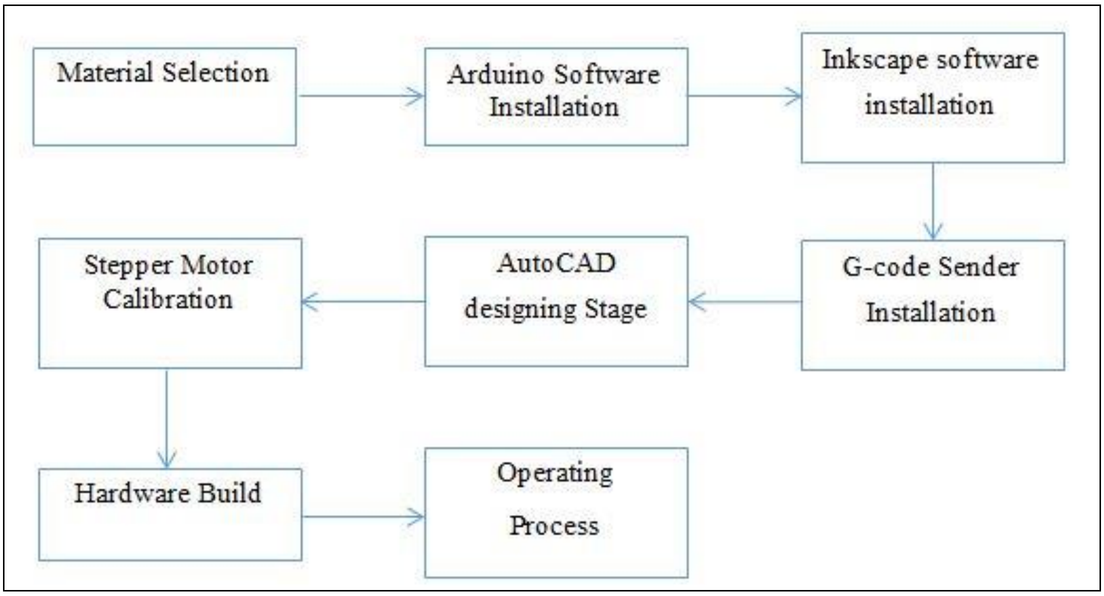


Figure 3.1: Project Flow for Arduino CNC Drawing Machine

3.3 Material Selection

This subsection will talked about the basic functionality of materials and component used in the CNC machine.

3.3.1 Motor Selection

Stepper motor in CNC machine functions as the rail for the machinery part to move along the X-axis and also the Y-axis. A Nema 17 Stepper motor has 200 steps-per-revolution which only steps the shaft for 1.8 degree per step. The Stepper motors were choose to build the CNC machine as the stepper motor is cheaper in price and the handling torque for the stepper motor is high to carry heavy load.

Technical Details:

- 200 steps pre revolution, 1.8 degree
- Bipolar stepper
- 4 wire, 8 inch leads
- 5 mm diameter drive shaft with a machine flat
- 12 V rated voltage at 1 – 1.5 A

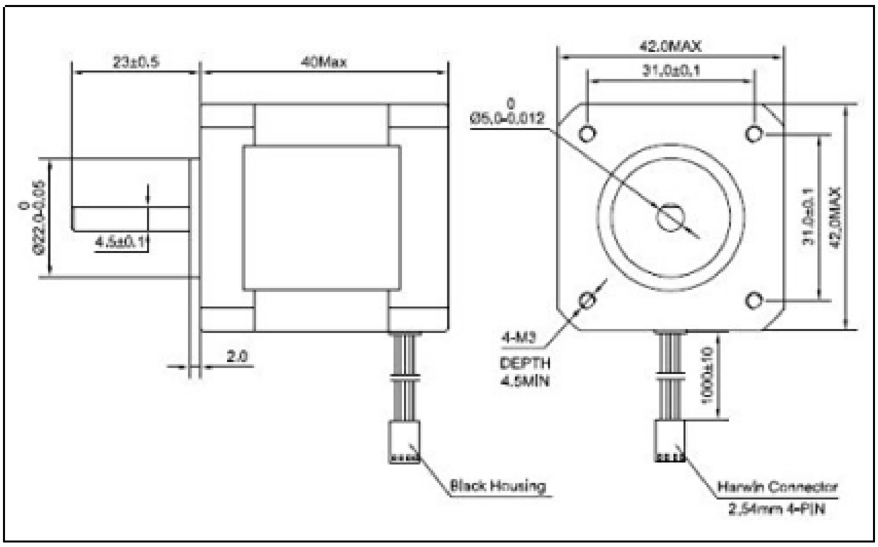


Figure 3.2: Dimension of Nema 17 Stepper Motor

3.3.2 Arduino Uno Microcontroller

Arduino Uno is a microcontroller board base on ATmega328. It has 14 digital I/O pins and 6 analog input pins. Out of the 14 pin, 6 I/O pins can be used as PWM outputs. Arduino Uno is an advanced microcontroller that used as the learning kit for building devices Arduino Uno microcontroller supports the C and C++ programming language which has been learn during last few year. . It is easy to upload a program inside the microcontroller compare to the traditional microcontroller. With Arduino, user can directly write the coding inside it with just a laptop that done Arduino software installation and an USB cable. The Arduino also can be rewrite at the instant time by directly upload a new coding in the microcontroller.

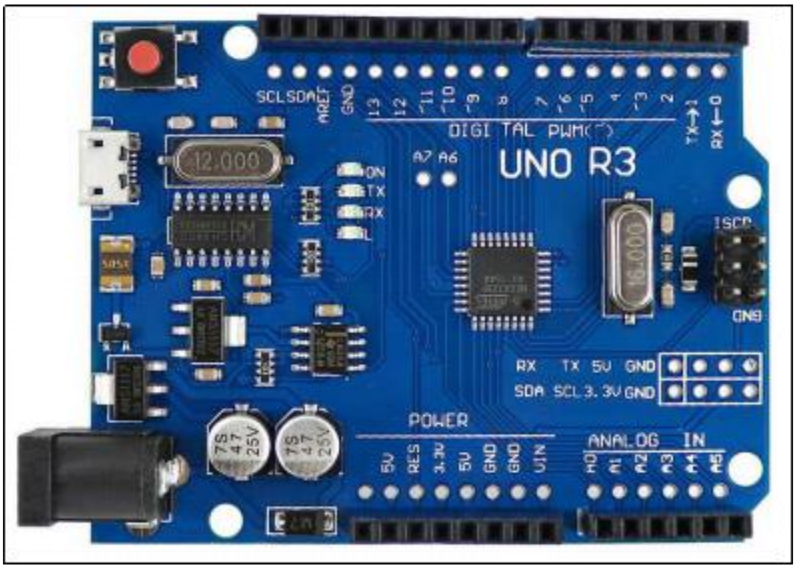


Figure 3.3: Arduino Uno Microcontroller

3.3.3 CNC Shield V3

CNC shield V3 was used in the project as it is compatible to the Arduino Uno. This shield allows the Arduino to drive up to four stepper motors. By using the CNC shield, it allows everyone to construct the CNC machine in more convenient way and to reduce the time spent in building process. This CNC shield requires extra power supply as it requires 12 V to power up the shield.

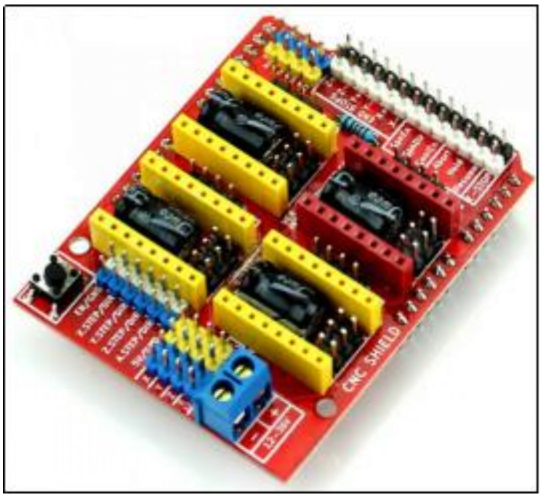


Figure 3.4: CNC Shield V3

3.3.4 A4988 Stepper Motor Driver

A4988 stepper motor driver has been selected to use in the project as it is compatible with the CNC shield V3. The driver of motor is cheaper and easily to use as it just need to plug on the CNC shield V3 slots. For this project, 2 A4988 are required to drive the x-axis and y-axis stepper motor. Heat sink was attached on the motor driver to absorb heat generated by the motor driver, thereby allowing regulation of the device’s temperature at the optimal level.

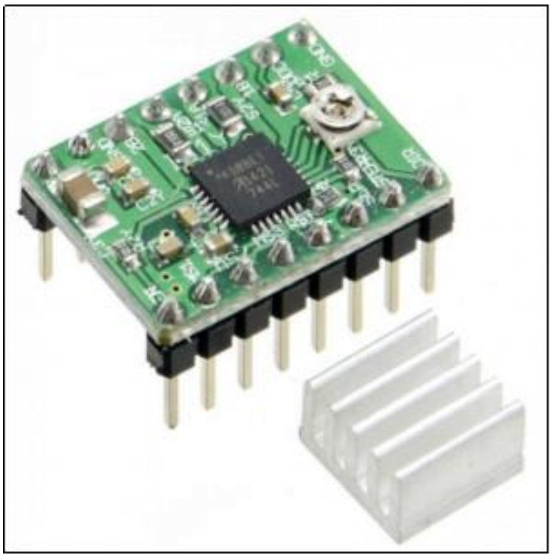


Figure 3.5: A4988 Stepper Motor Driver with Heat Sink

3.3.5 2020 Model Aluminium

The 2020 model aluminium was selected as the body of the machine. The machine body that built using aluminium is light enough to allow user to carry the machine along with them easily.

Figure 3.6: 2020 Model Aluminium

3.3.6 PLA Filament

PLA filament also known as the Polylactic Acid filament, which is the natural raw material used in 3D printing. Some components of CNC machine were printed by 3D printer using PLA filament to reduce the costs of the project.

Figure 3.7: PLA Filament

3.3.7 12 V 20 A Power Supply

A 12V 20A power supply has been used in this project as a power source to supply power to the x-axis and y-axis stepper motor. This power supply able to converts AC 110V/ 220V to DC 12V 20A 250W. It also has the short-circuit protection, over-voltage protection: 115% to 135%.

Figure 3.8: 12 V 20 A Power Supply

3.3.8 SG92R Servo Motor

SG92R servo motor is a new version of the SG90 servo motor. The gears set of this servo motor is made by the carbon fibre which is more durable compare to the nylon gears set. This servo motor been used as the z-axis to move the pen position up and down.

Figure 3.9: SG92R Servo Motor

3.3.9 Limit Switch

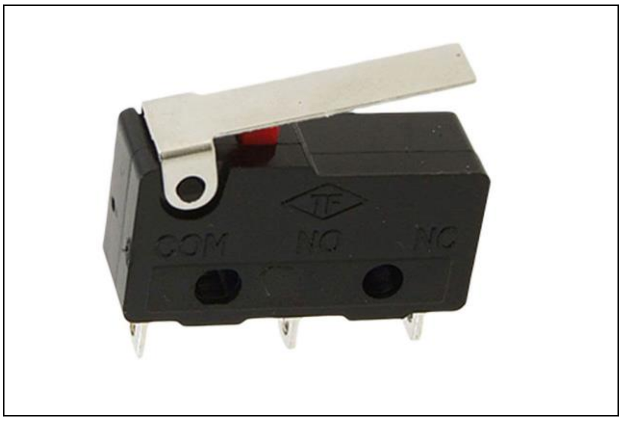


Figure 3.10: Limit Switch

The limit switch is switch that use to limit the travel object in a mechanism to past some predetermined point. In this project, the limit switches were used in the homing system of the machine.

3.4 Setup of Arduino IDE Software

The Arduino IDE software is open source which allow user to download the software through the IDE official website. The setup of Arduino Uno is simple. Once finish download and installed in the computer, the Arduino Uno microcontroller can be connected using the USB cable to power it.

Figure 3.11: Arduino IDE Software

One external library file, grbl required add on the Arduino IDE software before uploading the code to the microcontroller. The grbl library file contains the coding to functions the CNC machine which is open source file that be able to download from GitHub website. After done downloading, this file must be added in “This PC > Documents > Arduino > libraries”.

Figure 3.12: grbl Library File Location

This source file is development by Sungeun and Simen (2015) researchers. After added the source file, Arduino IDE software was restarted. The grbl source file been load from contribute library in the Arduino IDE at “Sketch > Include Library > grbl”. The code been uploaded to the microcontroller once the code done compiling.

3.5 Setup of Inkscape Software

Inkscape software is free software that allow user to draw some project without any charge of license fee for using the software. In this project, Inkscape has been used to convert some simple drawing from this software and the exported image into a Gcode file format.

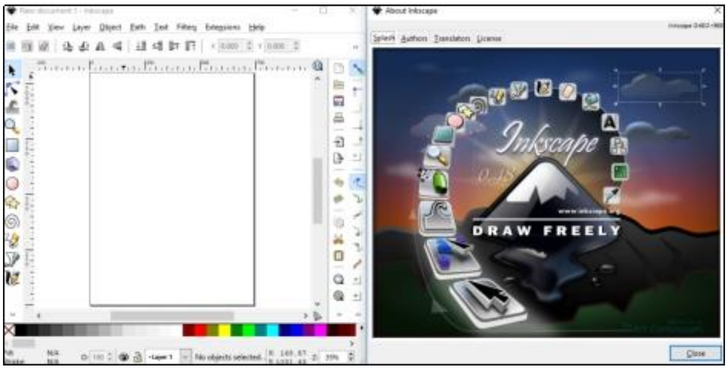


Figure 3.13: Inkscape Software Version 0.48.0

Inkscape software with version 0.48.5 below was choose to download as the MakerBot Unicorn Gcode Extension only support for version 0.48.5 or below. The MakerBot Unicorn Gcode Extension file can be downloaded from GitHub website. In order to export image into Gcode format, a MakerBot Unicorn Gcode Extension file need to add to the Inkscape software. Once finish downloaded the file, the file extension need to be unpacked and the 4 file below: _init_.py, context.py, entities.py, svg_parser.py need to copy to the following directory Program Files > Inkscape > share > extensions and restart the Inkscape.

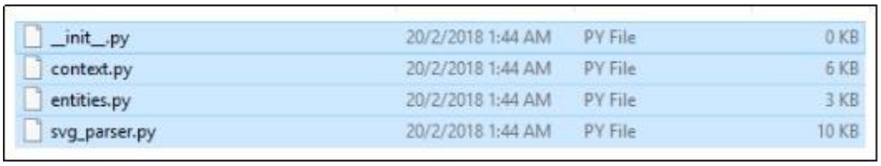


Figure 3.14: MakerBot Unicorn Gcode Extension File

3.5.1 Document Properties Setting

Before import an image folder, document properties window was opened to adjust the page size by clicking on the File > Document Properties. The Default units and the units in the Document Properties window have been set to mm. The page side has been changed to 100 mm × 100 mm which is smaller than the workspace of CNC machine build 200 mm × 150 mm.

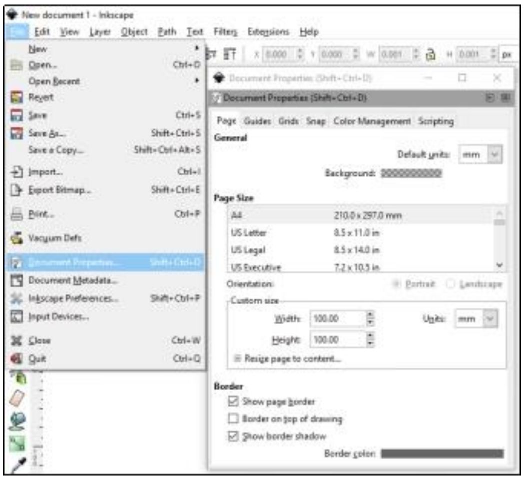


Figure 3.15: Document Properties Window Setting

This software allow user to create own drawing image and able user to imports original images. For this FYP, both type of image: drawing image and original import images have been exported to gcode file for CNC machine drawing.

3.5.2 Drawing Image

The drawing image is an image that draws using the Inkscape software. Figure 3.16 shows that the tools use for drawing. In this figure, a spiral shape image has been created.

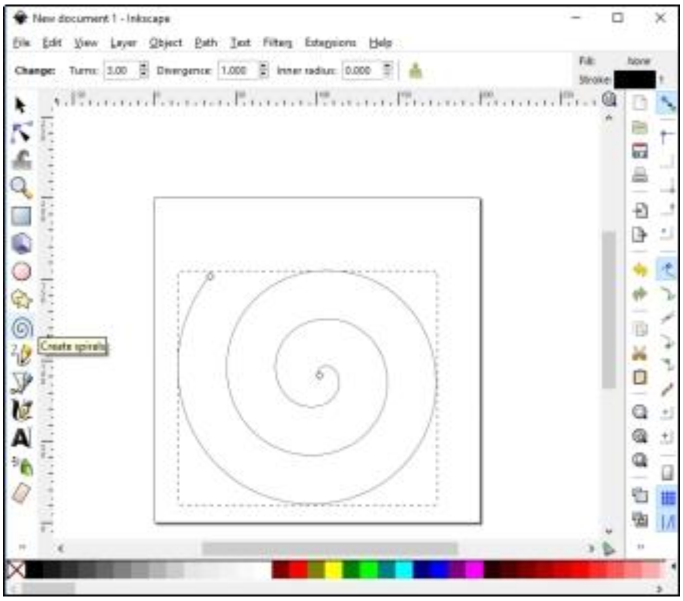


Figure 3.16: Spiral Shape Drawing Image

3.5.3 Original Import Image

The original image that download or import to the computer can be imported to the Inkscape software. Press on the File > Import or Ctrl + I to import the image. The image must be aligned on the square workplace as shown in the Figure 3.17.

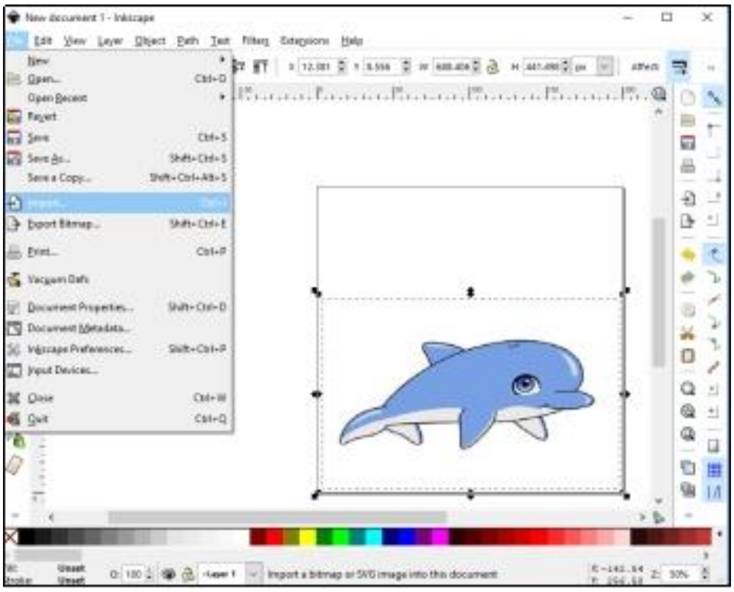


Figure 3.17: Original Import Image

3.5.4 Trace Bitmap of the Image

In order to trace the image into Bitmap, Path > Trace Bitmap… or Shift + Alt + B have been pressed. The Brightness cut-off with threshold of 0.450 on the Trace Bitmap window was selected and then pressed on the "Update" button follow by the "Ok" button. Figure 3.19 showed the image after Bitmap trace. The original image with colour was deleted after done tracing.

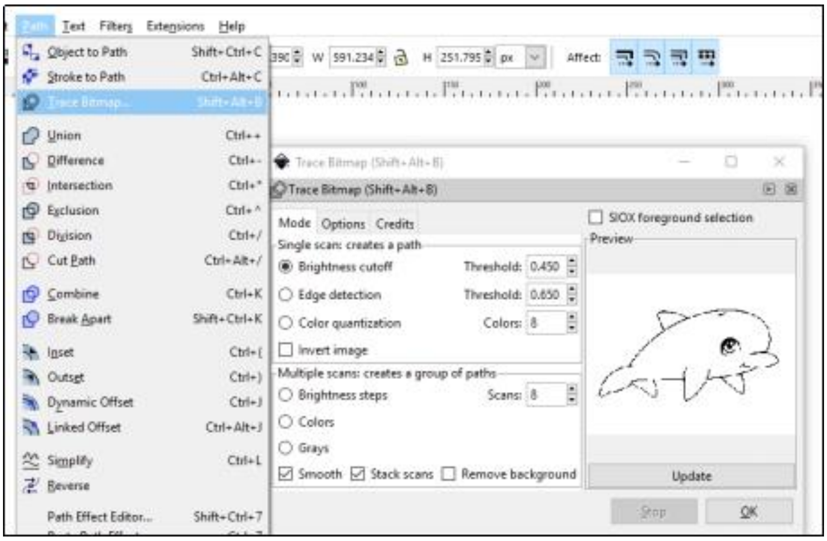


Figure 3.18: Trace Bitmap Setting

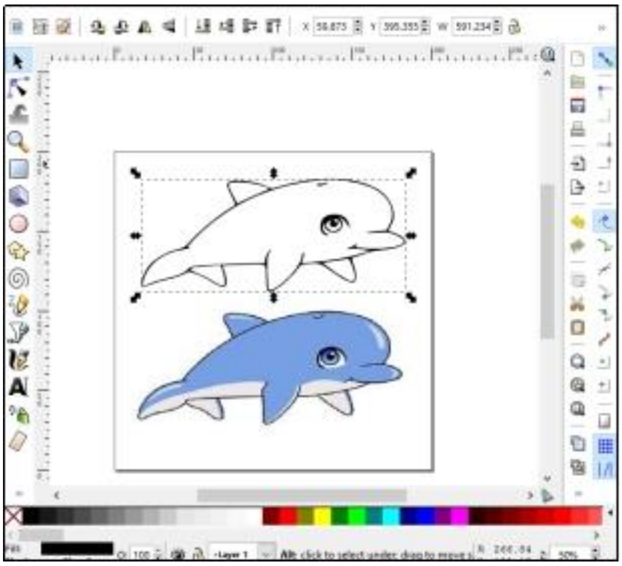


Figure 3.19: Bitmap Traced Image and Original Colour Image

3.5.5 Export Image as Gcode Format

Before export the image into Gcode format, the Bitmap trace image have been to path by going to Path > Stroke to Path or using Ctrl + Alt + C.

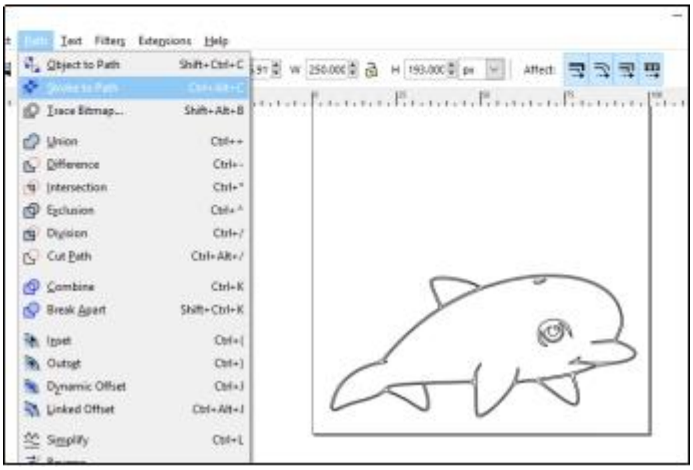


Figure 3.20: Stroke to Path Image

With the previous MakerBot Unicorn Gcode extension file added, the Inkscape can now export the image in gcode file format. Extensions > MI GRBL Z-AXIS Servo Controller > MI GRBL Z-AXIS Servo Controller been selected.

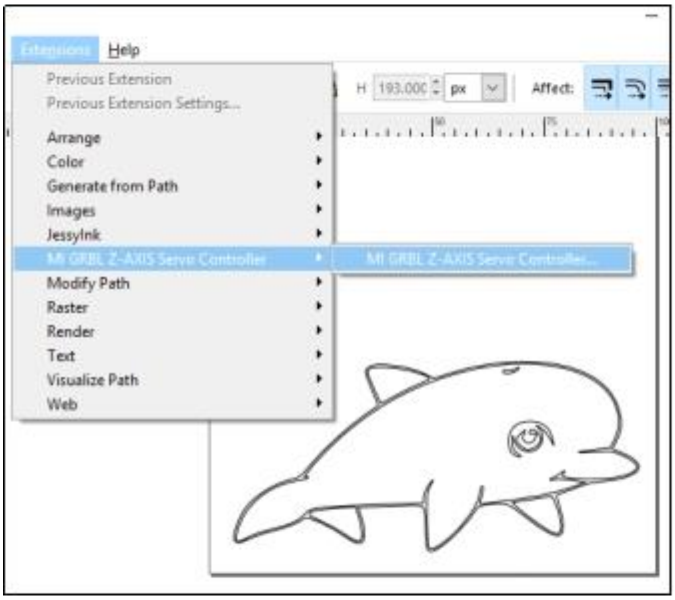


Figure 3.21: Location of Gcode Export File

Figure 3.22 below show the setting of the Gcode file setting. The Servo Up And down have been set to M3 and M5 respectively to represent the movement of the drawing pen on the Z-axis. The angle of the servo motor has been set to 50°. The speed of the X-axis and Y-axis must be same so that the drawing machine will be synchronised. The delay has been set to 1 second.

Figure 3.22: Export Gcode File Setting

3.6 Universal Gcode Sender Software

This Universal Gcode Sender software use for the CNC machine calibration purpose and also use for sending the Gcode file that created on the Inkscape to operating purpose for the CNC machine.

Figure 3.23: Universal Gcode Sender Software

Table 3.1 shows the command for function of Universal Gcode Sender and Table 3.2 shows the command for the Grbl settings of CNC machine. The CNC machine settings can be modified through the commands under the Table 3.1 and Table 3.2.

Table 3.1: Command for Function of Universal Gcode Sender

Command	Function
$$	view Grbl settings
$#	view # parameters
$G	view parser state
$I	view build info
$Nx	view start-up block
$C	check gcode mode
$X	kill alarm lock
$H	run homing cycle

~	cycle start
!	feed hold
?	current status
Ctrl-x	reset Grbl

Table 3.2: Grbl Settings of CNC Machine

Command	Function
$0	step pulse, µsec
$1	step idle delay, msec
$2	step port invert mask
$3	dir port invert mask
$4	step enable invert, bool
$5	limit pins invert, bool
$6	probe pin invert, bool
$10	status report mask
$11	junction deviation, mm
$12	arc tolerance, mm
$13	report inches, bool
$20	soft limits, bool
$21	hard limits, bool
$22	homing cycle, bool
$23	homing direction invert mask
$24	homing feed, mm / min
$25	homing seek, mm / min
$26	homing de-bounce, msec
$27	homing pull-off, mm
$100	x, step / mm
$101	y, step / mm
$102	z, step / mm
$110	x max rate, mm / min
$111	y max rate, mm / min
$112	z max rate, mm / min

$120	x acceleration, mm / sec^2
$121	y acceleration, mm / sec^2
$122	z acceleration, mm / sec^2
$130	x max travel, mm
$131	y max travel, mm
$132	z max travel, mm

3.7 Setup of FreeCAD Software

The FreeCAD software is a freeware that can use to create own 3D parametric modeller. The software was downloaded from the official website and installed on the computer. In this project, this software has been used to design some hardware components of the CNC machine.

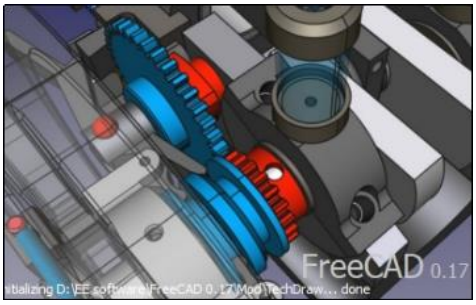


Figure 3.24: FreeCAD Software

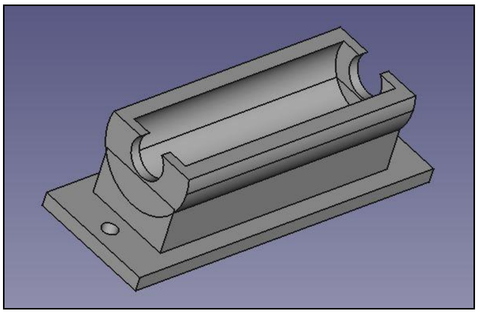


Figure 3.25: Sample Hardware Component Design using FreeCAD Software

Figure 3.25 shows the sample of hardware components been design using the FreeCAD software. All the hardware design will be showed and discuss in chapter 4. The done design hardware was exported into stl file format.

3.8 Setup of ideaMaker Software

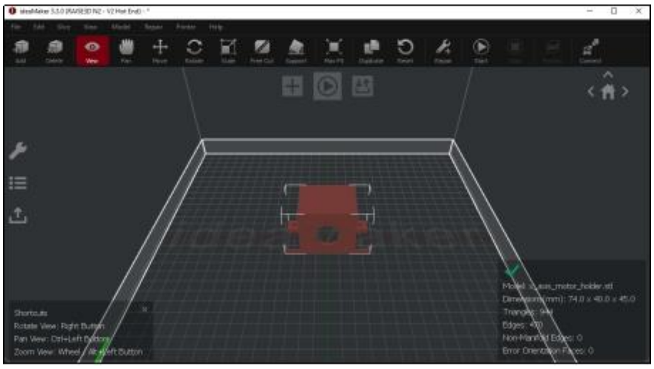


Figure 3.26: ideaMaker Software

The ideaMaker is open software that created by the RAISE3D Technologies. The software is the GUI for the 3D Printer. The ideaMaker software can be the RAISE3D official website. The stl file that created from the FreeCAD software was import to the ideaMaker and it will export as a gcode file after done setting properties of the printing components.

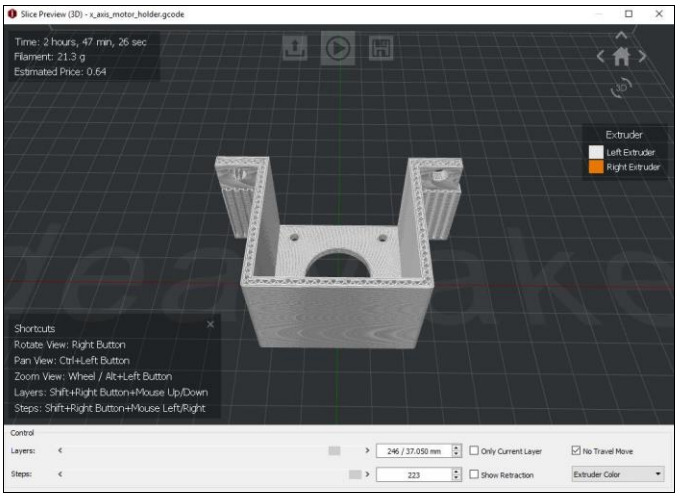


Figure 3.27: Print Preview of the Component

This software was user friendly as it allows user preview the model of the printing hardware before export to gcode file.

3.9 Hardware Build Stage

After done purchase and print the hardware components, the hardware of CNC machine started to assembly. The aluminium body was first to build so that other components able to attach on the aluminium body frame.

Figure 3.28: Body Frame of the CNC Machine

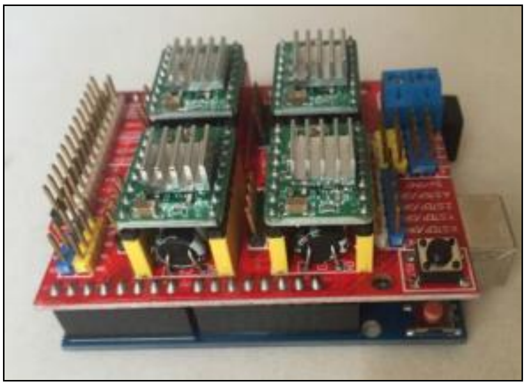


Figure 3.29: Arduino Uno + CNC Shield V3 + A4988 Stepper Motor Driver + Heat Sink

The CNC shield V3 was plug on the Arduino Uno board. The A4988 stepper motor driver attached with the heat sink and plug on the CNC shield V3 board as shown in Figure 3.29.

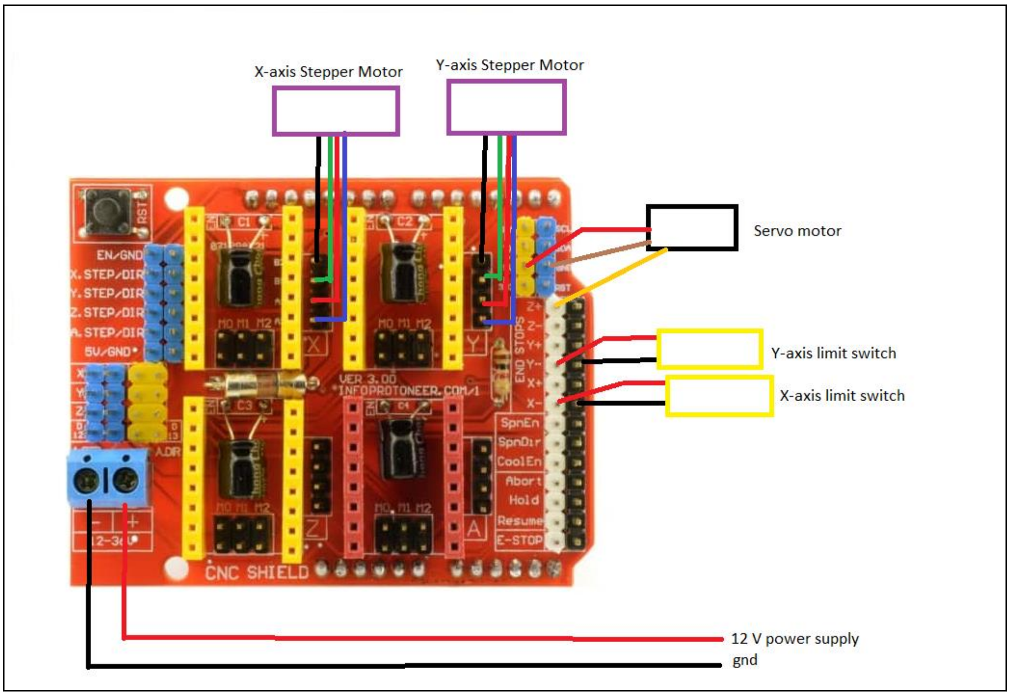


Figure 3.30: Wiring of Stepper Motors, Power Supply, Limit Switches and Servo Motor on CNC Shield

The 12 V 20 A power supply was connected to the blue socket of the CNC Shield. The X-axis stepper motor was connected to the left side motor driver while the Y-axis stepper motor was connected to the right side motor driver. The black wire must be at top of the connection to driver and the blue wire must be the last one connected to the driver. The red wire of the servo motor was connected to 5 V while the brown wire connected to ground. The orange wire of the servo was connected to the Z + axis. The common pin of both limit switch were connected to the white pins of X- and Y- on CNC shield while the normally open, NO pin of both limit switch were connected to the black pins of X- and Y- on CNC shield respectively.

Lead screw and the stepper motor were connected by using the connector.

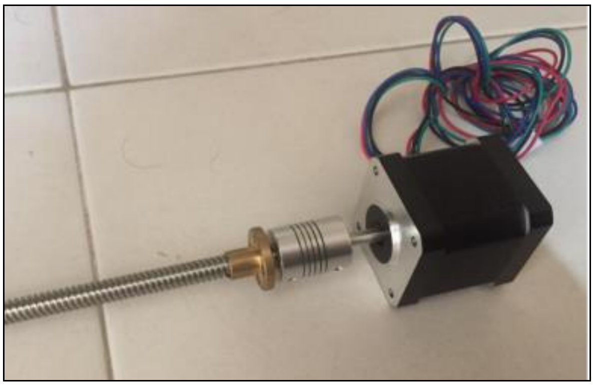


Figure 3.31: Connection of Stepper Motor and Lead Screw

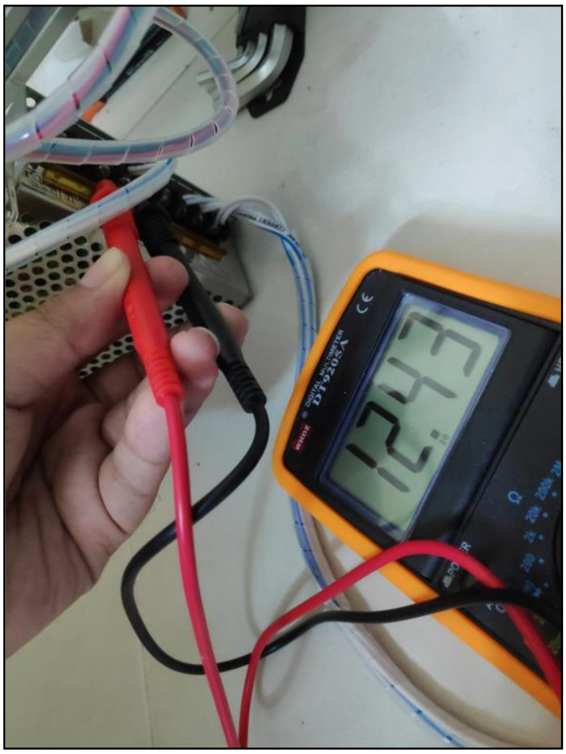


Figure 3.32: Voltage Checking on Power Supply

Once done construct the hardware of the CNC machine, the voltage of the power supply been checked before supply to the CNC shield to ensure that the power not oversupply on the motor. The voltage supply should be more than 12 V and less than 12.5 V.

3.10 Stepper Motor Calibration

Calibration of machine is the next step after building the hardware. For CNC machine, the motors on X-axis and Y-axis must be calibrated. 5 mm been set as the tuning reference.

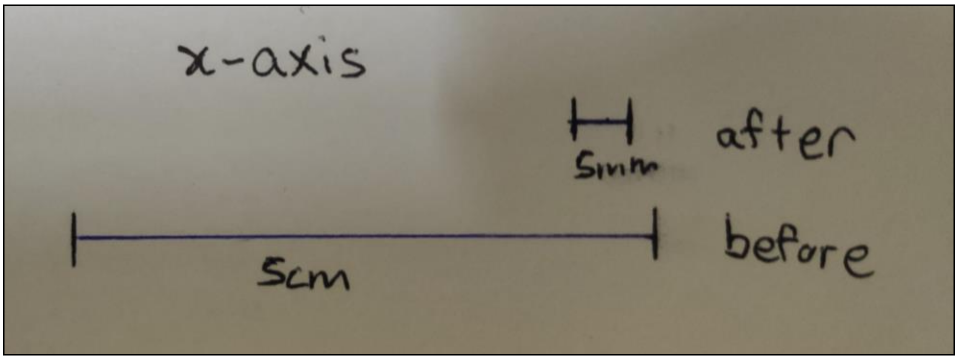


Figure 3.33: X-axis Stepper Motor Result before and after Calibration

The initial step of the X-axis stepper motor is 250 steps / mm. When drawn, it shows the result of 50 mm instead of 5 mm. Thus, the steps / mm must be tune 10 times smaller than the previous steps / mm. The formula for calculating shows below:

Final steps per mm = (target length / actual length) × Initial steps per mm
= (5 mm / 50 mm) × 250 steps per mm
= 25 steps per mm

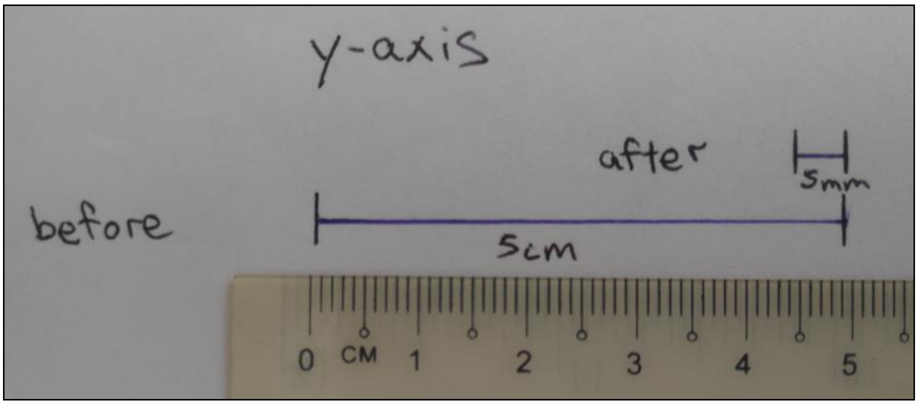


Figure 3.34: Y-axis Stepper Motor Result before and after Calibration

The initial step of the Y-axis stepper motor is 250 steps / mm. When drawn, it shows the result of 50 mm instead of 5 mm which is same with the X-axis. Thus, the steps / mm must be tune 10 times smaller than the previous steps / mm. The formula for calculating shows below:

Final steps per mm = (target length / actual length) × Initial steps per mm

= (5 mm / 50 mm) × 250 steps per mm

= 25 steps per mm

3.11 Operation Process

Block Diagram of the complete operation:

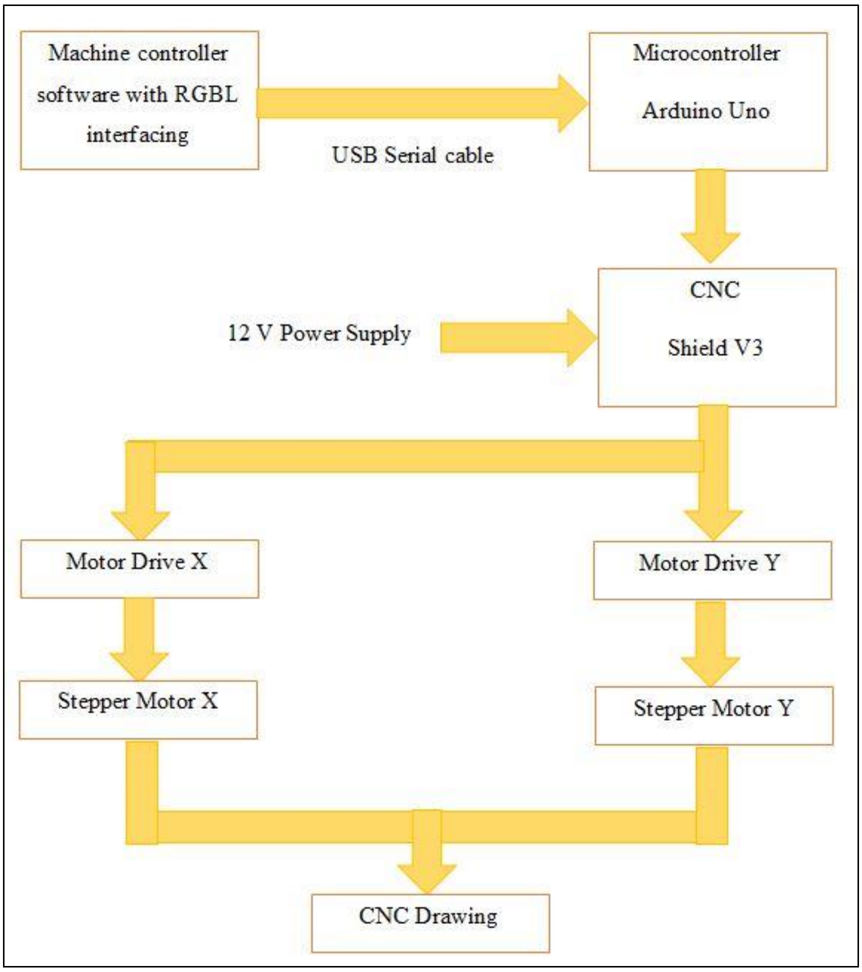


Figure 3.35: Operation Process of the CNC Drawing Machine

3.12 Equipment and Cost Analysis

Table 3.3: Cost Analysis for each Components and Equipment

No.	Component	Quantity	Price (RM)	Remarks
1	PLA 1.75mm Filament	1	44.00	From MYBOTIC
2	Arduino Uno + cable	1	18.60	From Robotedu
3	M4 stainless steel flat washer	21	2.10	From Robotedu
4	M3 stainless steel flat washer	50	5.00	From Robotedu
5	Allen key cap M4 screw	9	8.10	From Robotedu
6	Allen key cap M3 screw	10	6.00	From Robotedu
7	SG92R Servo Motor	1	8.00	From Robotedu
8	2020 EU 20 T slot Rhombus Nut M4 T Nut	30	21.00	From Robotedu
9	12V 20A power supply	1	28.00	From Lazada
10	M4 cap screw	50	5.00	From CNB Sdn. Bhd.
11	M4 SS csk crew	50	6.00	From CNB Sdn. Bhd.
12	M4 SS flat washer	50	1.50	From CNB Sdn. Bhd.
13	M3 screw + hex nut	50	5.90	From Delta Fasterners (M) Sdn. Bhd.
14	T-screw cube	2	20.52	From Taobao
15	400mm long 8mm cylinder rod	4	56.96	From Taobao
16	Nema 17 stepper motor	2	84.92	From Taobao
17	2020 model aluminium (1m)	4	35.58	From Taobao
18	T-screw holder	2	4.24	From Taobao
19	SK8 cylinder holder	8	12.00	From Taobao
20	Wire protector	1	2.74	From Taobao
21	Elastic coupling	2	7.76	From Taobao
22	A4988 motor driver	2	19.31	From Taobao
23	2020 model T-nut	40	12.40	From Taobao
24	2020 model corner bracket	18	11.16	From Taobao
25	T-screw	2	35.60	From Taobao

26	Linear bearing	8	15.52	From Taobao
27	CNC shield V3	1	3.77	From Taobao
28	Cable (10 meter)	1	12.00	Mr. DIY
29	3-pins socket	1	5.00	Mr. DIY
Total:			**RM 498.68**	

3.13 Project Milestone

Gantt Chat for FYP 1:

Table 3.4: Gantt Chart for FYP 1

Week / Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Research on background of project														
Preparation and submission of proposal														
Research on different type CNC machine														
Reasearch on material to build project														
Preparation for log report														
Progress for report submission														
Preparation for oral presentation														
Oral presentation														

Gantt Chat for FYP 2:

Table 3.5: Gantt Chart for FYP 2

Activities \ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Prepare material to build prototype																
Install Software needed for the project																
Calibrate the stepper motor																
Design the part needed using FreeCAD																
3D print out the part needed for the project																
Build and test the prototype																
Preparation for log report																
Preparation for final oral presentation																
Final oral presentation																
Final Submission																

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Results

Before some product is complete, there must be some testing phase carry out that the functionality and also the quality of the product. In this section, some printed hardware components and limit switch homing system for the machine have been discussed. Several types of image have been drawn and discussed in this section. Two users been invited to test on the product quality.

4.1.1 Printed Design Hardware Components

The part of the hardware components like the stepper motor holder, linear bearing holder, pen holder, X-axis plane have been design by using the FreeCAD software and printed by the 3D printer. In this section, the design hardware components and the printed components were discussed.

4.1.1.1 Linear Bearing Holder

Linear bearing holder was design for holding the linear bearing on both X-axis and Y-axis. For the X-axis, only two linear bearing holders were printed. Figure below shows the design of the X-axis linear bearing holder. The length of the X-axis linear bearing holder is longer compare to the Y-axis linear bearing holder as it designed to hold two linear bearings at the same time.

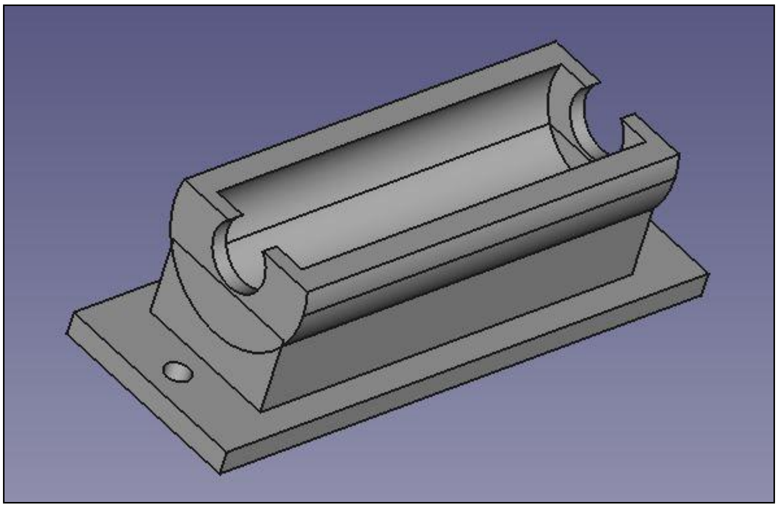


Figure 4.1: X-axis Linear Bearing Holder Design

Time use to print single X-axis linear bearing is about 1 hour. Thus, the total time used to print two copy of this hardware components are 2 hours.

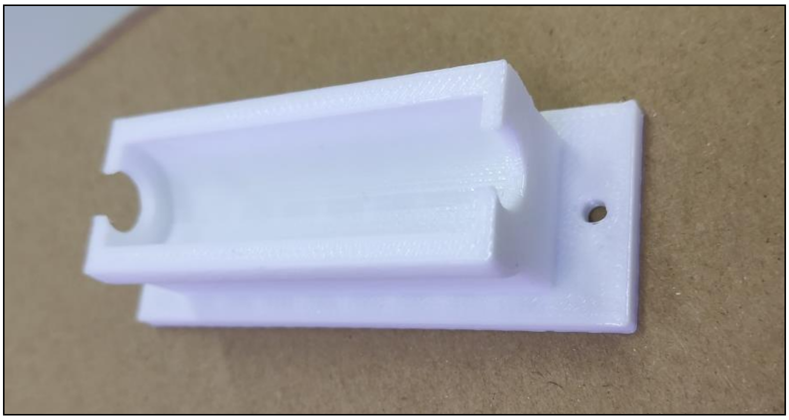


Figure 4.2: Printed X-axis Linear Bearing Holder

For the Y-axis linear bearing holder, it was designed for hold a linear bearing in Y-axis. Four Y-axis linear bearing holders were printed to hold the linear bearings on the Y-axis.

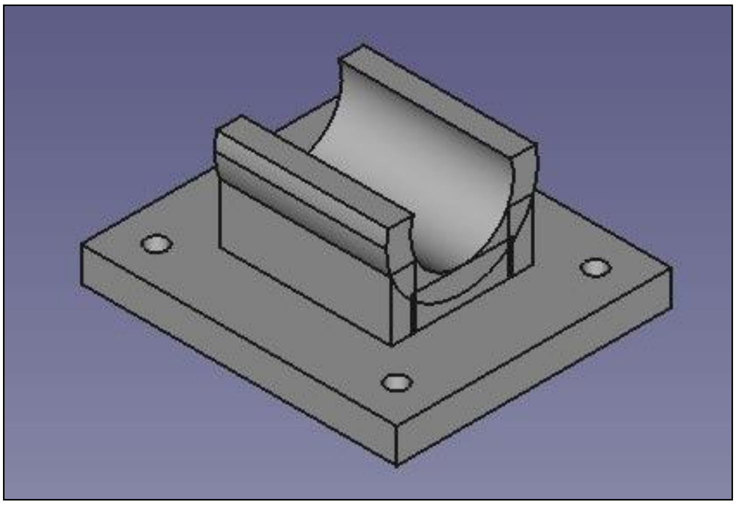


Figure 4.3: Y-axis Linear Bearing Holder Design

Around 45 minutes for printing single Y-axis linear bearing holder. The total time spent on printing the Y-axis linear bearing holders are 3 hours. Figure 4.4 shows the look of Y-axis linear bearing holder hardware component.

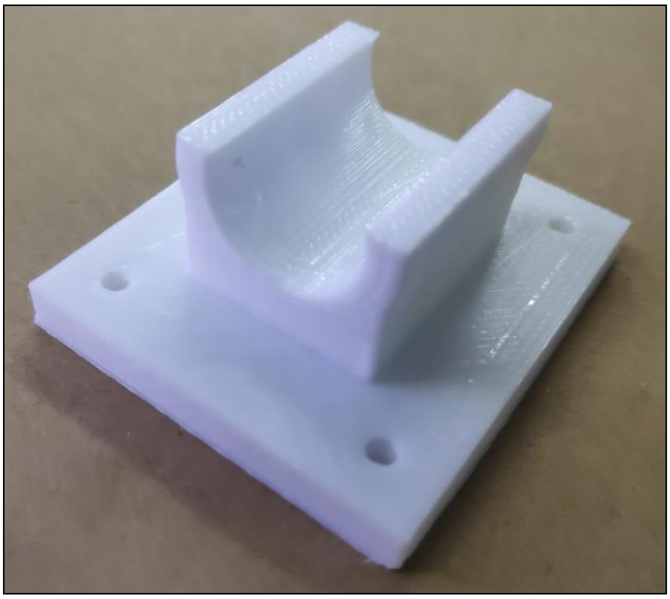


Figure 4.4: Printed Y-axis Linear Bearing Holder

4.1.1.2 Stepper Motor Holder

Stepper motor holder for X-axis and Y-axis were designed to hold the stepper motor so that the stepper motor can fix on the position.

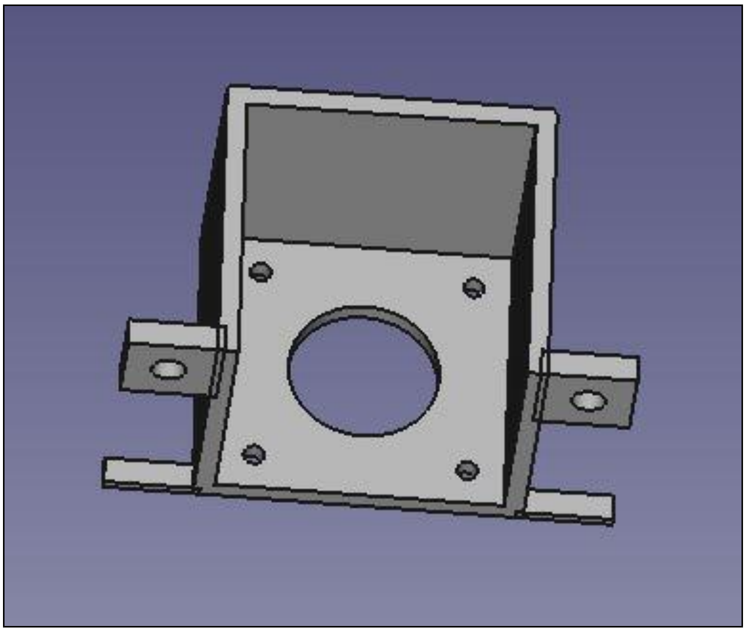


Figure 4.5: X-axis Stepper Motor Holder Design

For this component, addition two small bars were added on the design to create a base to support the printing part that not attached on the base. Time used to print out the X-axis stepper motor holder is 2 hours and 47 minutes.

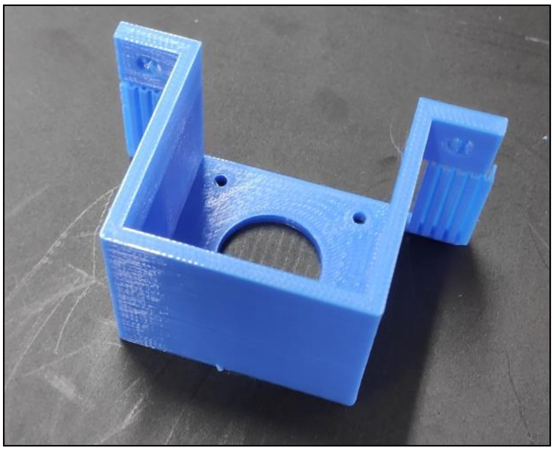


Figure 4.6: Printed X-axis Stepper Motor Holder

The design of the Y-axis stepper motor holder is a little bit different compare with the X-axis stepper motor holder. The different of the holder is the position of the side design.

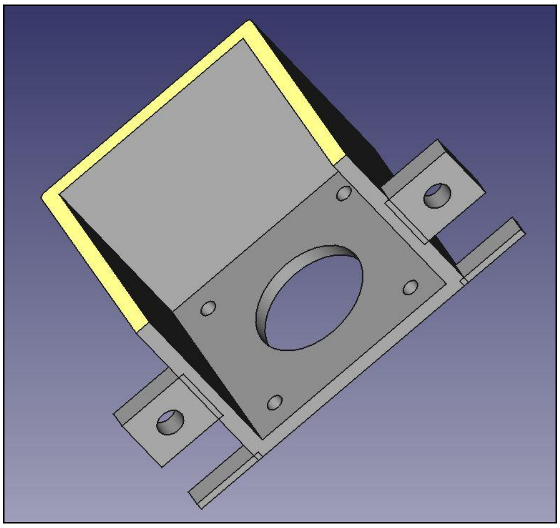


Figure 4.7: Y-axis Stepper Motor Holder Design

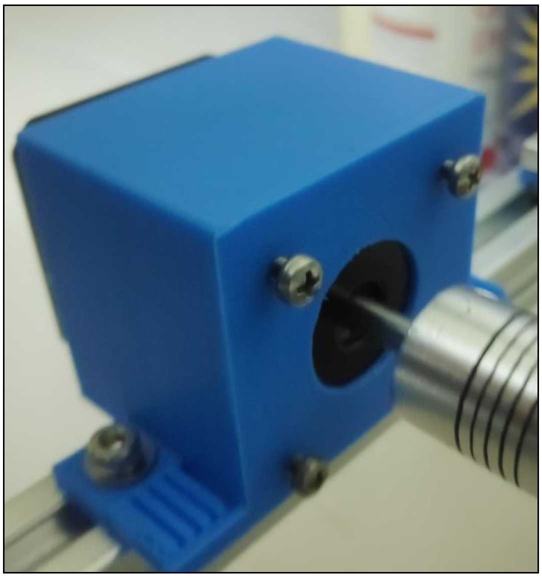


Figure 4.8: Printed Y-axis Stepper Motor Holder

From Figure 4.8, the side design of the Y-axis holder at middle of body while the X-axis holder side design at the end of the body. Time use to print the holder is 2 hours 42 minutes.

4.1.1.3 X-axis Plane

X-axis plan was designed as the plan body on X-axis which able to hold the servo motor and drawing components like pen or driller.

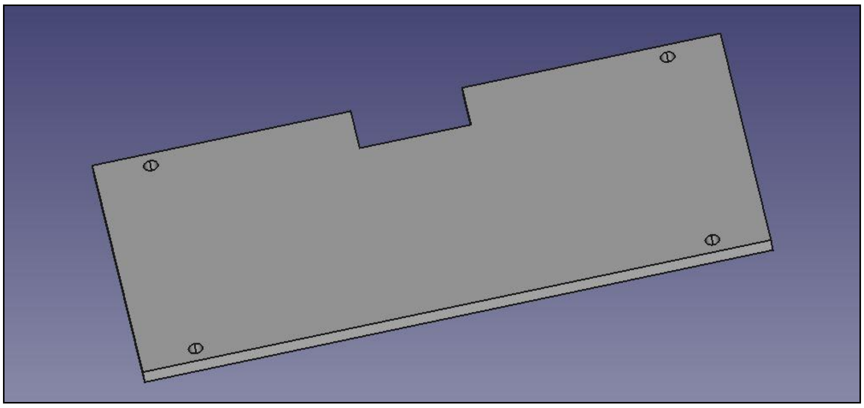


Figure 4.9: X-axis Plane Design

This X-axis plan was attached together with the X-axis linear bearing holders which allow the plane to move along in X-axis. 1 hour time was spent on printing the X-axis plane.

Figure 4.10: Printed X-axis Plane

4.1.1.4 Pen Holder

Pen holder was designed to hold the position of the pen on the X-axis. There were two design been created which is the upper pen holder and the lower pen holder. The upper pen holder was designed to hold the upper part of the pen while the other designed to hold the lower part of the pen and it can be adjust the screw to lock and unlock the pen according to size.

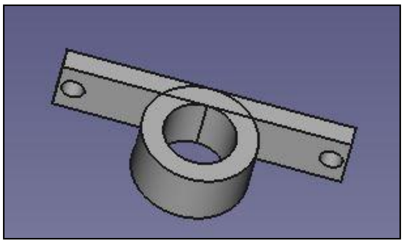


Figure 4.11: Upper Pen Holder Design

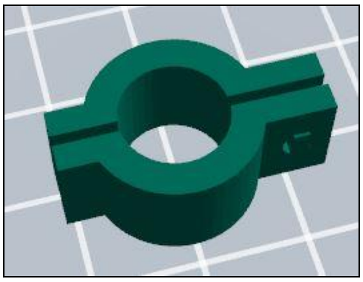


Figure 4.12: Lower Pen Holder Design

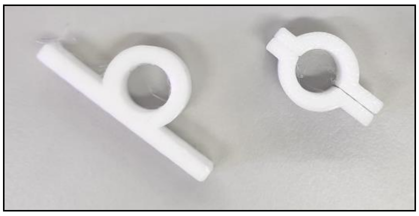


Figure 4.13: Printed Pen Holder Left to Right (Upper Pen Holder, Lower Pen Holder)

The time used to print the upper pen holder is 8 minutes while the lower pen holder is 11 minutes.

4.1.1.5 Holder Extension

These components were designed to fix the cylinder rod holder and lead screw holder to same height level with the stepper motor. Two types of component been designed: cylinder rod holder extension and lead screw holder extension.

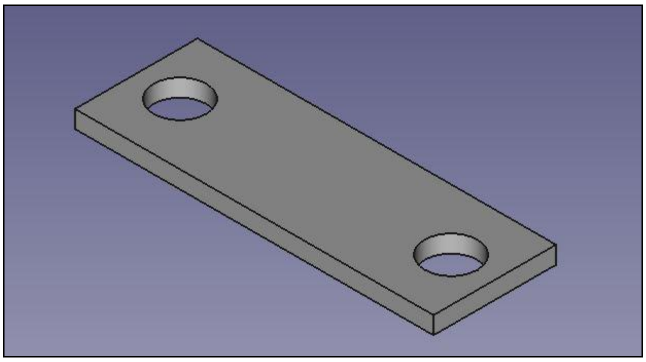


Figure 4.14: Cylinder Rod Holder Extension Design

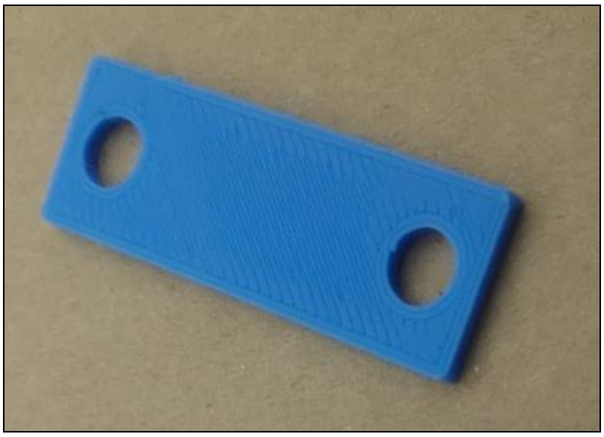


Figure 4.15: Printed Cylinder Rod Holder Extension

Total eight copy of cylinder rod holder extension printed as each axis required four cylinder rod holder extension. The time spent on printing single copy is 8 minutes and the total time spent to print all is 1hour and 5 minutes.

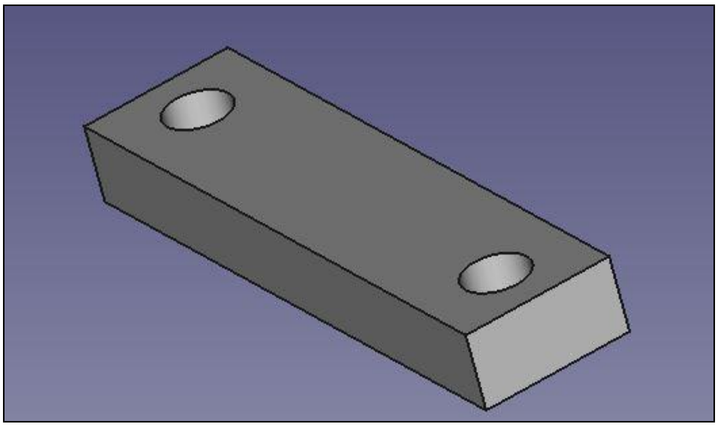


Figure 4.16: Lead Screw Holder Extension Design

Figure 4.17: Printed Lead Screw Holder Extension

For the lead screw extension, each axis only required one copy. Time spend for printing single copy is around 10 minutes and the total time spent is around 20 minutes.

4.1.2 Overall Look of the CNC Drawing Machine

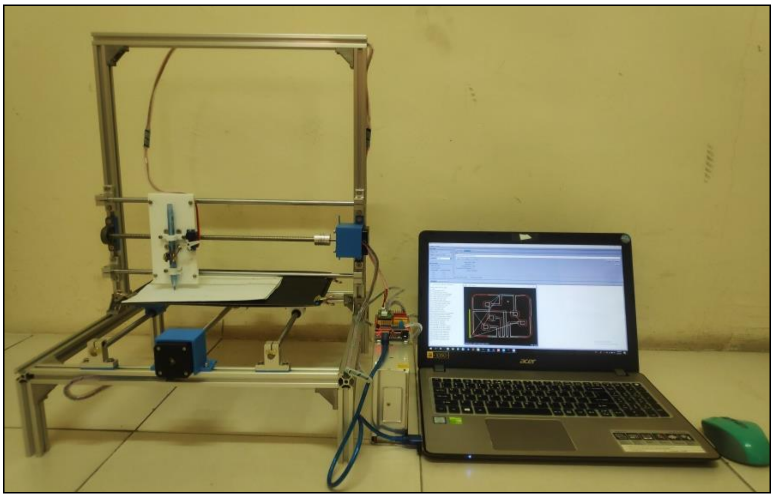


Figure 4.18: CNC Drawing Machine Hardware with Software

The Figure 4.1 above shows the hardware and software of the CNC drawing machine. The pen used as the components to perform drawing on the hardware. 12 V 20 A power supply connected to the CNC shield to power up the stepper motor while the USB cable that connected to the Arduino Uno microcontroller board was used for power the Arduino Uno and sending the instruction to the Arduino Uno.

4.1.3 Operation between the Hardware and Software of the CNC Machine

The image that imported to the Inkscape software was traced into Bitmap image and exported as gcode file. After done export the gcode file, the Universal G-Code Sender software was opened. The software then required to connect to the hardware using baud rate with value of 115200. Once the hardware connected, the gcode file can be opened and sent to the hardware. The Arduino Uno microcontroller will enable the CNC shield and the CNC shield will sending instruction to the motor driver according to the commands in the gcode file. The stepper motor then will perform the drawing.

4.1.4 Homing System

The homing system allows the CNC machine to locate to its origin point before start drawing. To use this function, the command $22 and $23 in Universal Gcode Sender software been set to 1 and 00000011 respectively. To call the homing function, a command "$H" was inserted in the command window of the Universal Gcode Sender software. Figure 4.19 show the working position of the CNC machine homing function being call.

Figure 4.19: Random Position

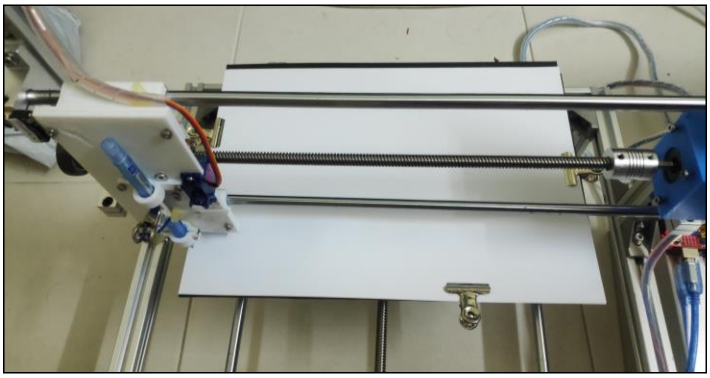


Figure 4.20: Homing Position

After done calling the homing function, both X-axis and Y-axis planes will move to the negative direction until the limit switches being triggered. The position that triggered the limit switches is the origin position of the machine.

4.1.5 Results of Drawing Image by CNC Machine

Several types of image such as the import image, drawing image and image with word have been used to test on the CNC machine.

4.1.5.1 Original Import Image

Original image firstly imported to the Inkscape software and traced into Bitmap. Once done tracing the image, the image then been created a path for the image and exported as a gcode format file. The gcode file then open using Universal G-Code Sender to perform drawing. Below is some image used to test draw.

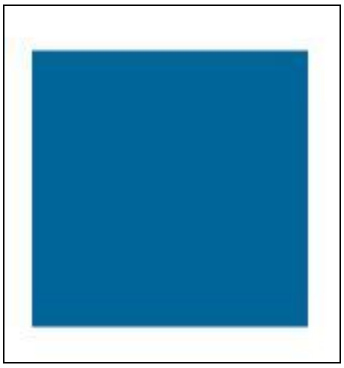


Figure 4.21: Original Import Image (Square)

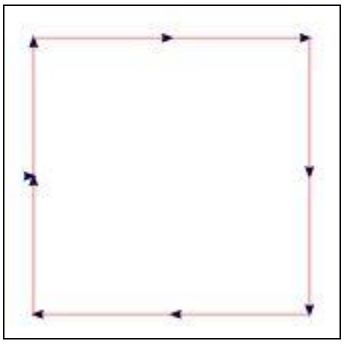


Figure 4.22: gcode File Image (Square)

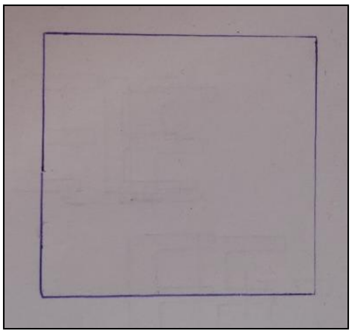


Figure 4.23: Drawn Image (Square)

The side of the square image drawn is same as the given scale of gcode file square image. Table below shows the results in scale comparison. The accuracy of the simple image drawn in first and second times are 100% same as the original image.

Table 4.1: Results of Image (Square)

	Original Image Scale (mm)	**1st Drawn Image Scale (mm)**	**Accuracy (%)**	**2nd Drawn Image Scale (mm)**	**Accuracy (%)**
X-axis	40	40	100	40	100
Y-axis	40	40	100	40	100
Time Complete Job (sec)	-	32	-	32	100

After testing on the simple image on the CNC machine, an import image with curve line and much complicate has been tested.

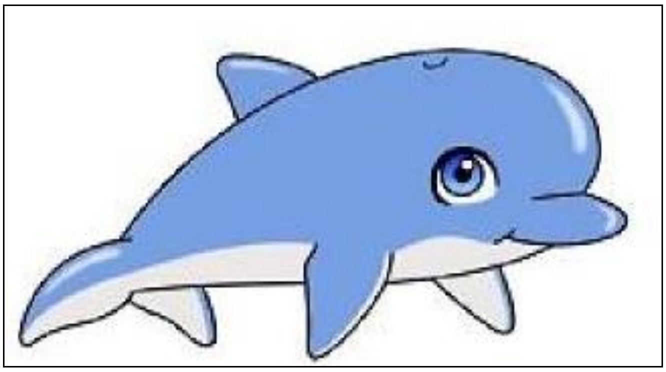


Figure 4.24: Original Import Image (Dolphin)

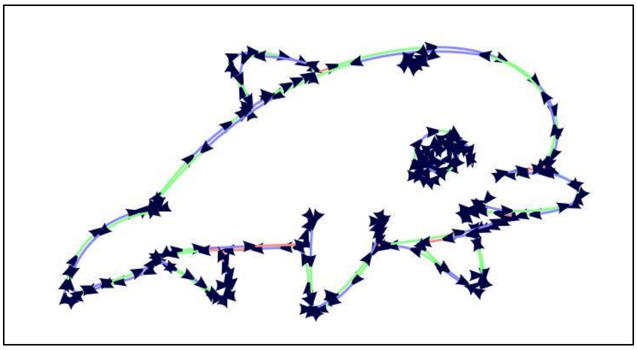


Figure 4.25: gcode File Image (Dolphin)

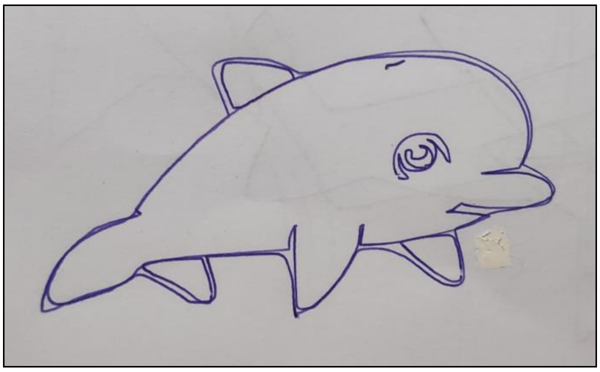


Figure 4.26: Drawn Image (Dolphin)

The results obtained in the first and second time drawn images are exactly same as the original gcode image. With the results, it shows that the stepper motor in X-axis and Y-axis are fully synchronized. The time spent on drawing the dolphin image is 194 seconds.

Table 4.2: Results of Image (Dolphin)

	Original Image Scale (mm)	1st Drawn Image Scale (mm)	Accuracy (%)	2nd Drawn Image Scale (mm)	Accuracy (%)
X-axis	61	61	100	61	100
Y-axis	32	32	100	32	100
Time Complete Job (sec)	-	194	-	194	100

4.1.5.2 Drawing Input Image

The imported images that done drawing on the CNC machine show excellent results. Below are the results testing on the drawn image using Inkscape software. The text input image and the shape input image in Inkscape software have been converted to gcode file and drawn by CNC machine.

Figure 4.27: Text Input Image (EE)

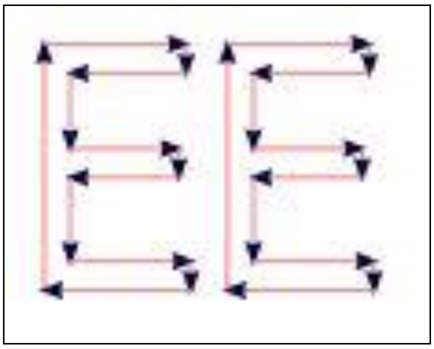


Figure 4.28: gcode File Image (EE)

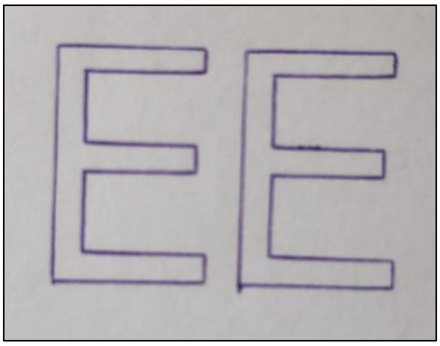


Figure 4.29: Drawn Image (EE)

The scale of the first drawn image and the second drawn image are similar to each other. Both of the drawn images have the same scale compare to the original image. The time spent for completing the first and the second drawn image are the same.

Table 4.3: Results of Image (EE)

	Original Image Scale (mm)	**1st Drawn Image Scale (mm)**	**Accuracy (%)**	**2nd Drawn Image Scale (mm)**	**Accuracy (%)**
X-axis	25	25	100	25	100
Y-axis	17	17	100	17	100
Time Complete Job (sec)	-	72	-	72	100

Next is the spiral line image testing on the CNC machine. This image chooses to test on the synchronization of the stepper motor in both X-axis and Y-axis.

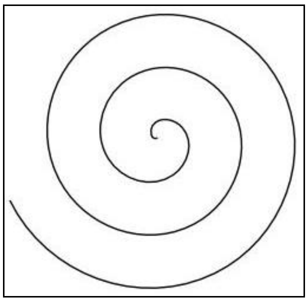


Figure 4.30: Shape Input Image (Spiral)

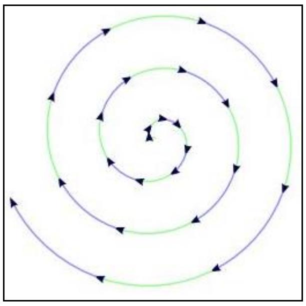


Figure 4.31: gcode File Image (Spiral)

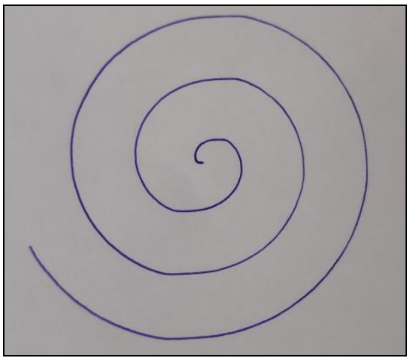


Figure 4.32: Drawn Image (Spiral)

From the spiral line image drawn by the CNC machine, it shows that the X-axis and Y-axis stepper motor being synchronized well as the Figure 4.32 shows a smooth drawn spiral line.

Table 4.4: Results of Image (Spiral)

	Original Image Scale (mm)	1st Drawn Image Scale (mm)	Accuracy (%)	2nd Drawn Image Scale (mm)	Accuracy (%)
X-axis	49	49	100	49	100
Y-axis	47	47	100	47	100
Time Complete Job (sec)	-	48	-	48	100

The results in Table 4.4 show that the first and the second drawn spiral image have the similar scale on X-axis and Y-axis. The time spent for completing the first drawn and the second drawn spiral line images are the same.

4.1.6 Users Testing

After done internal testing, two users have been invited for external testing purpose. Some reviews have received from the users to make some adjustment on the setting of the CNC machine.

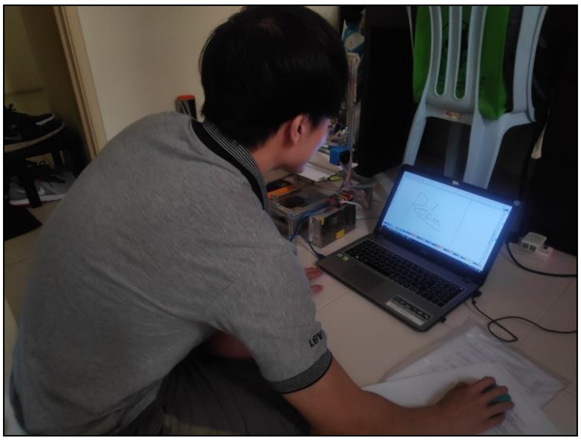


Figure 4.33: First User tests to use the CNC Machine

The first user are invited to use the CNC machine with his own input drawing. The first user have write a nickname and saved as the image. The image then be transformed into the gcode format file for CNC drawing.

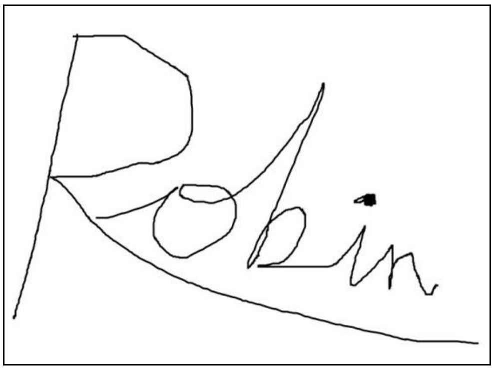


Figure 4.34: Image create by First User (Robin)

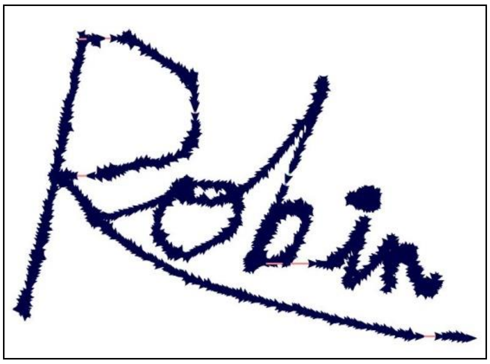


Figure 4.35: gcode File Image (Robin)

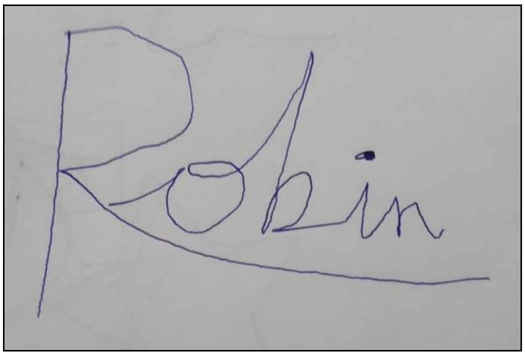


Figure 4.36: Drawn Image (Robin)

The nickname drawn image obtained look similar compare with the original drawing in the computer. The user gives a good review on the accuracy of the CNC machine. User also gives some comments on the drawing speed as the drawing speed is a bit slow.

Table 4.5: Results of Image (Robin)

	Original Image Scale (mm)	1st Drawn Image Scale (mm)	Accuracy (%)	2nd Drawn Image Scale (mm)	Accuracy (%)
X-axis	73	73	100	73	100
Y-axis	48	48	100	48	100
Time Complete Job (sec)	-	219	-	218	99.54

From the results obtained, the time recorded for the first drawn image is 1 second longer compare to the second drawn image. Both of the drawn images show exactly similar to its original image.

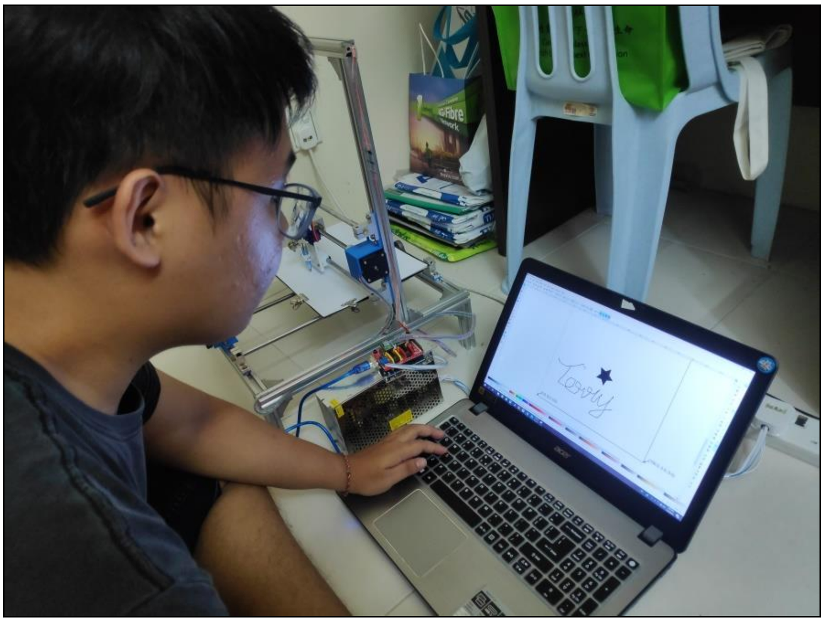


Figure 4.37: Second User test to use of the CNC Machine

Second user was being invited to test use of the CNC machine. The user was advised to create more complicate images to test on the machine.

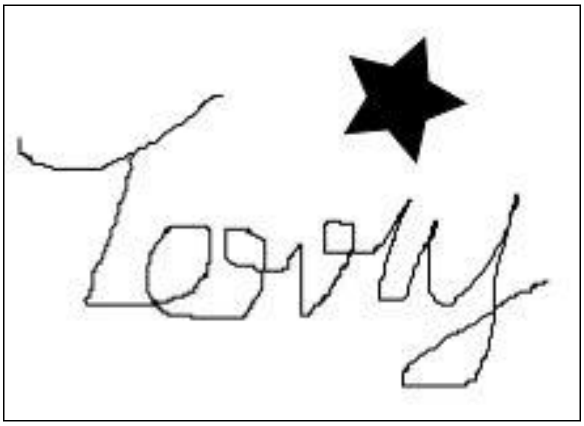


Figure 4.38: Image create by Second User (Terry + Star)

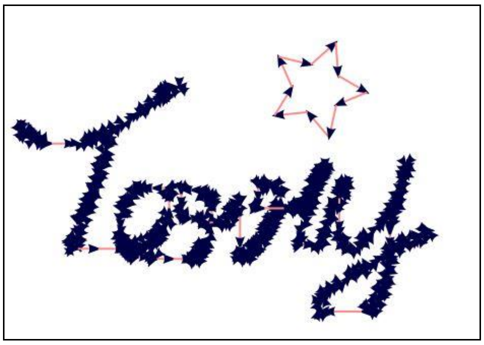


Figure 4.39: gcode File Image (Terry + Star)

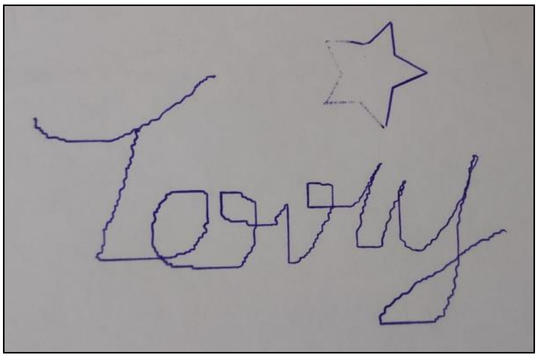


Figure 4.40: Drawn Image (Terry + Star)

Image that second user created consists of the shape drawing and word writing. The image created by the user been converted into the gcode file and run on the machine. Good review also been received from the second user as the images drawn by the user was able to draw out exactly same in scale compare with the original image.

Table 4.6: Results of Image (Terry + Star)

	Original Image Scale (mm)	**1st Drawn Image Scale (mm)**	**Accuracy (%)**	**2nd Drawn Image Scale (mm)**	**Accuracy (%)**
X-axis	58	58	100	58	100
Y-axis	38	38	100	38	100
Time Complete Job (sec)	-	181	-	181	100

From the results obtained in Table 4.5, it shows that the scales for both drawn images are same as the original image. The time spent on two drawn images also same.

4.2 Discussions

In order to build a good quality product, a few times of checking on hardware and software cannot skip. Before obtain good results shown in the section 4.1. There are some challenge parts face in this project. This section will discuss on the problems faced in this project and the solutions that came out to overcome the problems.

4.2.1 Components Used to Build CNC Machine

The selection of components and hardware used are time consuming. Coming out a draft design on the hardware and listing out all the components needed are important to keep the project on budget. For this project, some of the smaller components such as the X-axis and Y-axis linear holder, one part that cost around RM 10 and many of this part needed to build. Buying all this small components will lead to insufficient cost for buying more important part or hardware components. In order to overcome the problems, the smaller components have been designed using the FreeCAD software. After done all the design works, the designs were printed by using the 3D printer which available in university. One spool 1 kg PLA filament that cost around RM 44 was used as the material for 3D print the components. By using 3D printed hardware components, the cost for building the machine has successfully reduce by 50 % compare to directly buy the components. Some of the hardware components like the 2020 model aluminium, cylinder rod were bought directly from China after done some survey on the market price of the product between Malaysia and China. This will help to cut-down the cost use to build the whole CNC machine.

4.2.2 Accuracy of Stepper Motor in X-axis and Y-axis

The accuracy is the most challenging part of this project. The settings of the stepper motor in X-axis and Y-axis must be same so the CNC machine will be synchronized. The problem face by this project is both X-axis and Y-axis motor cannot synchronize after both X-axis and Y-axis done the same setting. To overcome this problem, some further checking such as checking on stepper motor speed setting and the hardware checking have been conducted. Before checking on the software setting part, hardware is considering to look over first. The connection of the hardware must be correct in order to generated correct output. After done checking the hardware connection, the setting of the stepper motor for X-axis and Y-axis needed to retune and calibrate until both X-axis and Y-axis stepper motors been synchronized. The settings of the maximum rate of the stepper motor in mm / min and the acceleration of the stepper motor in mm / s^2. The optimize settings for maximum rate and acceleration of the stepper motor in X-axis and Y-axis are 250 mm / min and 10 mm / s^2. With this setting the drawn image obtained from the CNC machine is same as the original image.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, the objectives of this project have been achieved. An Arduino based CNC drawing machine which able to move along x-axis and y-axis was built. The cost for building the CNC drawing machine is lower compare to the industries which able apply on small businesses and family use as the cost is affordable by family and small businesses. The CNC drawing machine built was successfully communicated with the software to carry out given task. The gcode file image that created from the Inkscape software was successfully transferred to CNC machine for drawing. The import images and the input images were successfully convert to the gcode file and been drawn by the CNC machine. The drawn images scale is exactly same with its original import images and input images. Two users have been invited to use the CNC machine. Both users were satisfied with the results drawn by the CNC drawing machine. The drawing speed of the CNC machine has been increase according to the user feedback. Extra feature like the homing system had successfully added on this project. Some of the hardware components have been designed and printed using 3D printer to cut down the building cost of CNC machine.

5.2 Future Work and Enhancement

Some recommendations on future enhancement of this project are listed below. The recommended enhancements can be implemented for project extension in future.

5.2.1 Three Dimension Printing

The concept use for the 3D printing is same as the CNC drawing machine. Extra axis need to be added on the CNC drawing machine to perform 3D printing. With additional axis added, a CNC machine can carry out different function task.

5.2.2 Software Development

As the functionalities of single CNC machine increase, extra software will be required to install so that the CNC machine can carry out the tasks. For example, to use the CNC machine 3D printing function, 3D printing software is required. However, user may fail to use the correct software to carry out the given tasks and this will not be user friendly to the user. GUI software has to create for the CNC machine and include all functionality of the CNC machine. Software that includes all functionality of the CNC machine will be simpler to handle and operate by user. A user friendly software and hardware will make the product look more attractive to the user.

REFERENCES

Arduino.cc. (2017). *Getting Stared with Arduino and Genuino UNO.* [online] Available at: <https://www.arduino.cc/en/Guide/ArduinoUno> [Accessed 1 January 2019]

Dey, D., Mondal, S. and Barik, A.K. (2016). 3-Axis CNC Router Modifiable to 3D Printer. *International Journal of Innovative Research in Science, Engineering and Technology,* [e-journal] 5(9), pp. 16983-16990. Available through: IJIRSET website <http://ijirset.com/upload/2016/september/69_28_3_Axis.pdf> [Accessed 13 January 2019]

GitHub, Inc. (2019). *MakerBot Unicorn G-Code for Inkscape.* [online] Available at: <https://github.com/martymcguire/inkscape-unicorn> [Accessed 20 January 2019]

GitHub, Inc. (2019). *Grbl with Pen Servo Feature (Arduino UNO – ATMega 328p version).* [online] Available at: <https://github.com/bdring/Grbl_Pen_Servo> [Accessed 21 January 2019]

Modi, H.A. and Prof. Patel, D.M. (2015). Automated Design for Pick & Place of M/C Components of CNC-Lathe. *International Journal for Innovative Research in Science & Technology,* [e-journal] 2(2), pp. 36-39. Available through: IJIRST website <https://ijirst.org/Article.php?manuscript=IJIRSTV2I2021> [Accessed 20 June 2018]

Nematollahi, B., Ming, X. and Sanjayan, J. (2017). Current Progress of 3D Concrete Printing Technologies. *34th International Symposium on Automation and Robotics in Construction,* [online] Available at: <https://www.researchgate.net/publication/318472250_Current_Progress_of_3D_Concrete_Printing_Technologies> [Accessed 25 June 2018]

Radovanovic, M. (2002). Laser Cutting Machines For 3-D Thin Sheet Parts. *8th International Conference,* [online] Available at: <https://www.researchgate.net/publication/242259668_Laser_Cutting_Machines_for_3-D_Thin_Sheet_Parts> [Accessed 25 June 2018]

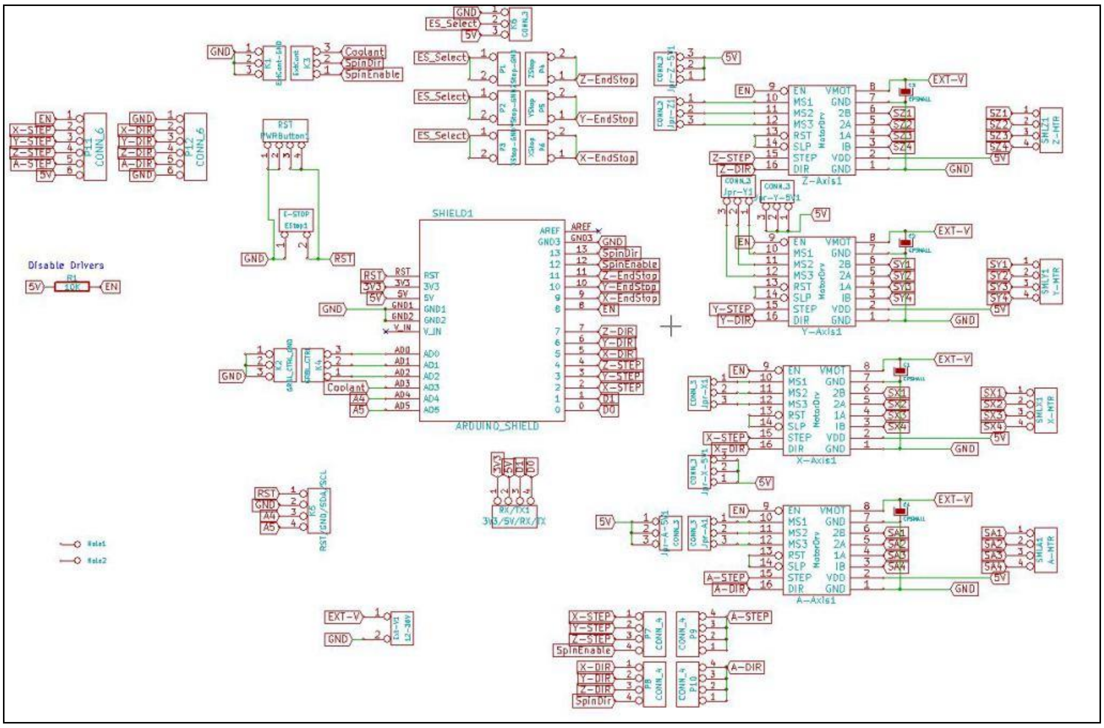
Rupanagudi, S.R., Bhat, V.G., Savarni, V.R.K.R. and Bharadwaj, S. (2015). A Novel Automatic Low Cost Cutting Machine-cum-3D Printer Using an Image Processing Based Control. *IEEE Bombay Section Symposium (IBSS)*, [e-journal] Available through: Universiti Tunku Abdul Rahman Library IEEE website <https://ieeexplore.ieee.org/document/7456641/> [Accessed 23 February 2019]

Shivakumar, T. and Selvajyothi, K. (2016). Python based 3-Axis CNC plotter. *IEEE International Conference on Power and Energy (PECon)*, [e-journal] pp. 823-827. Available through: Universiti Tunku Abdul Rahman Library IEEE website <http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7951672&isnumber=7951457> [Accessed 12 January 2019]

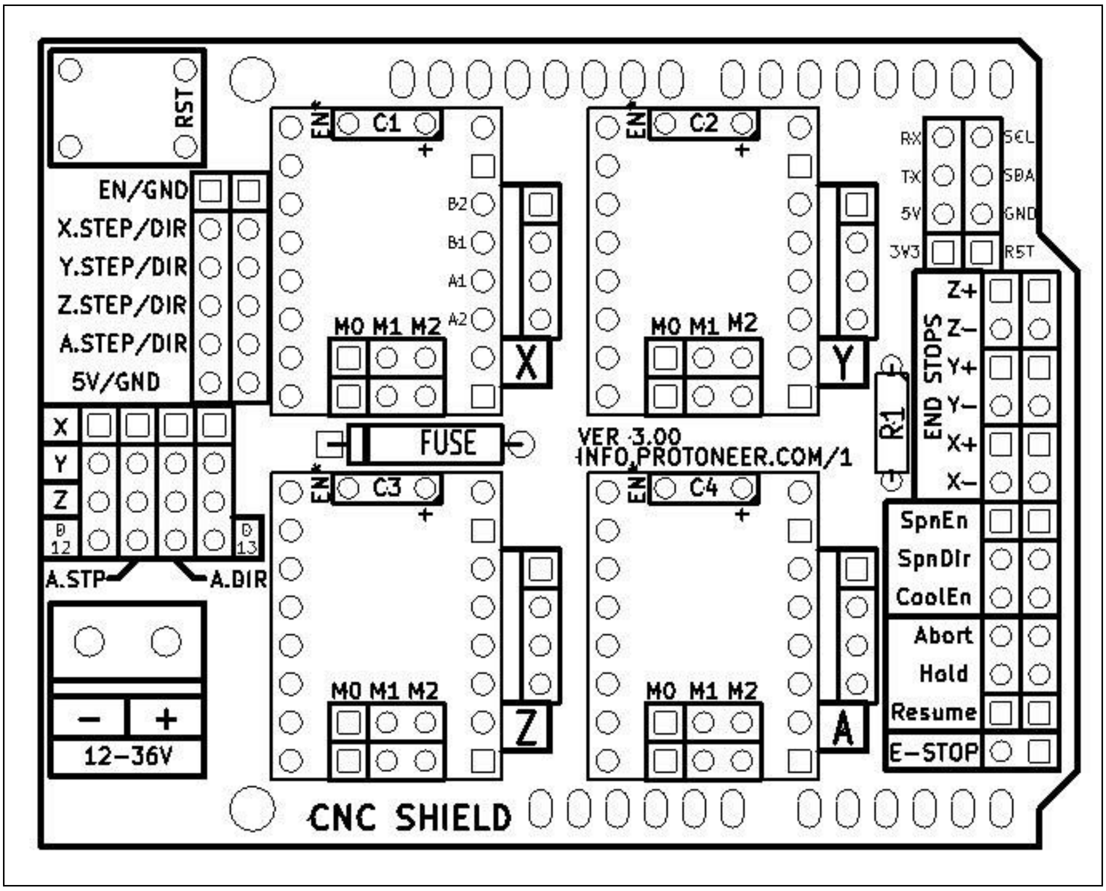
Sutarman, EdiHermawan, H. and Sarmidi. (2017). Computer Numerical Control (CNC) Milling and Turning for Machining Process in Xintai Indonesia. *Journal of Research in Mechanical Engineering*, [e-journal] 3(5), pp. 01-07. Available through: Quest Journals Inc. <http://www.questjournals.org/jrme/papers/vol3-issue5/A350107.pdf> [Accessed 21 January 2019]

APPENDICES

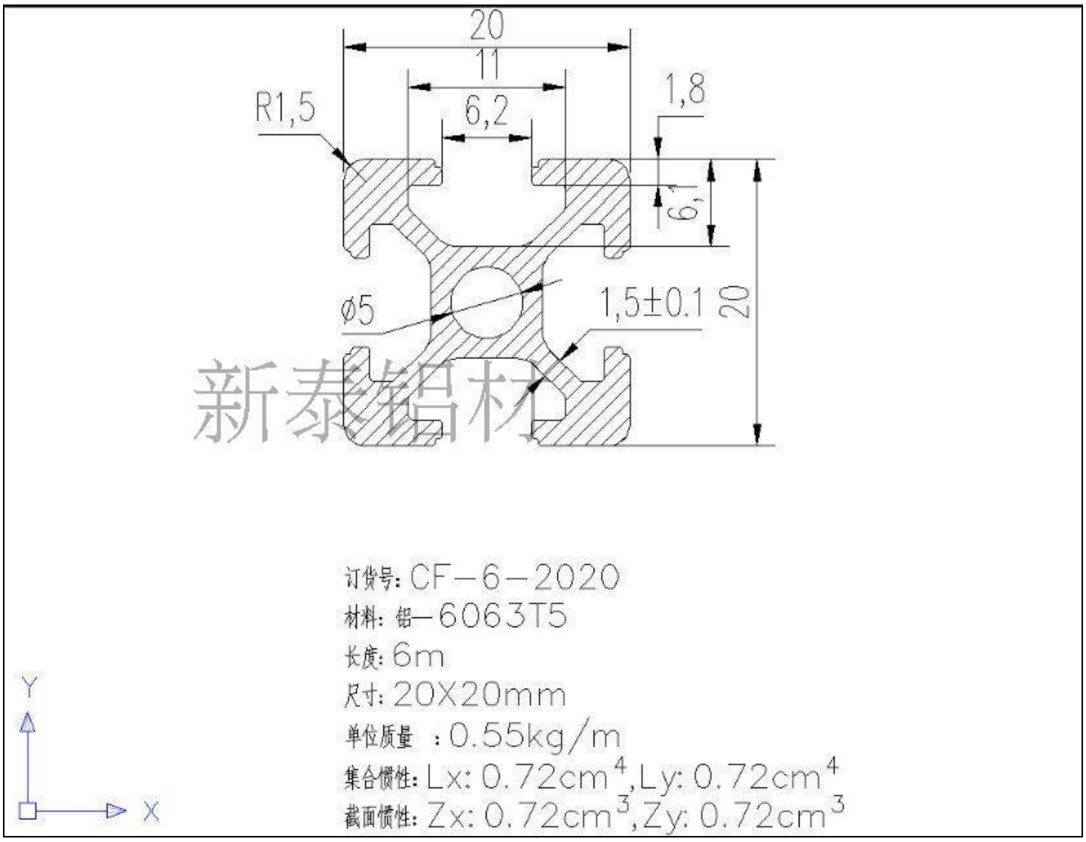
APPENDIX A: CNC Shield V3 Schematic Diagram



APPENDIX B: CNC Shield V3 Layout



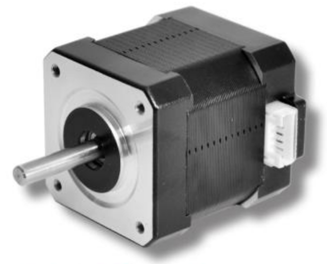
APPENDIX C: Dimension for 2020 Aluminium Steel



APPENDIX D: Nema 17 Stepper Motor Datasheet

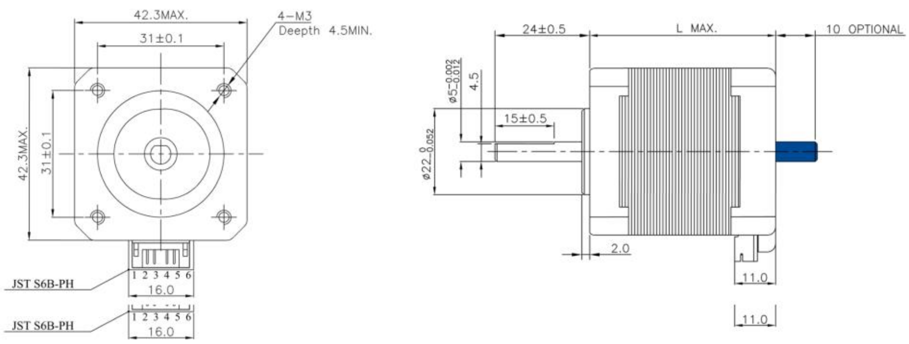
1.8°Size 17(42mm)

Item	Specifications
Step Angle	1.8°
Step Angle Accuracy	1.8°±5% (full step, no load)
Resistance Accuracy	±10%
Inductance Accuracy	±20%
Temperature Rise	85°C Max.(2 phase on)
Ambient Temperature	-20°C~+50°C
Insulation Resistance	100MΩMin. , 500VDC
Dielectric Strength	500VAC for one minute
Shaft Radial Play	0.02Max. (450 g-load)
Shaft Axial Play	0.08Max. (450 g-load)
Max. radial force	28N (20mm from the flange)
Max. axial force	10N



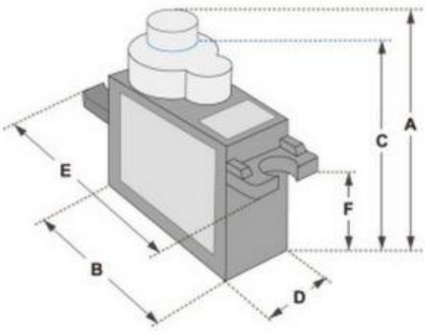
Dimension "L" Max	Model #	Rated Current (Amps/Phase)	Holding Torque (oz.in)	Holding Torque (kg.cm)	Resistance (Ohms/Phase)	Inductance (mH/Phase)	Inertia (g.cm²)	Detent Torque (g.cm)	Weight (kg)
26.0mm	[redacted]						20	75	0.15
(1.02")	1701HS140A	1.40	21.0	1.5	1.9	2.0			
34.0mm	[redacted]						35	120	0.22
(1.34")	1702HS133A	1.33	44.0	3.2	2.1	2.5			
40.0mm	[redacted]						54	150	0.28
(1.58")	1703HS168A	1.68	62.0	4.4	1.65	3.6			
48.0mm	[redacted]						68	200	0.35
(1.89")	1704HS168A	1.68	77.0	5.5	1.65	2.8			
60.0mm (1.89")	1705HS200A	2.00	114	8.2	2.0	3.3	102	280	0.55

DIMENSIONS (INTEGRAL CONNECTOR)



APPENDIX E: Servo Motor SG92R Datasheet

Tiny and lightweight with high output power. Servo can rotate approximately 180 degrees (90 in each direction), and works just like the standard kinds but smaller. You can use any servo code, hardware or library to control these servos. Good for beginners who want to make stuff move without building a motor controller with feedback & gear box, especially since it will fit in small places. It comes with a 3 horns (arms) and hardware.



Dimensions & Specifications
A (mm) : 32
B (mm) : 23
C (mm) : 28.5
D (mm) : 12
E (mm) : 32
F (mm) : 19.5
Speed (sec) : 0.1
Torque (kg-cm) : 2.5
Weight (g) : 14.7
Voltage : 4.8 - 6

Position "0" (1.5 ms pulse) is middle, "90" (~2ms pulse) is middle, is all the way to the right, "-90" (~1ms pulse) is all the way to the left.