

PCB DRILLING USING ARDUINO

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Thesis is submitted in fulfilment of the requirements for the award of the B. Eng (Hons.)  
Mechatronics Engineering

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**Dedicated to my parents**

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## **ABSTRACT**

PCB drilling machine is used to drill holes on the PCB in order to provide component mounting and to make electrical interconnection between the bottom and top of the PCB. PCB drilling machine can be divided into two types. One is Manual Controlled Machines and the other is Computer Numerically Controlled Machine. This project is focusing on the designs and fabricates a prototype of low cost 3 axes PCB drilling machine. Arduino Uno is used as the main controller of the PCB drilling machine to control the motors and other electrical components. The PCB drilling machine is specific designed for single sided PCB only.

## **ABSTRAK**

Mesin gerudi PCB digunakan untuk menyediakan komponen pemasangan dan membuat sambungan elektrik antara bahagian bawah dan atas PCB. Mesin gerudi PCB boleh dibahagikan kepada dua jenis. Mesin Pertama ialah mesin Kawalan manual dan satu lagi ialah mesin kawalan komputer berangka. Projek ini menekan kepada rekabentuk dan memalsukan prototaip mesin PCB yang kos rendah. Arduino Uno digunakan sebagai pengawal utama mesin gerudi untuk mengawal motor dan komponen elektrik yang lain. Mesin penggerudian direka untuk “single sided PCB” sahaja.



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**LIST OF SYMBOLS**

$t_{ij}$	Travelling time for the drill bit
$V_X$	Linear velocities in the x directions
$V_Y$	Linear velocities in the y directions
$F$	Feed rate
$D$	Diameter of the drill bit
$N$	Rotational speed of drilling bit
$\omega$	Angular speed of the spindle

**LIST OF ABBREVIATIONS**

PCB      Printed Circuit Board

MRR      Material removal rate



## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 INTRODUCTION**

Chapter I is the introduction of the overall project which included background of project, problem statement, objective of the project as well as scope of the project is highlighted in this chapter.

#### **1.2 BACKGROUND OF STUDY**

Printed Circuit Board, PCB is invented by an Austrian inventor born in Vienna called Paul Eisler in 1936. (Mackenzie Ward Research, 2015) It is a board made of glass reinforced plastic with conductive lines printed on board. (Elsevier 2015) Electrical and electronic components such as resistor, inductor, capacitor, and many more are mounted on the board and connected by conductive lines printed on board instead of wire in order to form a complete circuit. Holes are necessary to be drilled on the PCB in order to mount electronic components on the PCB.

In order to overcome this issue, it is essential to develop a machine called PCB drilling machine. In the Printed Circuit Board manufacturing, PCB drilling process is a very important stage. There are two purposes of drilling operation. One is to provide component lead mounting and with structural integrity and another one is to make an electrical interconnection between top and bottom of the board. (Thomas Dvorak 2014)

PCB drilling machine can be divided into two types. One is Manual Controlled Machine, and another one is Computer Numerically Controlled Machine. A manual

controlled PCB machine requires an operation in order to position the work piece and initiate the drilling cycle. Computer Numerical controlled (CNC) machine requires inputs from the computer to positioning and initiates the drilling cycles. The quality of a hole is depended on various factors such as drilling techniques, quality of the drilling tool, and operator skill in control. Therefore, it is important to give a great attention on drilling operation.

The PCB drilling machine must be able to work in precise and accurate. PCB drilling machine can moves in three axes X, Y, Z in order to drill holes on PCB depends on the coordinate projected manually or automatically. In the industry, complex and expensive PCB drilling machine is designed and used to do the drilling process but a simple and cheap PCB drilling machine can be made by using various microcontrollers as well. Among these microcontroller that available for develop a PCB drilling machine, Arduino is the one that was studied in this research study. Arduino is a very small computer used to read a variety of sensors or switches. Besides that, Arduino can be used to control a variety of motor such as DC motor and stepper motor and light-emitting diode. Furthermore, it can be used to communicate with software running on a computer in a project.

### **1.3 PROBLEM STATEMENT**

Drilling process is a very important stage in the PCB manufacturing. The PCB drilling machine is developed as the substitution of the manual drilling but the price of a PCB drilling machine is expensive nowadays. Besides that, the holes drilled by manual are not accurate and consistent compared to machine.

### **1.4 OBJECTIVE OF PROJECT**

- I To design a PCB drilling machine with high accuracy to locate the holes to be drilled.
- II To fabricate a 3 axes low cost PCB drilling machine.

## **1.5 SCOPE OF PROJECT**

- I Designing a PCB drilling machine by using Catias
- II Fabricating a PCB drilling machine using CNC and milling machine
- III Controlling stepper motors by using Arduino board and CNC shield

## **1.6 THESIS OUTLINE**

This thesis comprised of five chapters, which are as follows; Introduction, Literature Review, Methodology, Result analysis and Discussion and Conclusion respectively. Chapter I is the Introduction of the overall PCB drilling machine project which included project background, problem statement, objective of the project as well as scope of the project is highlighted in this chapter.

Chapter II is to provide some information about the theory related to the thesis subject.

Chapter III is covers with methodology of the project. The process and methods that were employed to complete the project are discussed in this chapter. As the project includes both hardware and software developments, therefore, components and implementations used are discussed in detail in this section.

Chapter IV is covers with the result and discussion of the project. The picture of the project is shown in this chapter. The problems in making the PCB drilling machine are discussed in this chapter too.

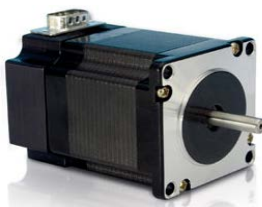
Chapter V is covers with a conclusion of the overall project. Besides that, limitations and improvements are included in this section as well.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 STEPPER MOTOR

A stepper motor is a dc motor which converts electrical pulse into discrete mechanical movement. (Solarbotics 2014) A stepper motor rotates in discrete steps, and each step is the same size when there are electrical pulses applied to it. The size of step is measured in degree. Typical size of a step is 0.9 or 1.8 degrees, and a stepper motor rotates a full rotation with 200 steps or 400 steps. It can be rotated in both directions, clockwise and anticlockwise. Stepper motor rotates with precision angle in each step. (Images SI Inc 2014) The holding torque of a stepper motor is strongest at zero speed whereas low or even no holding torque at high speed. The speed of the stepper motor is depending on the frequency of electrical pulses, and the number of rotation is depending on the number of electrical pulses. (Kerk & Haydo 2014) One of the disadvantages of the stepper motor is more vibration than other motors.



**Figure 2.1:** Stepper motor

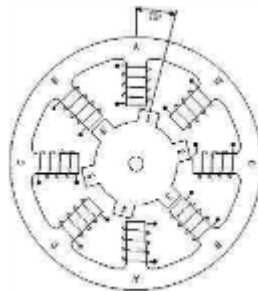
Source: Anaheim Automation 2014.

There are three basic types of stepper motor:

1. Variable reluctance steppe
2. Permanent magnet stepper
3. Hybrid stepper

### 2.1.1 Variable Reluctance Stepper

Variable reluctance stepper motor consists of an irregularly shaped soft iron magnetic rotor. (R Kuphaldt Tony 2014) The field strength is adjustable since it is not using a permanent magnet. The rotor of a variable reluctance stepper motor will move to complete a magnetic circuit in order to minimize the length of any high reluctance air gap <sup>[2]</sup>. The resolution can be increased as more teeth are added.

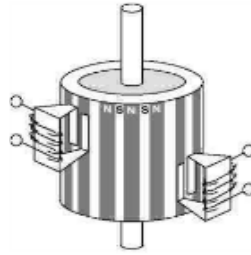


**Figure 2.2:**Horizontal cross section of a variable reluctance stepper motor

Source: Lakshmi Anand K 2014

### 2.1.2 Permanent Magnet Stepper Motor

A permanent magnet stepper motor consists of a cylindrical magnetic rotor, and it is called Canstack Rotor. <sup>[7]</sup> It is a type of low resolution stepper motor and it has a large stepping angle of  $7.5^\circ$  to  $18^\circ$ . The operation of a permanent magnet stepper motor is based on the repulsion or attraction between the rotor and the stator.

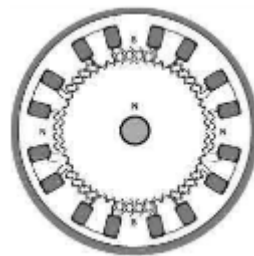


**Figure 2.3:** Illustration of permanent magnet stepper motor

Source: Lakshmi Anand K 2014

### 2.1.3 Hybrid Stepper Motor

The hybrid stepper motor combined the feature of variable reluctance and permanent magnet stepper motor in order to rotate in smaller steps. <sup>[7]</sup> A standard hybrid stepper motor rotates 1.8 degree in each step, and its rotor has 200 teeth. Normally, it is used in the application such as printer, CD player and many more.

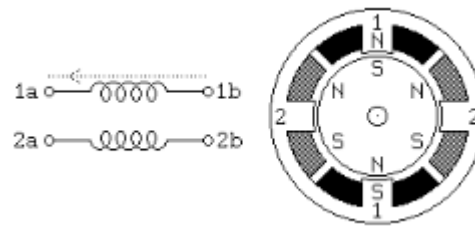


**Figure 2.4:**Horizontal cross section of hybrid stepper motor

Source: Lakshmi Anand K 2014

### 2.1.4 Bipolar Stepper Motor

Bipolar stepper motors have a single winding per phase. The magnetic pole can be reversed if the current in a winding is reversed. Normally, there are four wires and no common in a bipolar stepper motor. (Ghosh\_Sucheta, 2014)

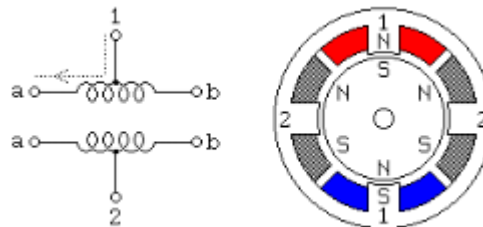


**Figure 2.5:** Bipolar Stepper motor

Source: Lakshmi Anand K 2014

### 2.1.5 Unipolar Stepper Motor

Unipolar stepper motors have two windings per phase. The magnetic pole can be reversed without changing the direction of current. Normally, there are five wires and a common in a unipolar stepper motor. <sup>[8]</sup>



**Figure 2.6:** Unipolar stepper motor

Source: Lakshmi Anand K 2014

## 2.2 LIMIT SWITCH

Limit switch is an electrical mechanical device which used as a sensor to determine a location of an object. It consist an actuator mechanically linked to a set of contacts. Limit switch contact or break an electrical connection if there is any object come in contact with the actuator. There are several types of limit switches and there are

classified based on their application. Limit switch can be divided into two types regarding on the limit switch contact. One is normally open (NO) and another one is normally closed (NC). The pin in between the pin of normally closed and open is the com. (OMRON IA 2014)



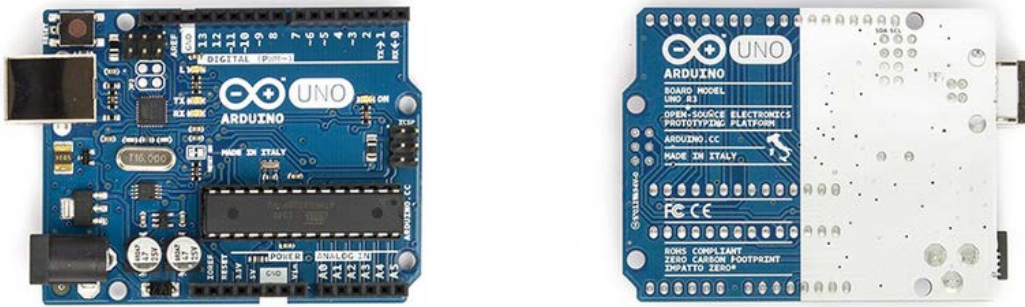
**Figure 2.7:** Limit Switch

Source: Will O'Brien 2014

## 2.3 MICROCONTROLLER

Arduino is a small computer on a single integrated circuit containing processor core, memory, and programmable input and output peripheral. Normally, we called it as microcontroller. Arduino is used to read a variety of sensors or switches. Besides that, Arduino can be used to control a variety of motor and light emitting diode. Arduino can be used to communicate with software running on a computer in a project. IDE is a compiler who runs on computer, which is used to read and upload sketches into Arduino. Arduino called programming code as a sketch. Code can be transferred by connecting Arduino to computer using USB cable. In this thesis project, Atmel ATmega328 microcontroller is used to be the controller. (Arduino, 2014) The picture of Arduino Uno microcontroller board is shown in figure below:





**Figure 2.8:** Arduino Uno Board Front and Back

Source: Arduino 2014

**Table 2.1:** Specification of Arduino Uno board

Microcontroller Chip	ATmega328
Operation Voltage	5 V
Input Voltage	6 V – 20V
Digital Input Output Pins	14
PWM Pins	6
Analog Output Pins	6
Dc Current Per Input Output Pins	40 mA
Flash Memory	256 kB
SRAM	8 kB
EEPROM	4 kB

Source: Arduino 2014



**Figure 2.9:** Pin diagram of Atmel ATmega328

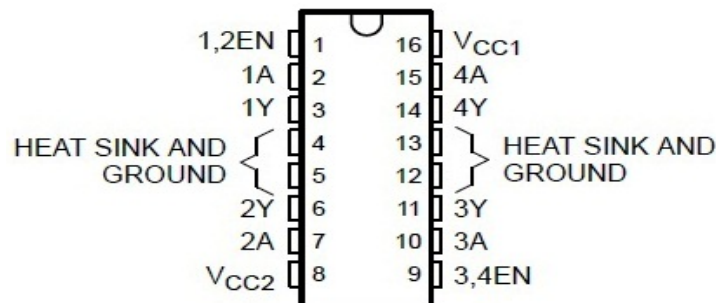
Source: Arduino 2014

**Table 2.2:** Specification of Atmel328

Pin	Description
VCC	Digital supply voltage
GND	Ground
Port A - C	Port A-C is an 8-bit bi-directional I/O port with internal pull-up resistors. The Port A-C output buffers have symmetrical drive characteristics with both high sink and source capability. As inputs, Port A-C pins that are externally pulled low will source current if the pull-up resistors are activated. The Port A-L pins are tri-stated when a reset condition becomes active, even if the clock is not running.
Reset	Reset input. This pin will generate a reset if there is a low level on this pin for longer than the minimum pulse length, even if the clock is not running.
XTAL1	Input to the inverting Oscillator amplifier and input to the internal clock operating circuit.
XTAL2	Output from the inverting Oscillator amplifier.
AVCC	AVCC is the supply voltage pin for Port C and the A/D Converter. It is externally connected to VCC.
AREF	This is the analog reference pin for the A/D Converter.

## 2.4 STEPPER MOTOR DRIVER

Motor drivers are designed to drive an electromagnetic load. It can be stepper motor, Dc motor, Dc gear motor, relay, solenoid, etc. The voltage produce from output pin of microcontroller is not high enough to operate a stepper motor. Normally, a stepper motor is needed 12 to 24 voltages to drive it. So a motor driver is needed to amplify the voltage from 5 volt to 12 – 24 volt in order to make a stepper motor run. There are a variety of motor drivers such as L293D. (Future Electronic 2014) The pin diagram of L293D is shown in figure below:



**Figure 2.10:** Pin diagram of L293D

Source: Future Electronics 2014.

## 2.5 POWER SUPPLY

Power supply is an electronic device which is used to supply voltage to some electrical device. Some of the power supply may have the feature to convert the magnitude of power supply. In this thesis project, NES-25 is used to be the power supply. The picture of NES-25 is shown in figure below:



**Figure 2.11:** NES -25

Source: Peak to Peak Power Inc 2014

## **2.6 PRINTED CIRCUIT BOARD**

Printed Circuit Board, PCB is invented by an Austrian inventor born in Vienna called Paul Eisler in 1936. It is a board made of glass reinforced plastic with conductive lines printed on the board. Holes are necessary to be drilled on the PCB in order to mount electrical and electronic components such as resistor, inductor, capacitor, and many more are mounted on the board and connected by conductive lines printed on the board instead of wire in order to form a complete circuit.

## **2.7 X – Y DRIVE SYSTEM CONCEPT**

Moving of the drill bit of a machine is an important consideration in early stage of mechanical part designed of machine. (Prasetya\_Hemanto\_Yohan 2006) Load should be kept to a minimum in order to keep the motor size down. One of the solutions is to keep the drill bit stationary and using a flexible drive shaft. Coordinate system used in a machine also affects the accuracy of positioning the holes' location. For example, Cartesian coordinate system works more accuracy than polar coordinate and cylindrical coordinate system. The reason is polar coordinate, and cylindrical coordinate system has greater positioning error with the respect of fulcrum.

There are three possibility of X - Y drive system in the Cartesian coordinate system:

1. The drill bit will move in X and Y axis but the PCB is stationary. This option gives the minimum area required but it is a maximum load option.



**Figure 2.12:** Twin axis arrangements

Sources: Prasetya Hemanto Yohan 2006

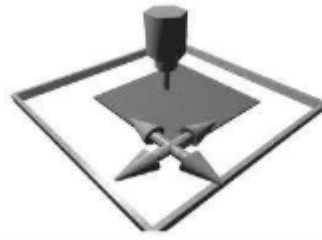
2. Both the drill bit and PCB are moving. Drill bit move in X – axis and PCB move in Y – axis or PCB move in X – axis and Drill bit move in Y – axis.



**Figure 2.13:** Separate split axis arrangement

Sources: Prasetya Hemanto Yohan 2006

3. The drill bit is stationary but the PCB move in X and Y axis. This option has the maximum area required but it is a minimum load option.



**Figure 2.14:** Twin axis arrangements

Sources: Prasetya Hemanto Yohan 2006

## 2.8 TRAVELLING TIME OF DRILLING BIT

The traveling time of a drill bit is the time required for the machine to move from position,  $i$  to  $j$  but travelling time cannot be calculated exactly. (Wei Chen Esmonde Lim, G. Kanagaraj, and S. G. Ponnambalam 2014) The drilling process is unavoidable in manufacturing process. The productivity can be improved obviously if there is a significant reduction in machining time. If there is a large number of PCB to be drilled, the path traveled by the drill bit becomes an important consideration on the overall manufacturing process since optimum holes drilling sequence can be significant reduce the time take for holes drilling process. <sup>[13]</sup>

The table of CNC machine is driven back and forth in the X and Y axis in order to drill holes in its designed position while there is a group of holes to be drilled on PCB. Stepper motors are used in X – Y drive system to move in X and Y direction. Traveling of a drill bit consists of three phases. The first phase is accelerating of the machine. The next one is running at full speed, and the third is slowing down to a complete stop. <sup>[3]</sup>

The following are the formula used to calculate the travelling time for the drill bit to move from hole,  $i$  to  $j$

Case 1

Case 2

$$t_{ij} = \frac{|x_i - x_j|}{V_x} + \frac{|y_i - y_j|}{V_y}, \quad t_{ij} = \max\left(\frac{|x_i - x_j|}{V_x}, \frac{|y_i - y_j|}{V_y}\right),$$

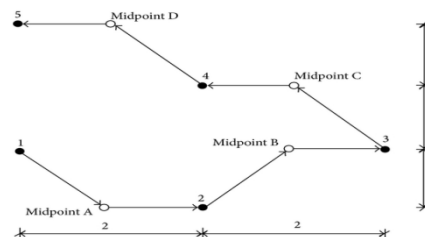
There is only one gear is allowed to turn at a time in the first case. This mean only one axis can move at a time. In actuality, there is no difference which gear is to move first because the time taken for the drill bit to travel from one hole to another hole is the same. The worktable is shown in Figure 2.15.



**Figure 2.15:** Worktable movement for case 1

Sources: Wei Chen Esmonde Lim, G. Kanagaraj, and S. G. Ponnambalam 2014

Both gears are allowed to turn simultaneously in the second case. This mean both axes can move simultaneously. The worktable movement is shown in Figure 2.16.



**Figure 2.16** Worktable movements for case 2

Sources: Wei Chen Esmonde Lim, G. Kanagaraj, and S. G. Ponnambalam. 2014

## 2.9 DRILLING OPERATION

Drilling process is the most important process in manufacturing of a PCB. There are purposes of drilling process on PCB. One is to mount electrical and electronic components such as resistor, inductor, capacitor, and many more are mounted on the board and connected by conductive lines printed on a board instead of wire in order to form a complete circuit, and another one is to form an electrical connection between top, bottom, and internal conductor pathways.

The ability to interface with the process such as soldering and plating is measured to represent the quality of a drilled hole on a PCB. However, the friction will occur during a drilling process when the drill bit touches the surface of PCB. As a result, the rpm of the motor will decrease. Besides that, this will make the hole drilling process become less accurate.

Material removal rate (MRR) in drilling is the volume of material removed per unit time. Below is the equation for MRR: (Frederick Institute of University2014)

$$\text{MRR} = (\pi \times D^2/4) \times FN$$

The value of MRR will be reduced if only if the speed of rotation is reduced too. As a result, the performance of the drilling process becomes less efficiency and power. The rotational speed of the drill has to be increase in order to drilling process more effective. We can use the power equation to calculate the power required for the drilling process. (Henderson\_Tom, 2014)

The equation of power is as shown below:

$$\text{POWER} = \text{MRR} \times \text{SPECIFIC ENERGY}$$



Torque is another parameter which is affected the rotational speed of the drill bit.  
(Carl Rod Nave 2014) The equation of torque is as shown below:

$$T = \text{POWER} / \omega$$

## **CHAPTER 3**

### **METHODOLOGY**

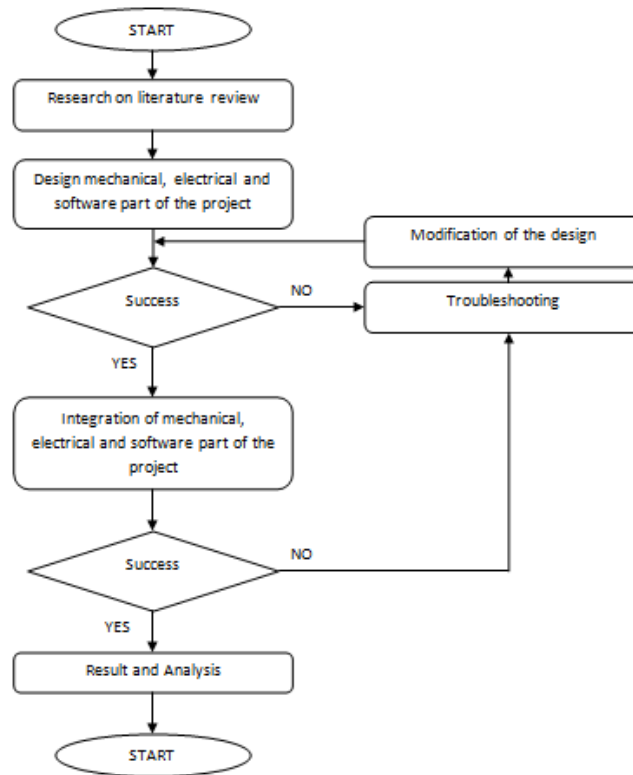
#### **3.1 INTRODUCTION**

The overall flowchart of the project will be discussed at the beginning of this chapter. The whole system of PCB drilling machine will be discussed next. Design and fabricate a PCB drilling machine with drilling bit that can be positioned to certain point is the goal of this project. This goal can be accomplished by designing and integrating the mechanical and electrical system and design. Those mechanical and electrical system and software design will be discussed more detail in this chapter.

#### **3.2 PROJECT GUIDELINE AND PROCEDURE**

The project was started with research on literature review in order to gather information for decide the most suitable design for developing a PCB drilling machine. The mechanical, electrical and software of the PCB drilling machine is designed based on the information gathered earlier. At the same time, troubleshooting and modification of the mechanical, electrical and programming of the PCB drilling machine are carried simultaneously to make sure they are relevant and functioning. After that, mechanical, electrical and software of the project are integrated and makes it into a system of a PCB drilling machine. At the same time, troubleshooting and modification of the system are carried simultaneously to make sure they are relevant and functioning. Last but not least, the PCB drilling machine is tested run and the result of the system was obtained and recorded.

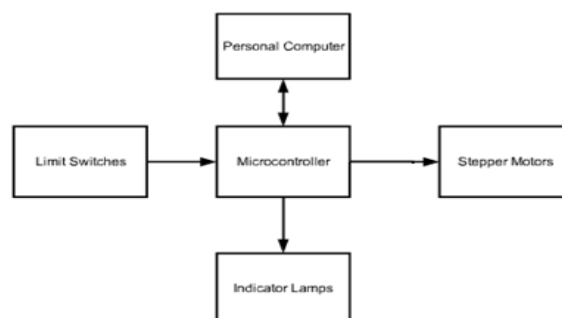
The flow chart is drawn to depict a brief view of the project guidelines and procedure.



**Figure 3.1:** Flowchart of overall project

### 3.3 OPERATION SYSTEM OF PCB DRILLING MACHINE

The block diagram of the operation system of PCB drilling is shown as in figure below

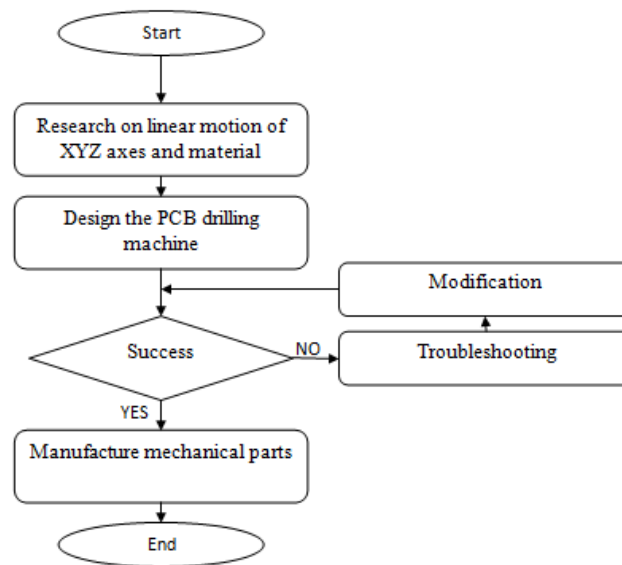


**Figure 3.2:** Block diagram of whole system of PCB drilling machine

When a personal computer gives a command, microcontroller will receive the command as an input signal. Then it will send the input signal to indicator led and stepper motor in order to operate the PCB drilling machine. The stepper motor will take the role as an actuator to control the X-Y-Z drives system. The function of the limit switches is to sense the position and gives the feedback to the microcontroller. The microcontroller will send a signal after one cycle of the process to the personal computer in order to tell the personal computer the process is done.

### 3.4 MECHANICAL DESIGN

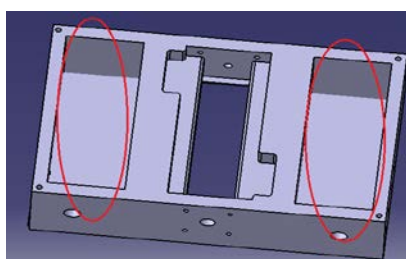
This section is started with flow chart of the mechanical design. The following is the flow chart of the mechanical design.



**Figure 3.3:** Flowchart of mechanical design

### 3.4.1 Drilling Table

I designed a drilling table of the machine is made of steel. The drilling table contains two spaces which were used to place microcontroller and motor drivers' circuit board. The front side of the drilling table was designed with 2 holes in order to place the two indicators led, red and green. Red led to indicate the machine is on and green led to indicate the machine is in operation. There are two holes at the back side of the drilling table of the machine for a cable line.

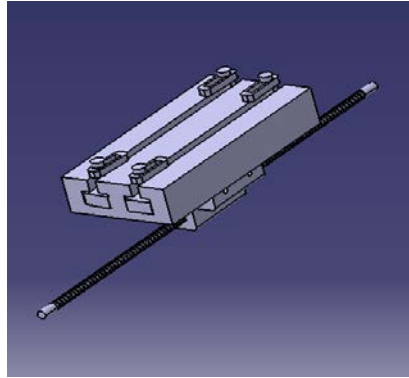


**Figure 3.4:** Base of PCB drilling machine

### 3.4.2 Linear Movement of Machine

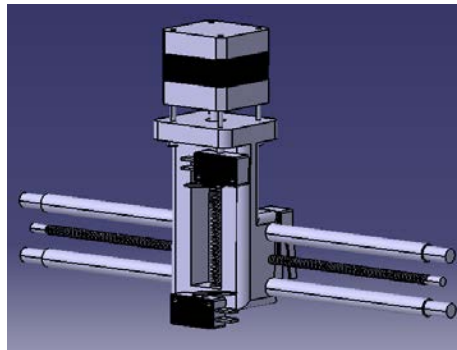
The linear movement of the machine is designed by using Cartesian coordinate system. The drilling bit of the machine will move in both Z and Y axes, and the PCB board will move in X axis. There are three axes; X, Y and Z are used in the drive system of the machine.

Linear movement of X axis is designed with a slot table and thread screw at the center of the drilling table, and a stepper motor attached at the back side of the drilling table. A coupling is fabricated and attached to the shaft and thread bar at both end. It is used to lock the shaft of the stepper motor in order to rotate with the shaft of stepper motor. A thread bar is used to make the rotational of the stepper motor into linear movement of the drilling bit. A stepper motor is used to move the PCB in X axis. The movement of X axis is designed based on the concept of rotational to linear translation.



**Figure 3.5:** X axis of PCB drilling machine

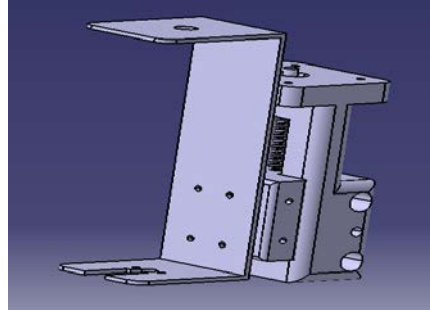
Linear movement of Y axis is designed with a slot bar and thread bar attached between two side stands of the machine. The slot bar is used to stable and balances the drilling unit holder. A coupling is fabricated and attached to the shaft and thread bar at both end. It is used to lock the shaft of the stepper motor in order to rotate with the shaft of stepper motor. The thread bar is used to make the rotational of the stepper motor into linear movement of the drilling bit. A stepper motor is used to move the drilling bit in Y axis.



**Figure 3.6:** Y axis of PCB drilling machine

Linear movement of Z axis is designed with a thread bar and slot table. The slot table is designed to a holder the drilling bit of the machine. A coupling is fabricated and attached to the shaft and thread bar at both end. It is used to lock the shaft of the stepper motor in order to rotate with the shaft of the stepper motor. The thread bar is used to

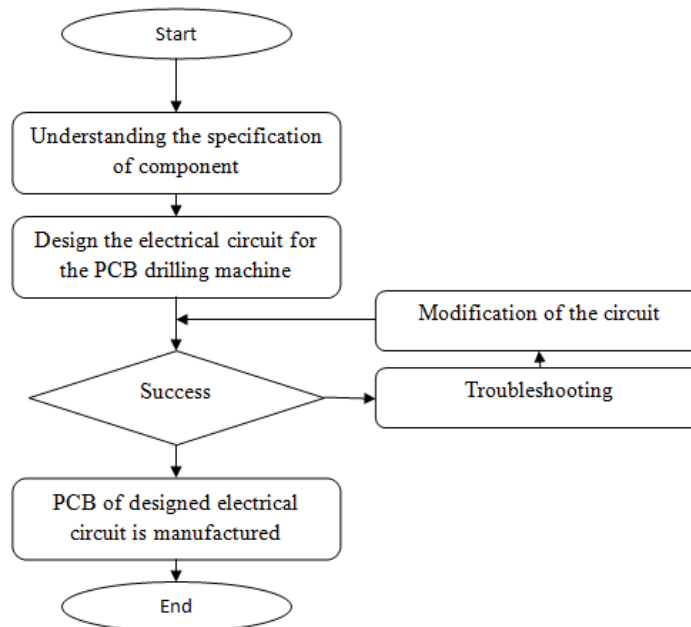
make the rotational of stepper motor into linear movement of the drilling bit. A stepper motor is used to move the drilling bit in Z axis.



**Figure 3.7:** Z axis of PCB drilling machine

### 3.5 ELECTRICAL DESIGN

This section is started with flowchart of electrical design. The following is the flow chart of electrical design.



**Figure 3.8:** Flowchart of electrical design

### 3.5.1 Stepper Motor

This project is using three stepper motor in order to control the movement of all three axes. All the stepper motors was giving by the lab of our Manufacture Faculty. Each stepper motor has different specification. The following is the specification of the stepper motors which are used in my project.

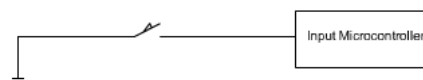


**Figure 3.9:** Stepper motor 42BYCHD439-02

**Table 3.1:** Specification of 42BYCHD439-02

Model	42BYCHD439-02
Operating voltage	12 – 24 volt
Operating current	0.8 ampere
Rotation per Step	1.8 degree per step

### 3.5.2 Limit Switch



**Figure 3.10:** Schematic diagram of limit switch and microcontroller



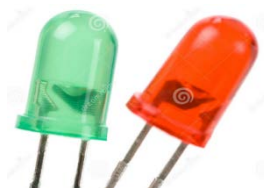
There are six limit switches are used in the project. All the limit switches are used as a sensor. Three limit switches are used to positioning the home position of machine. These three limit switches also have the same function as the other three limit switches that are used to give the information about the limit of linear movement in X, Y and Z axes. The limit switches will give a feedback to the microcontroller if the mechanical switch of the limit switch is triggered or being touched.

### **3.5.3 ON / OFF Switch**

There is one on / off switch used in the project. This switch is used to on and off the machine.

### **3.5.4 Indicator Led**

There are two indicators led used in the project. Both of the led are operated at 3 volt with the help of the resistor in order to reduce the voltage from 12 volt to 3 volt. (Kruger Bertus 2014) One is red color led, and another one is the green color led. The red color led indicates the machine is on whereas the green color led indicates the machine is running.



**Figure 3.11:** Red and green led

Source: Miniorb Engineers Pvt Ltd. 2014

### **3.5.5 Drilling Unit**

The drilling module used in the project was obtained from market. The following are the specification of the drilling module obtained from the market.



**Figure 3.12:** Pro kit Driller

**Table 3.2:** Specification of Pro kit driller

<b>Type</b>	DC motor
<b>Manufacture</b>	Pro-kit
<b>Operating Voltage</b>	12 volt
<b>Operating Current</b>	0.8 ampere

### 3.5.6 Power Supply

Power supply is an electronic device which is used to supply voltage to some electrical device. Some of the power supply may have the feature to convert the magnitude of power supply. The power supply obtained from the market. In the project, 12 volt is needed to operate stepper motors and 2.8 ampere is needed to operate all stepper motor and drilling modules. In this thesis project, NES-25 is used to be the power supply. The picture of NES-25 and its specification are shown in figure below:

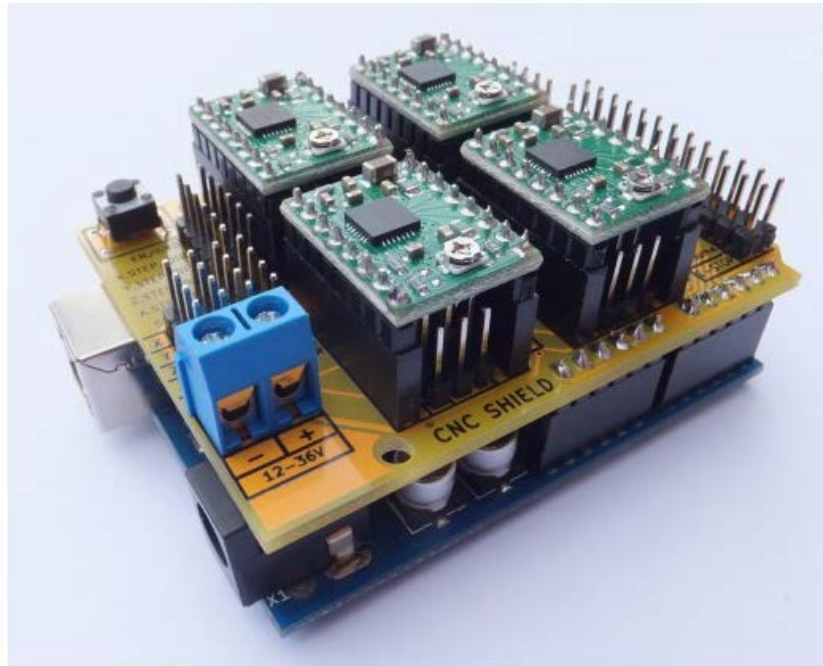


**Figure 3.13:** NES -25

**Table 3.3:** Specification of Power supply NES – 25

<b>Type</b>	Power supply
<b>Manufacture</b>	NES
<b>Input Voltage</b>	240 volt
<b>Output Voltage</b>	12 volt
<b>Output Current</b>	3 ampere

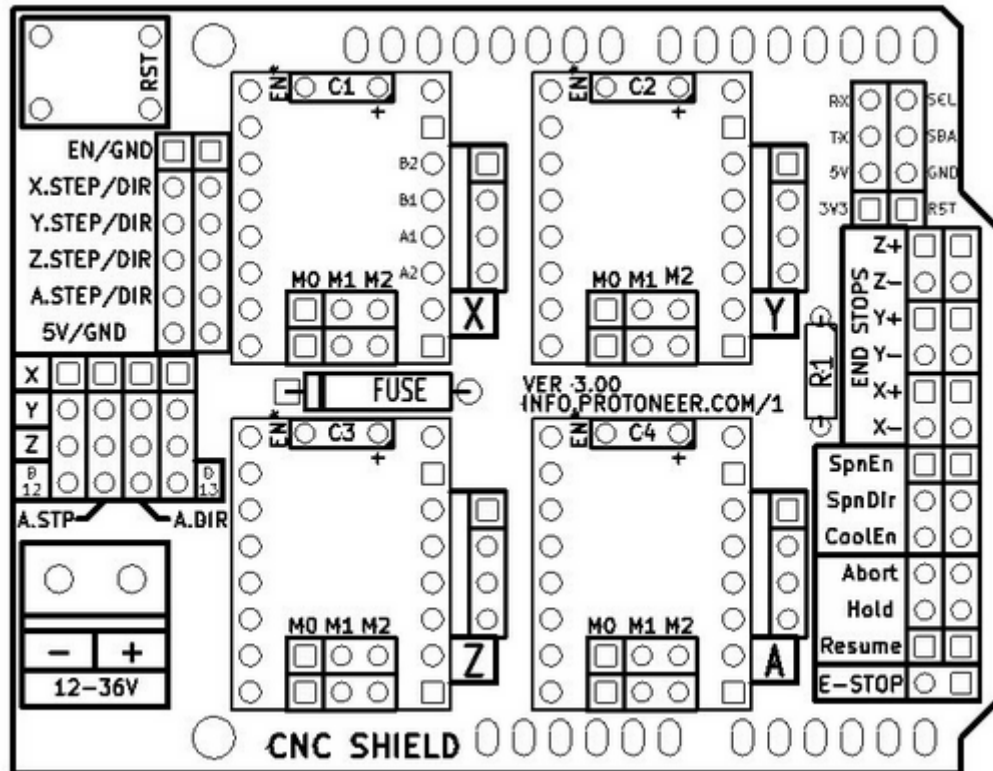
### 3.5.7 Arduino CNC Shield

**Figure 3.14:** Arduino CNC Shield

Source: Kruger Bertus 2014.

Arduino would not be able to process an entire design file all by itself. <sup>[18]</sup>This is due to it not having enough memory to handle more than one G - Code command at a time. In fact, not all G-Code commands are currently completely implemented in the Arduino CNC Shield software. However, the Arduino does directly interface with the

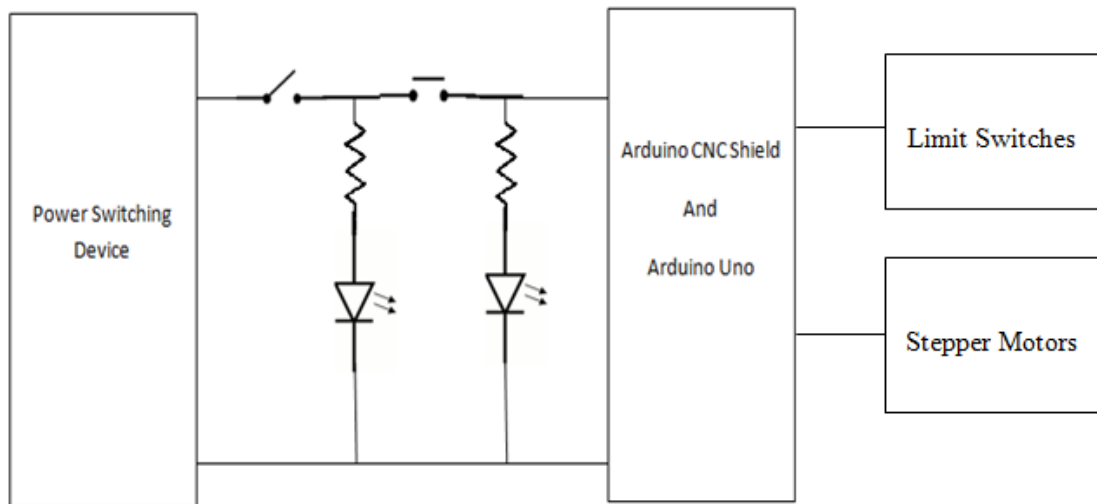
CNC Controller shield and can pass commands to the stepper drivers on the CNC Controller shield without any additional circuitry. The features of Arduino CNC Shield are compact design, GRBL compatible, 4-Axis support, and removable A4988 compatible stepper drivers. Besides that, stepper Motors can be connected with 4 pin connectors and runs on 12 – 36 volt.



**Figure 3.15:** Board Layout of Arduino CNC Shield

Source: Kruger Bertus 2014.

### 3.5.8 Overall Circuit Diagram

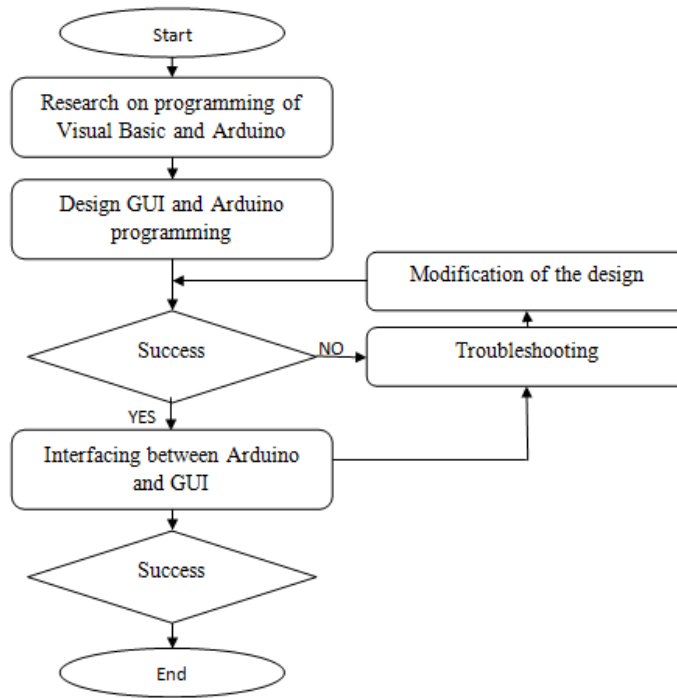


**Figure 3.16:** Block Diagram of overall circuit

The above diagram is showing the overall electrical connection of the PCB drilling machine. Firstly, the power source is supplied by the power switching device called NES – 25. This device supplies dc voltage source to the machine (12 v and 3 A). There is a 100 ohm resistors connected with LED in series but parallel with the power switching device and Arduino UNO and Arduino CNC Shield. There are two sets of this connection. One is for red indicator, and this indicates the power source is on and another for green indicator and this indicates the emergency button is released. A push button is used as an emergency button in this project. There are three stepper motors, and six limits switches are connecter to the Arduino CNC Shield.

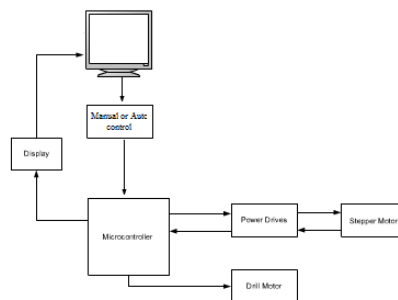
### 3.6 SOFTWARE DEVELOPMENT

This section is started with the flowchart of software development.



**Figure 3.17:** Flowchart of software development

This program is used to control the stepper motor and indicator led. The following is the general sequence of the program operation



**Figure 3.18:** General sequence of the program operation

### **3.6.1 Manual Mode**

In this mode, the button on the graphic user interface was used to give an input to drive the stepper motor through microcontroller. The input signal from the personal computer is sent to the microcontroller by using USB cable. This input will be calculated by the microcontroller how many distance is traveled and show on the personal computer.

### **3.6.2 Automatic Mode**

In this mode, the user has to load a Excellon file which can be generated from the PCB design software like Protel or Eagle in order to send the input to the microcontroller. Visual basic is used to convert the data from Protel or Eagle to produce the exact coordinate to be sent. The input signal from the personal computer is sent to the microcontroller by using USB cable.

## **CHAPTER 4**

### **RESULT & DISCUSSION**

#### **4.1 INTRODUCTION**

The result of the mechanical part of this project will be discussed at the beginning of this chapter. The electrical and software will discuss next. Design and fabricate a PCB drilling machine with drilling bit that can be positioned to certain point is one of the goals of this project. This goal can be accomplished by designing and integrating the mechanical and electrical system and design. The total budget used in this is calculated in this chapter too. The cost used in the project will be discussion in this chapter too, but the procurement lists for mechanical and electrical part will be attached to the appendix.

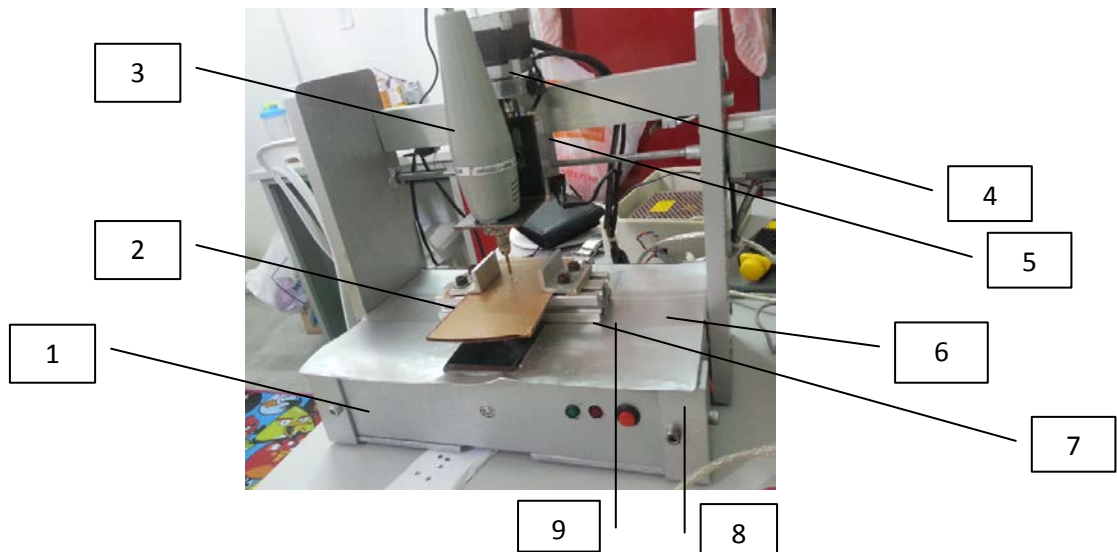
#### **4.2 MECHANICAL DESIGN RESULT**

Figure 4.1 show the overall final design of the PCB drilling machine. The machine consists of three main parts. They are X, Y and Z axis. The mechanical parts for all three axes are working well. The X moves back and front whereas Y moves right and left the desired coordinate whereas Z axis moves up and down to drill the holes on the PCB. All the electrical components are placed in the base. Besides that, there are two switches and two indicators led installed on the base too. One is the main power switch, and another is the emergency switch. These two indicators led are used to indicate that whether the machine is ready to be used.

The table used to clamp the PCB is installed on X axis. There two clamps can be used to the PCB, and it can be fixed in the position by fasten the screws with Allen key.



PCBs have to be clamped firmly on the table to prevent it from slipping during drilling process. It may cause lower accuracy if the PCBs do not clamp nicely. The Z axis is installed together with Y axis. The Y axis can move right and left whereas the Z axis move up and down. Stepper motors are installed in each axis in order to move the thread rods. There are three shafts used to interconnect the stepper motors and the thread rods. All axes are made of aluminium but only the side stands are made of Perspex.



**Figure 4.1:** Front view of mechanical part

**Table 4.1:** List of mechanical parts in figure 4.1

No	Mechanical Parts
1	Base
2	Table of the Machine
3	Drilling Unit
4	Z-axis
5	Y-axis
6	Cover of the Base
7	X-axis
8	Switches
9	Indicators led



**Figure 4.2:** Back view of mechanical part

**Table 4.2:** List of mechanical parts in figure 4.2

No	Mechanical Part
1	USB Connector
2	Thread Lead Screw
3	Plate
4	Sliding Bar
5	Connection Hole

The sliding bar on the Y axis is used to guide the axis to move in the desired direction – right and left. There is a plate clamped to stable Z axis from fall forward. The function of the thread rod is to make the axis to move by using rotation to translation theory. Most of the wires are wrapped by using heat shrink tube in order to make the machine look better and professional.

#### 4.2.1 Problems on Mechanical Design

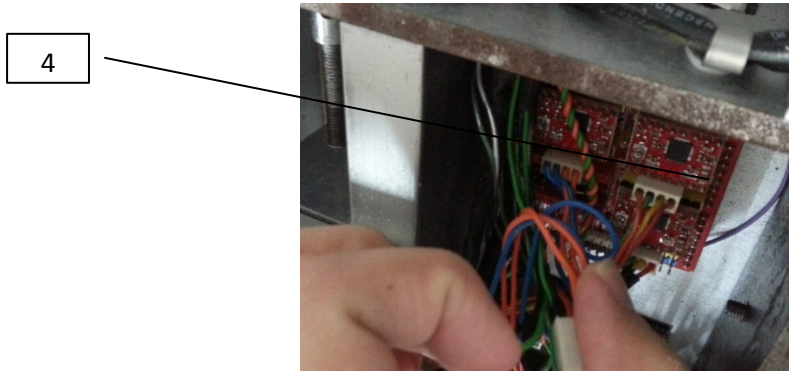
The first design of the X axis was using two rods to support the Y and Z axes but I found that it is hard to be manufactured. A rectangular sliding bar is used instead

of rods in order to support the axes. The rectangular sliding bar is easier to be manufactured compared to rods but I have to spend more money on raw material. Another problem is the movement of the X and Z axes are not as smooth as expected due to the poor machining skill. There is some vibration produced during the drilling process and it may vary the accuracy of drilling. Furthermore, the drilling unit can move up and down smoothly due to lead screw do not assembled perpendicularly to the Z axis. This problem lead to the drilling unit head is unable to drill the centreline of the coordinate very accurately. The only solution to the above problem is re – machining all these error mechanical parts. But until the submission of this paper, this step has not been done yet. Maybe my supervisor will do this modification on the further research. This idea will be written on the recommendation section- chapter 5.

#### 4.3 Electrical Design Result



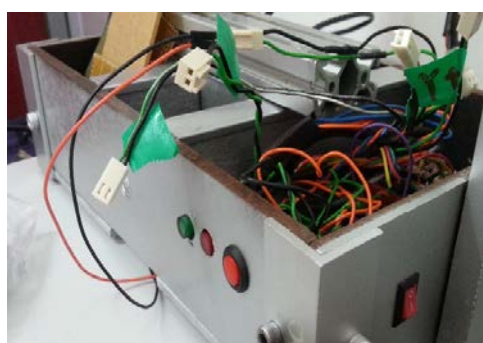
**Figure 4.3:** Led and Switch



**Figure 4.4:** Arduino and Shield

**Table 4.3:** List of electrical and electronic components in figure 4.3 & 4.4

No	Electronic & Electrical Components
1	Indicators led
2	Circuit Board for Switches and led
3	Switches
4	Arduino and Shield



**Figure 4.5:** Main and Emergency Switch

The figure 4.2 and 4.3 show the final design of the electrical part of the project. The most difficult part is to find the correct wires used to connect from stepper motors to the Arduino. The method used to solve the problem is to measure the resistance between each wire. A stepper motor normally consists of 4 to 6 wires but only 4 wires

needed to be used and so my task is to find these wires. Arduino CNC shield is added into this project after I found out that Arduino Uno alone can read the input file to make the machine run automatically. The shield has the capability to read G –code then converts it to readable data which can be understood by the Arduino Uno. There are few problems occurred in electrical part.

#### **4.4 GRAPHIC USER INTERFACE**

The program is used to control the PCB drilling from the Laptop or Personal computer. There is coordinate in X, Y and Z axis display on the program. Users can give the command to the machine by pressing the button display on the screen. The program is capable to send the G – code to the Arduino CNC shield through USB cable. The program can read G – code text file to make the machine run automatically.

#### **4.5 EXPERIMENT OF LOCATING POSITION OF HOLES**



**Figure 4.6:** Result of Testing

The above figure 4.6 shows the result of the test run. After all aspects are completed, there is an experiment is carried out in order to find out error with the PCB drilling machine. This experiment is very important due to PCB drilling machine have to drill holes with good precision and consistency. There is some error occurred with the machine after the experiment is done. The human error will also influence the errors. The table below shows the experiment result of the system. There are some errors occurred from 6 times calculation. From the calculation, the average error is calculated.

**Table 4.4:** Result obtained from experiment

Desired point / mm	Actual point / mm	Error / %
10	9.5	5
10	9.5	5
10	9.5	5
10	9.5	5
10	9.5	5
10	9.5	5
	Average error	5

The error is calculated with the formula:

$$\text{Error} = [(\text{actual} - \text{desired point}) / \text{actual point}] \times 100\%$$

#### 4.6 Financial Report

The total cost used in the project is RM 799.48. The cost is quite low compared to the others PCB drilling machine sold in the market. The procurement lists will be attached to the appendix A & B. Table below show the price of machine sold in some company.

**Table 4.5:** List of PCB machines' price from companies

Company Name	Price RM
Jinan Dexian Trading Co., Ltd.	5472
Jinan Hopetool CNC Equipment Co., Ltd.	5400
Shenzhen Scotle Technology Ltd.	4700
Jinan Zhuoke CNC Equipment Co., Ltd.	5000
Shenzhen Okacc Automation Equipment Co., Ltd.	4000

Source: Group Alibaba 2014

## **CHAPTER 5**

### **CONCLUSION AND RECOMMENDATIONS**

#### **5.1 INTRODUCTION**

The goal of this study was to develop a prototype of PCB drilling machine which is able to drill holes with high accuracy. As the prototype is not perfect, there for limitation and improvements are included in this section as well.

#### **5.2 CONCLUSION**

The PCB drilling machine can be controlled by using a personal computer or a laptop. The drilling unit can move in three axes. They are X, Y and Z axes. Both axes X and Y are used to locate the coordinates of the drilling holes by moving front, back, left and right whereas Z axis is used to drill holes by moving up and down. The PCB drilling machine can move manually from one point to another point by using a personal computer to give the command through USB. The machine can run in automatically by inserted text file with G – code. A CNC shield is used to control stepper motor and other electronic components. Besides that, it helps to convert G – code sent from personal computer. This machine can help to reduce the human error while drilling PCB. In addition some parts of the machine are made from the recycled part. But the machine cannot produce a veryhigh precision because of some problems encountered during making the PCB machine. The machine can locate the point with accuracy based on the result show on the chapter 4, As a conclusion, a low cost PCB drilling machine is successfully designed and fabricated which can move in 3 axes by using Cartesian coordinate system as XYZ drive system to locate position of hole with

high accuracy. As a result, the prototype developed is able to meet the requirements of drilling process.

### **5.3 RECOMMEDATIONS**

- To make X, Y and Z axes run smooth. It is recommended using a timing belt instead of lead screw.
- To reduce the time of drilling process. It is recommended using particle swarm optimization algorithm to find the shortest distance between points.
- To design a machine more safety to be used. It is recommended to add on a protector shield in order to protect the user from dangerous during operation.



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APPENDIXES

## APPENDIX A

**Table 4.6:** List of Procurement of Mechanical

MECHANICAL COMPONENT							
NO	PART	MATERIAL	DIMENSION	UNIT	PRICE/UNIT	TOTAL COST	LOCATION
1	Base Frame	Steel Steel	250 mm x 60 mm x 5 mm	3	Rm17.36	Rm52.08	Fkp Lab Fkp Lab
2	Base Frame Cover	Wood	240 mm x 150 mm x 5 mm	1	-	-	Fkp Lab
3	Side Stands	Acrylic	245 mmx 95 mm x15 mm	1	Rm10.00	Rm10.00	Fkp Lab
4	Coupling	Aluminium	D6 mm x 18 mm	1	Rm37.7	Rm37.7	Fkp Lab
8	X, Y and Z-axis	Aluminium	250 mm x 250mm x 250 mm	3	Rm36.00	Rm108.00	Fkp Lab
9	Z-axis Holder	Aluminium	50 mm x 40 mm x 20 mm	1	Rm69.00	Rm69.00	Fkp Lab
11	Nut	Steel	M4 M5	2 2	Rm 0.40 Rm 0.40	Rm 0.80 Rm 0.80	Advance Bolt SdnBhd Advance Bolt SdnBhd
12	Screw	Steel	M3 x 20 mm M3 x 10 mm M4 x 10 mm M4 x 15 mm M5 x 10 mm	13 10 10 18 1 set	Rm 0.20 Rm 0.20 Rm 0.20 Rm 0.20 Rm 10.00	Rm 2.60 Rm 2.00 Rm 2.00 RM3.60 Rm 10.00	Advance Bolt SdnBhd Advance Bolt SdnBhd Advance Bolt SdnBhd Advance Bolt SdnBhd Tuck Lee Hardware
13	Plastic Casing	Plastic	55 mm x 105 mm x 126 mm	1	Rm 10.00	Rm 10.00	
14	618/5 Ball Groove Bearing	Steel	-	3	Rm 10.00	Rm 30.00	LianHup Industrial SdnBhd
15	Drill Bit	Steel	3 mm -6 mm	1	Rm 3.00	Rm 3.00	MBJ Jaya Bina SdnBhd
<b>TOTAL</b>						<b>Rm 341.58</b>	

## APPENDIX B

**Table 4.7:** List of Procurement of Electrical

ELECTRICAL COMPONENT						
NO	PART	DESCRIPTION	UNIT	PRICE/UNIT	TOTAL COST	LOCATION
1	Mini Drill Kit	-	1	Rm 70.00	Rm 70.00	Connectronic Trading
2	Unipolar Stepper Motor	Voltage = 12V Current= 0.8A	3	Rm60.00	Rm180.00	Fkp Lab
3	Arduino CNC Shield	Refer Datasheet	1	Rm 75.00	Rm 75.00	Nixie Electronics Trading
4	Connector Pin	-	20	Rm 0.20	Rm 4.00	Advance Bolts Supplies SdnBhd
5	Power Switching Device	Voltage = 12V Current= 3A	1	Rm 45.00	Rm 45.00	Nixie Electronics Trading
6	Arduino Uno	Refer Datasheet	1	Rm 50.00	Rm 50.00	Nixie Electronics Trading
9	A4955 Compatible Stepper Drivers	Refer Datasheet	3	Rm 3.00	Rm 9.00	Nixie Electronics Trading
10	Emergency Stop Button	Push Button	1	Rm 2.50	Rm 2.50	Connectronic Trading
11	NO Push Button	-	1	Rm 2.00	Rm 2.00	Nixie Electronics Trading
12	Limit Switch	-	6	Rm 0.80	Rm 4.80	Nixie Electronics Trading
13	Wire	Single core	3	-	-	Fkp Lab
		Multicore	3			Fkp Lab
14	LED	Green & Red	2	Rm0.10	Rm0.20	Fkp Lab
15	Resistor	1k	2	Rm0.20	Rm0.40	Fkp Lab
16	Plug	-	1	Rm5.00	Rm5.00	Fkp Lab
17	Strip Board	-	1	Rm10.00	Rm10.00	Fkp Lab
<b>TOTAL</b>					<b>Rm 457.90</b>	

