DEVELOPMENT OF A PORTABLE 3D PRINTER FOR MEDICAL MODELLING

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Biomedical Engineering

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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.

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APPROVAL FOR SUBMISSION

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ABSTRACT

The application of rapid prototyping such as 3D printing in medical modelling helps the doctor to have a better illustration on the structure by looking into 3D printed model. Besides, during COVID-19 pandemic period, 3D printing technology solved the shortage of supply chain for PPE, tester or spare parts for medical equipment. The most common used 3D printing method is FDM, fused deposition modelling and Cartesian 3D printer is the most ordinary 3D printer in the market. However, the heavy and bulky design of 3D printer cause the printer inconvenient to be carried, which cannot meet the needs of mobile printing.

This research aims to review on the development of portable 3D printer that optimize the space usage. The portable 3D printer is designed in such that the Z-gantry axis is able to be folded down during non-usage period. The folding mechanism apply the concept of ball plunger spring that is applied in the mechanism of the folding handle of a luggage at the locking position when it is extended.

The hardware parts of the portable 3D printer consists of aluminium profiles, 3D printed parts and acrylic sheet. In the other hand, RAMPS 1.4 is used to as control board together with Arduino Mega 2560 board and A4988 Stepper Motor Driver. The firmware of the portable 3D printer implements Marlin x2.0 and Pronterface is used to simulate the printing. Fine adjustment has been made on hardware and firmware to achieve the best quality of printing.

The developed portable 3D printer is 390 mm x 320 mm x 115 mm during folding stage and 220 mm x 323 mm x 329 mm during upright stage with printing volume 90 mm x 90mm x 90 mm. The weight of the portable 3D printer is 3.90 kg, where the power supply unit has a weight of 0.7 kg. The developed 3D printer able to achieve folding within 5 seconds period.

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LIST OF SYMBOLS / ABBREVIATIONS

AEC	Architecture, Engineering and Construction
3D	3 Dimension
FDM	Fused Deposition Modelling
SLA	Stereolithography
SLS	Selective Laser Sintering
SLM	Selective Laser Melting
LOM	Laminated Object Manufacturing
EBM	Digital Beam Melting
PLA	Polylactic Acid
ABS	Acrylonitrile Butadiene Styrene
PC	Polycarbonate
PVA	Polyvinyl Alcohol
PS	Polystyrene
PE	Polyethylene
PTFE	Polytetrafluoroethylene
LCD	Liquid Crystal Display
PID	Porportional-Integral-Derivative
SD	Secure Digital
NO	Normally Open
NC	Normally Close
PSU	Power Supply Unit

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

3D printing technology has been broadly used in industrial design, architecture, construction (AEC), aerospace, automotive, medical industries, education and many more other related fields (Liu et al., 2017). Today, 3D printing technology can also manufacture processed foods, where it indicates the infinite possibilities of the future development of 3D printing technology.

3D printing is a rapid prototyping technology that started in the 80's late 20th century. According to the research of Chichernea (2013), in 1981, the first printed solid model has been studied and published by Hideo Kodama of the Nagoya Municipal Industrial Research Institute (Nagoya, Japan). The technology of "rapid prototyping" and "additive manufacturing" are first introduced to people. This technology has been researched and improved until the year 1984, the first 3D printer was designed by Charles W.Hull.

There are many type of 3D printing that is used in the medical device field, one of the example is medical modelling. The production of medical modelling such as bone structure will reduce the period for the doctor or any medical–related worker to study for the structure.

During the start of year 2020, coronavirus COVID-19 pandemic is the defining global health crisis of the time and the greatest challenge have faced since World War II. The biggest problem is the shortage in the supply chain such as manufacturing. By implementing 3D printing technologies, the continuity of production able to be secured and the most critical problem able to be solved in a shorter period and safer method. For example, 3D printed face shield provided additional protection for front-liners in the situation which is shortage of personal protective equipment (PPE) and the production of 3D printed nasopharyngeal (NP) swab solves the problem of the shortage for NP swab.

The existing 3D printing technology consists of 3 main phases – the printing, the modelling and the finishing of the product. Nowadays, 3D printing technology has been developed in such that there are few type of 3D printing such as FDM, SLA, SLS, SLM, LOM and EBM. The most commonly available 3D printing method used is Fused Deposition Modelling, FDM.

FDM printing works in layer by layer printing. A spool of filament such as PLA and ABS is inserted into the 3D printer and fed through printer nozzle in the extrusion head. The nozzle of the printer will be heated to a desired temperature according to the different melting temperature of filament; extruder stepper motor will push the filament through the heated nozzle, causing it to melt. The extrusion head will move according to the specified coordinates from G-code file and laying down the molten filament onto the build plate layer by layer. The object is fully formed after the completion of the printing.

While there are various type of technologies for 3D printing, there are also different types of FDM 3D printer such as Delta, Cartesian, Polar and robotics arm. The most ordinary FDM 3D printer is the Cartesian 3D printer as it can be easily found in the market. The position and the direction of the print head and built plate are determined by using Cartesian coordinate system, X, Y and Z direction in mathematics. The well-known brand are Ultimaker and Makerbolt. In Delta 3D printer, a round built plate that is coupled with an extruder that is fixed at triangular points and operated by using Cartesian coordinates (Bell, 2015). The head of the extruder will be able to move in any direction with unmovable build plate.

The positioning of Polar 3D printer is determined by an angle and length with a rotatable plate in any direction except Z direction with the extruder that movable in Z direction (Cambron et al., 2018). The process of the robotic arm 3D printing is not fixed to a built plate, in which has contributed flexibility to the extruder head of the 3D printer (Ismayuzri Ishak et al., 2016).

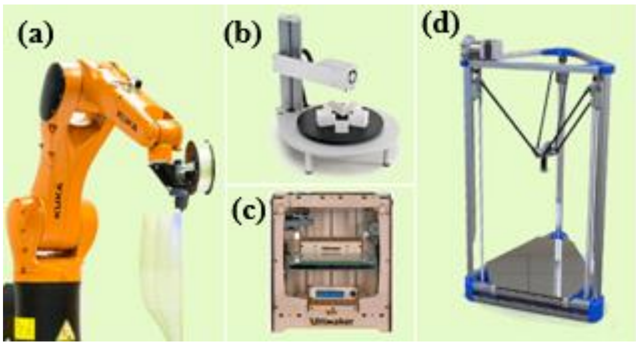

Figure 1.1: Type of FDM 3D printer (a) Robotic Arm, (b) Polar, (c) Cartesian, (d) Delta. (Alex, 2017)

1.2 Importance of the Study

The normal desktop 3D printers are three-dimensional frame integrally, cannot be folded. The conventional 3D printer's extruder is located above the printing platform and the cartridge of axis is perpendicular to the base assembly. More and more people get themselves involve in rapid prototyping technology such as 3D printing, even a housewife as well. The daily production and prototyping tends to rely on 3D printing. Accessibility and portability on 3D printer are under research and it is important to develop portable 3D printer that enable people to easily access to 3D printer anywhere and anytime.

Besides, with the technology of 3D printing, the workload of the medical front liners will reduced in such that the production of medical modelling will enable the medical front liners to study the structure with actual ratio model rather than study through X-ray result or collected data. With the occurrence of pandemic COVID-19, 3D printing technologies able to solve the shortage or problem faced through the period such as production of ventilator expansion splitter to solve the shortage of ventilator or NP swab.

1.3 Problem Statement

The design of normal 3D printer makes the printer accommodate larger space. Besides, 3D printer also need to be disassembled to facilitate transport and reassemble for the use of the printer (Dong et al., 2016). The current large volume of 3D printer, inconvenient to carry, cannot meet the needs of mobile printing. There is also need on power supply plug to provide electricity for the operation of the 3D printer.

The bulky and the need to detach 3D printer parts in order to travel from one place to another cause inconvenience to the user and decrease the accuracy of 3D printing due to the wear and tear of the 3D printer parts. In home life, there is a need of 3D printer that can provide solution where the 3D printer is convenient to carry and transport and provide services in anywhere and anytime.

In the other hand, bulky and heavy 3D printer will be hard for any medical – related workers to be carry around to print medical modelling at anywhere or anytime. It will be more convenience for the printer to be space saving and high mobility for them to carry it around.

1.4 Aim and Objectives

i. Design a 3D printer which optimize the space usage with improved mobility.

ii. Build a 3D printer prototype which is convenient to carry and transport.

1.5 Scope and Limitation of the Study

i. Trade off the accuracy or resolution.

- The foldable structure affect the stability of the structure and the resolution during printing.
- The usage of acrylic parts as the support will cause bending of the structure.

ii. Precision and limitation of 3D printing under different environment.

- The stability of the 3D printer is lesser when it is placed at rough surface.
- The structure of the 3D printer limit the motion of the moving axis.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Portability in digital fabrications increases the flexibility in space usage and thus enable site-specific fabrication. For foldable 3D printer design, there are few usual methods which are Z-axis folding (single shaft support and double shaft support) and Y-axis folding. The fixed axis to be folded is Z-axis which consumed the largest space usage.

First, foldable Z-axis with moving XY stage. The overall architecture was the built surface is moving rather than the extruder head. Two-axis shaft folding involved gantry type of Z-axis in the 3D printer. Normally, the 3D printer had a moving Y-axis built plate with fixing Z-axis with movable extruder head on X-axis rod. There is also a design with extra folding part which is the built plate of 3D printer. In order to obtain an efficient and accurate algorithm, a review on the methods proposed by other researchers has been done.

The literatures reviewed on the overview design of folding portable 3D printers.

2.2 Literature Review

There are several portable 3D printer design approaches, which different in term of storage and folding axis. Few approaches that discussed in this report are portable 3D printer with foldable Z-axis with single shaft support and double shaft support and foldable Y-axis.

2.3 Portable 3D Printer

2.3.1 Foldable Z axis with single shaft support

Peek and Moyer (2017) proposed and produced multi-purpose portable digital fabrication machine - Popfab, which able to perform 3D printing, milling and leather-crafting. The portability of machine was achieved with a XY stage built into base of briefcase, together with changeable mounted toolhead on cantilevered arm which was held by a foldable Z-axis. Two-axis folding stage was not utilised in the design to avoid inconstant mechanical alignment and thus reduce the user’s setup time. Besides, the design is limited to one foldable axis that decreased the complexity of the folding mechanism. Z-axis was fixed at popped-up position with two thumbscrew. The preferred model of toolhead was then fixed by using thumbscrew on the kinematic mount.

CoreXY reference mechanism was used for XY stage. The motors were fixed at the front corners of the base and belts were moved by the motor in direction A (red) and direction B (blue) as shown in Figure 2.1. Additional crossing applied in the timing belt and H-bot kinematics also provided low inertia that suitable for 3D printing and high spatial efficiency. The only constraints in this project was moving XY stage where it would cause unstable printing for tall prints due to the inertia of the moving stage and rapid movement of shaking base. However, as the build volume of Popfab is small, the factor is not considered as a concern.

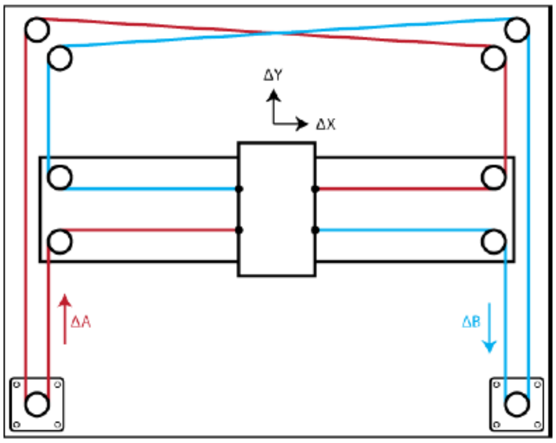

Figure 2.1: CoreXY reference mechanism. (Peek and Moyer, 2017)

Pang et al. (2016) proposed a design of foldable 3D printer that similar to Peek and Moyer's idea. The differences between both designs are the locking mechanism for Z-axis to the base and the movable part for the 3D printer. The 3D printer was enclosed inside a suitcase together with the support frame for the printing filament. In this design, the X-axis was enclosed inside the inner box of the casing that held the base assembly of 3D printer. The Z-axis connecting members consisted of two parts with first rotation connecting member with plug and second rotation connecting member with jack as shown in Figure 2.2. There was a pressing member on top of first rotating locking member. When it was pressed to a certain contact pressure, the plug will be inserted into the jack. When certain pressure was exerted onto the pressing member again, elastic restoring force recovered and enabled second rotating locking member separated from the first rotating locking member. Besides, the moveable axes in this printer were Z-axis with Y-axis. The movement of X-axis belt and Z-axis belt will drove the movement of the shaft for Z-axis and Y-axis respectively. The bed in this printer was not moveable which decreased the variation on printing due to the movement of bed.

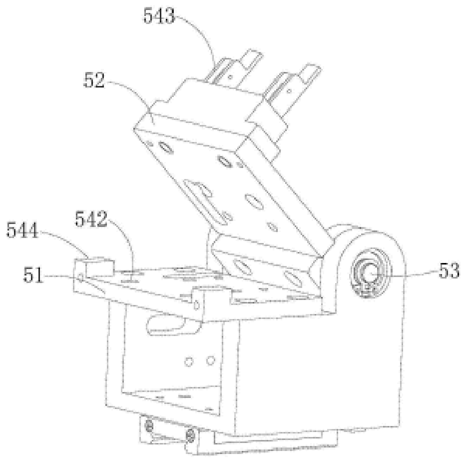

Figure 2.2: Structure of the connecting members for Z-axis. (Pang et al., 2016)

Besides, Liu (2015) proposed a design of portable 3D printer with foldable X-axis, Y-axis and built plate with single Z-axis shaft. The built plate was able to be folded in parallel with Z-axis direction with rotatable liner optical axis that connected with the built plate. 90° positioning rotary connecter that is connected between Z mobile platforms with X-axis enable rotation of X-axis until parallel with Z axis. The mechanism was duplicated in the connection between X-axis and Y-axis. Thus, X, Y and Z-axis able to rotate until form parallel with each other. The volume occupied by the commencement of each axis and heated bed had reduced to achieve the purpose of space saving. The space saving of this 3D printer is more efficient as compared to the other printers. It is also considered as small volume printers that have lesser requirements on printing environment, thus able to carry 3D printing anywhere.

2.3.2 Foldable Z axis with Dual Shaft Support

Wu (2015) proposed a 3D printer that disclosed by the utility model is convenient to fold and receive, simple in structure, and easy to construct. The 3D printer was a gantry type printer that consisted of dual Z-axis shaft and X-axis shaft that sliding along Z-axis. The base plate that attached to Z-axis was hinged at a hinge axis, comprising a flat head bolt. It was fast in folding rate and easy to operate. During the folding state of the printer, the X-axis with extruder head will be moved to the upper end of the Z-axis slide as the height of the gantry stand is greater than the distance to the front end of the base plate folding part. The gantry support lowered the centre of gravity, thus decreased the possibility of the shaking for the printer that improved the printing accuracy. As the movable members increased, the possibility of the number of mutual wear between moving parts when folding frequently will be increased that affected its accuracy relative to the Y-axis section.

Besides, Liu et al. (2017) proposed another design of casing box-type structure 3D printer which is easy in transportation and provides effective protection that improve the lifespan of the body. Before the operation of 3D printer, gantry Z-axis shaft was applied force and then dragged to the upper right. Then, the brackets were opened until Z-axis vertical upright to 90°. At the same time, the base plate and the base stopper of Z-axis contacted each other that limited Z-axis from moving towards right. Positioning rod was used to fix the axis in place through positioning holes and connection holes and the printer was ready for usage. The completion of deformation folding could be done by manually pushing Z-axis shaft after pulling the positioning rod out of positioning and connection holes. Thus, the Z-axis shafts were falling onto the positioning block. The support parts at Z-axis that formed 90° angle with the base assembly of the printer effectively distributed the weight of the column evenly, thus reducing the overall body weight as shown in Figure 2.3.

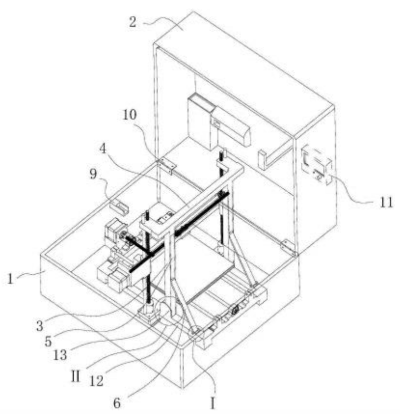

Figure 2.3: The schematic view of the foldable 3D printer. (Liu et al., 2017)

According to Liu et al. (2014), a portable 3D printer included a base assembly and a moveable assembly was proposed and invented. The 3D printer was divided into two portions which are base assembly and a moveable assembly body connected by using four bar linkage hinged with the use of auxiliary spring stopper as shown in Figure 2.4. The linkages consisted of long link and short link with the same horizontal position of pivot point. The moveable assembly is adjusted to the standing state which perpendicular to the base assembly by adjusting the position of the long link and short link. The spring stopper was tighten to fix the position of the short link and the spring between the long link and the spring stopper was lengthen to fix the four bar linkage. After used, the X-axis with extruder head was slide to the lower part of the Z-axis gantry column to avoid the collision of the built plate with the head during folding. The column was then folded down along with the adjustment of the links.

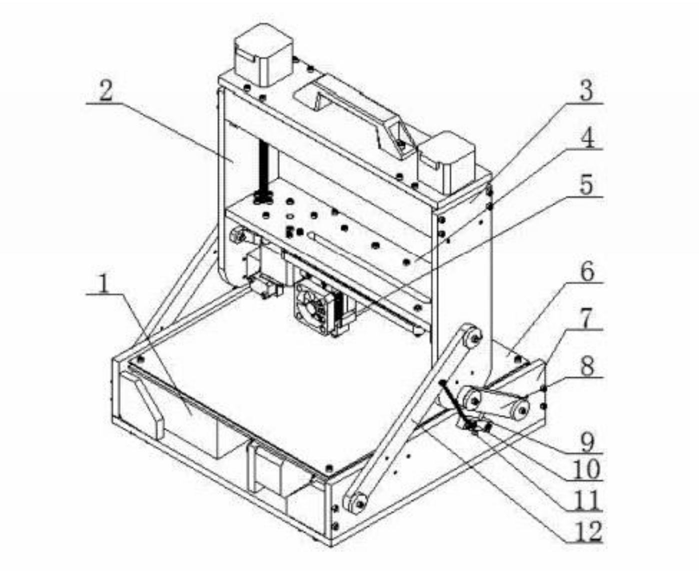

Figure 2.4: The structural view of the 3D printer. (Liu et al., 2014)

According to Xie (2017) had proposed a 3D printer with a folding part at the lower end of the Z-axis and the rotation axis was fixed connected to the mounting block that slide along Y-axis. Built plate in this printer was stationary to decrease the movement of the bed that bring poor impact to printing. Both side of Z-axis mounting blocks were connected to Y-axis fixed plate with a rotary lock block. Z-axis mounting block was rotated upward and fixed to Y-axis fixed plate with second locking bolt. In order to achieve folding mechanism, X-axis will be moved to the top of Z-axis. The rotary mounting block rotated downward along the rotating shaft. There was a fold buckle with "U" shaped slot at the base plate to fix Z-axis during folding. Thus, it will avoid crashing tamper printer and maintain good stability for the folded state of the printing.

Zhang (2017) also proposed a design where the 3D printer has foldable Z-axis which includes a base assembly, a column assembly and a support frame as shown in Figure 2.5. The base assembly is mainly consists of Y-axis guide rail, heated bed, power supply and LCD control panel. Column assembly include X-axis guide rail, Z-axis guide rail and extruder head. The base end of the column was connected with the base chain connection and the upper end of the column was connected with the support frame. The column could be folded until vertical during the use of 3D printer. First, the locking screws are being loosen and pull the support bracket until the column rotated until vertical. Then, the column will slide along the moving groove of support frame. The locking screw is then tightened to enable the 3D printing operation. Extruder moved in X and Z-axis whereas heated bed moved in Y-axis during the printing. When the column was folded away, the locking screws were released and the column will slowly slid down until horizontal position with the damping action of the spring. After that, the locking screws will be tightened again. The support frame was designed with a window that functions to pull the support frame and avoid the collision of the extruder head during printing.

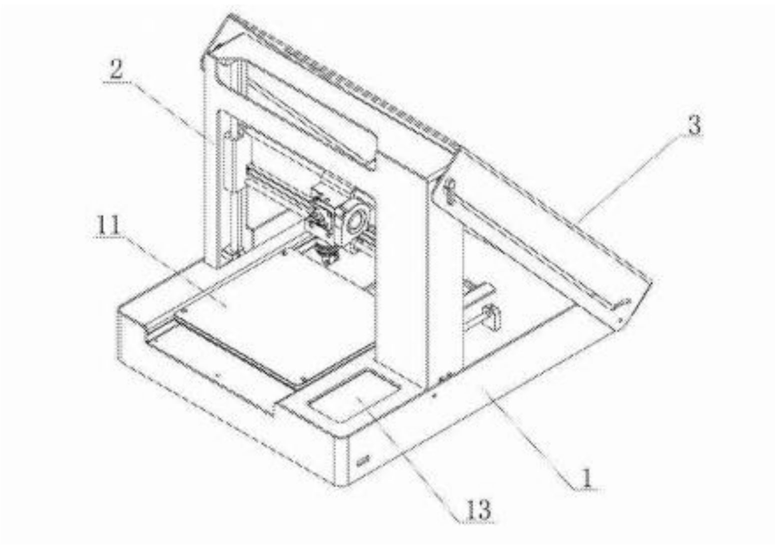

Figure 2.5: The structure of the 3D printer during upstanding state. (Zhang, 2017)

He et.al (2016) proposed one mechanism where the movement of the foldable axis is through slide rails on each axis to help with the movement of each axis. The design is similar to the design that proposed by Zhang (2017) with the different in overall casing of the printer. Besides, there was an extendable cover for the opening on the support frame that prevents the collision during the X direction movement of extruder head with the support frame. The support frame was pulled up and both the Z-axis shafts were slid long until the maximum height whereas the bottom part of the Z-axis shafts will be rotated 90° upward and the 3D printer was ready to print the object. The process was vice versa when the 3D printer was prepared to fold back.

Furthermore, Emmanuel had developed and researched on portable 3D printer which is called FoldaRap and in year 2017, he developed a folding mechanism which apply the concept of the concept of ball plunger spring. The concept is originated from the locking mechanism of the luggage handle and this has reduce the time taken to fold the Z-axis gantry from several minutes to within 10 seconds. The Y-axis is movable by using belt-drive and mounting of sliders at both side of the aluminium profiles. The X-axis is moved by using 3D printer which is driven by gear.

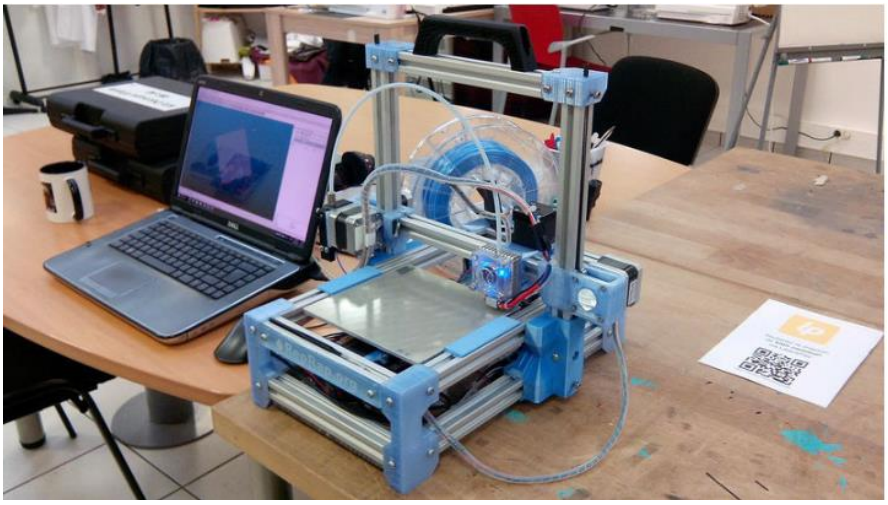

Figure 2.6: The structure of the FoldaRap. (Emmanuel, 2017)

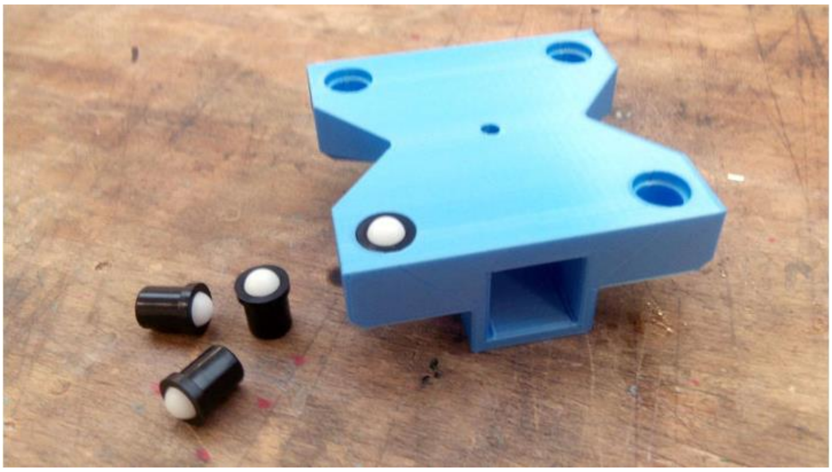

Figure 2.7: The 3D printed part of Z-axis foldable support. (Emmanuel, 2017)

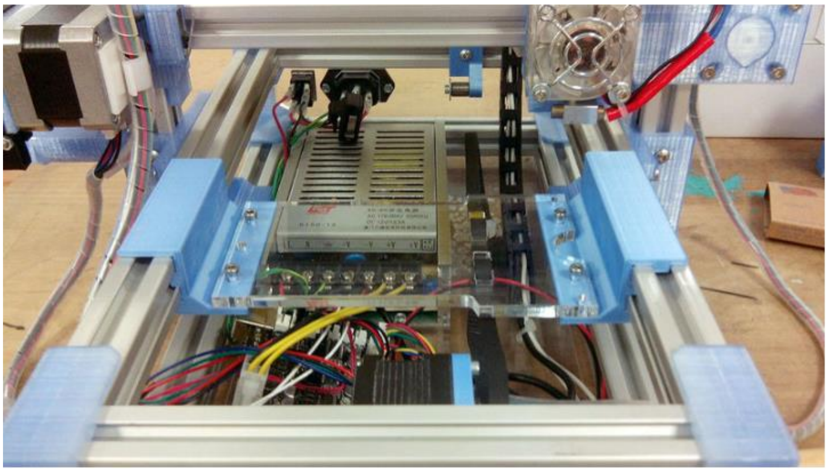

Figure 2.8: The printed slider for Y-axis. (Emmanuel, 2017)

2.3.3 Foldable Y axis

Zou and Gan (2016) proposed a portable folded cascade 3D printer, including box, pull rod, toolbox, work bin, universal wheel which ease the accessibility of movement as shown in Figure 2.9. The Y-axis rotatable disposed on the housing. When the printing is needed, the rotary wheels, caster rod, tool box were removed and the first bin and second bin that held PLA filament are moved along the slide rails on the opposite sides. Then, the Y-axis will be lowered down together with the base plate by pulling the handle at the base plate. The condition and steps to store 3D printer is by pushed the handle back to the original position and store the rotary wheels, caster rod and tool box back when the 3D printer is not used. This design has storage box for 3D printing filament and extruder that enable dual colour printing.

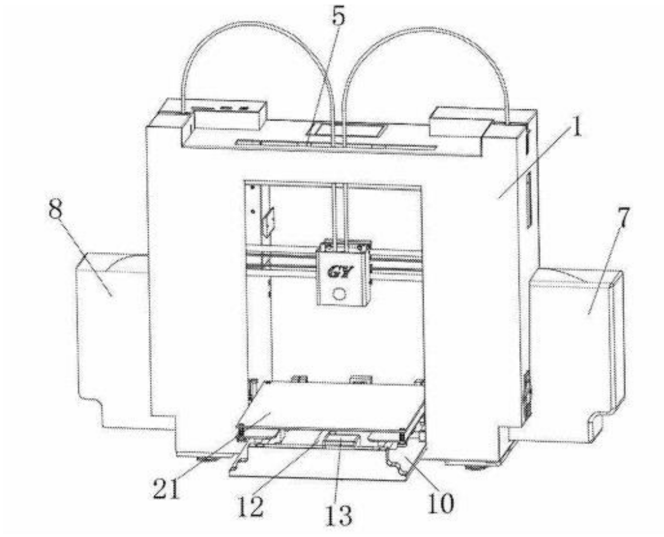

Figure 2.9: Front view of portable 3D printer after expanded (Zou and Gan, 2016)

2.4 Summary

The results of all compared articles are summarised in the table below.

Table 2.1: Results of compared articles.

Reference	**Advantages**	**Disadvantages**
Foldable Z axis with single shaft support		
Peek and Moyer (2017)	1. One foldable axis - Decrease complexity of folding mechanism -Reduce setup time -Avoid inconstant mechanical alignment	1. Moving XY stage -Unstable printing for tall prints
Pang et al. (2016)	1. Unmoveable built plate -More stable printing 2. Lesser setup time due to locking mechanism 3. Space saving -Filament storage inside casing	1. Spring locking mechanism -Rapid replacement of spring due to wear and tear
Liu (2015)	1. Space saving	1.Rapid foldable parts

		-Higher rate of wear and tear 2.Unstable printing
Foldable Z axis with dual shaft support		
Wu (2015)	1. Low centre of gravity - Stable printing	1. Higher number of moveable parts 2. High possibility of collision of extruder head 3. Unsymmetrical folding of Z-axis gantry with base assembly
Liu et al. (2017)	1.Casing type foldable 3D printer -Effective protection	1. Larger space consumed 2. Higher rate of wear and tear
Xie (2017)	1.Slotting parts for Z-axis shaft - Good stability for folding state of 3D printer.	1. Higher rate of wear and tear at rotating block.
Liu et al. (2014)	1.More stable structure 2. Smaller, space saving	1. Complex locking mechanism 2. Low stability -Z-axis stepper motor on top of gantry column
Zhang (2017)	1. Simple locking mechanism 2. Compact design	1. Smaller printing volume 2. High possibility of rapid replacement for locking screw
He et.al (2016)	1. Fully covered casing for folding stage	1.Unstable printing - No locking mechanism of 3D printer
Emmanuel (2017)	1.Reduce the setup time for the locking mechanism	1) Nonadjustable bed 2) Smaller printing volume

	2.Space saving during non-usage period 3. Optimize the mobility	
Foldable Y axis		
Zou and Gan (2016)	1. Easy to be carried 2. Dual colour printing 3. Compact design	1. Longer setup time 2.Higher number of moveable parts - High rate of wear and tear

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

After reviewing other researches, the method of choice is 3D printer with Z-axis folding with double shaft support by applying the concept of ball plunger spring. The design will be demonstrated in Solidwork for prototyping purpose and the software that used to fine-tune the Marlin firmware by using Arduino IDE.

According to the literature review, it is noted that each of the foldable types of 3D printer has different advantages and disadvantages. Therefore, by implementing the idea from Emmanuel (2017) on the mechanism of the foldable part, the first prototype design of the portable 3D printer is drafted out. The portable 3D printer is a Cartesian FDM 3D printer and has a foldable dual Z-axis gantry. The printer has printing volume of 90 mm x 90 mm x 90 mm and the volume of the 3D printer does not exceed 400 mm x 400 mm x 400 mm. The weight of the portable 3D printer will not exceed 5 kg. The firmware of the portable 3D printer will use Marlin x2.0 and the printer is controlled and printed by using Pronterface. The portable 3D printer is powered by using power supply unit of 12 V, 20 A.

3.2 Project task and activities

The development of portable 3D printer will required some stages to complete the initial stage of research. Figure 3.1 shows the procedure on development of portable 3D printer before the prototyping of the actual model.

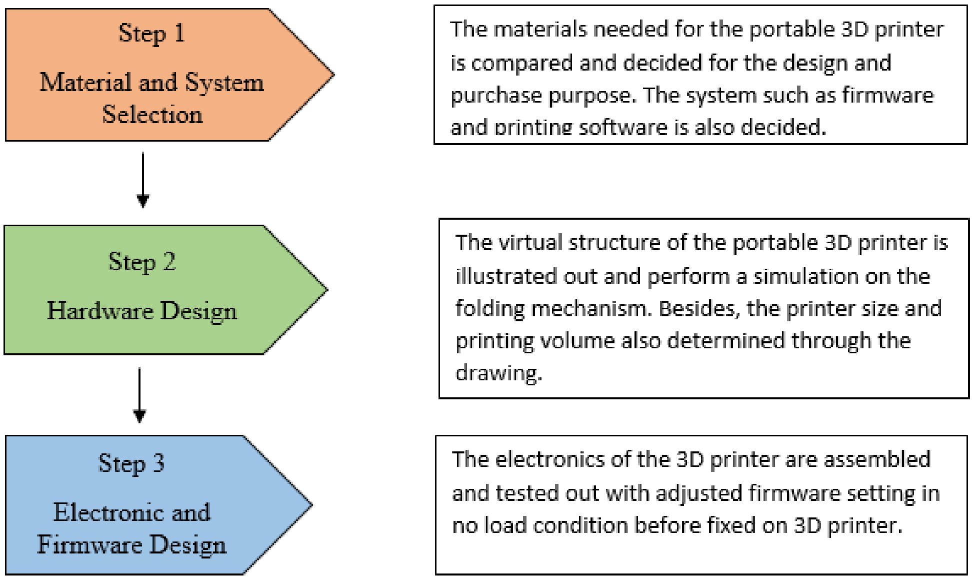

Figure 3.1: The overall flowchart for methodology.

3.2.1 Material and System Selection

3.2.1.1 Control Board

The control board is made up of two components: a circuit board and a microcontroller and can be either separate units attached together or combined into one board. It is used to distribute power and control all other components listed below. There are many different type of controls boards found in the market with different features, cost, capabilities and reliability. Table 3.1 summarize the characteristics of different type of control board.

Table 3.1: Summarization of Features for Control Board (Gorman et al, 2017).

Board Name	Features and Capabilities	Availability of Single Unit	Cost (RM)

RAMPS 1.4	-Ability to be modified -Provide massive online support -Serviceable -Maximum 5 stepper motors	No (involve an Arduino Mega Microcontroller)	54.30 (Lazada)
MKS v1.4	-4 layer circuit board -12v to 24 power input -Great heat dissipation -Maximum 5 stepper motors	Yes	81.00 (Lazada)
RUMBA	-Require high power stepper drivers (DRV8825) -Consists of blown fuse indicator -Include MosFet drivers for cooler operating temperatures -12v to 24v power input -Maximum 5 stepper motors	No (Require a BeagleBone Black microcontroller)	255.00 (Lazada)
Megatronics	-4 layer circuit board -4 thermistors are supported -6 stepper drivers are supported -Maximum 5 stepper motors	Yes	279.40 (Lazada)
Replicape	-Require high power stepper drivers (DRV8825) -6 stepper drivers are supported.	Yes	305.20 (Lazada)

In this project, the control board selected is RAMPS 1.4. It provides the most reasonable price compared to the other board based on the price range exhibit in Lazada platform. Besides, only four stepper motors are used in this project. Therefore, RAMPS v1.4 with maximum 5 stepper motors allow to be used is chosen as the suitable control board. Besides, it uses a microcontroller and shield setup that makes it more serviceable. Either one of the board is failed, we will not have to replace the entire unit.

3.2.1.2 Firmware

The firmware on a 3D printer is the programming within the control board. Firmware is used to interpret G-code commands and control the movement of the stepper motors through the commands. G-code commands will be uploaded to the control board where firmware will read the code and send signals to the stepper motor drivers. The print head and relative parts will be able to move based on the commands to finish the printing. Table 3.2 shows the types of firmware used in 3D printers.

Table 3.2: Summarizations for Types of Firmware used in 3D Printers (Gorman et al, 2017).

Firmware Name	Features	Compatible Controller
Marlin	High step rate, full endstop support, SD card and LCD support, temperature oversampling, Temperature setpointing (AutoTemp)	-Ramps -RUMBA -Megatronics
Sprinter	SD card reader, stepper extruder, movement and extruder speed contrel, heated build platform	-RAMPS
Teacup	SD card reader, unlimited number of heaters, temperature sensors, moves steppers smoothly.	-Most ATmega boards -8 to 64-bit controllers
Sailfish	High step rate, full endstop support, SD card and LCD support, PID based temperature control, interrupt based temperature and movement protection.	-Gen 3, Gen 4 -MightyBoard
Repetier	RAMP acceleration support, PID control for extruder temperature, SD card and LCD support,	-Ramps -RADDS -Printrboard

	continuous temperature monitoring	

The selection of the firmware is based on the amount of support available, the required features and the compatibility with the selected control board. In this project, the Marlin firmware is used due to its extensive support and popularity.

3.2.1.3 Printing Software

The printing software selected in this project is Pronterface. Pronterface control program that works from a computer. The programs create printer instructions in G-code commands to create the models. After that, the program interpret the G-code to send instructions to the stepper motor and control the movement of 3D printer.

3.2.1.4 Stepper Motor

NEMA 17 stepper motors are used in this project for axis movement and filament extrusion. The motor is designed for the use in 3D printer. The consistency, good reliability and low cost compared to the other stepper motor also lead to the selection of NEMA 17 as the stepper motor. Between the different types of NEMA 17 stepper motor, NEMA 17HS3410-S is chosen to provide axis movement for the portable 3D printer. The datasheet of NEMA 17 HS3410-S is provided in Appendix A.

3.2.1.5 X,Y and Z-Axis End stops

End stops in 3D printer are switches that trigger before an axis reaches its limit that prevent the printer from going beyond the frame for 3D printer. End stops are used as the reference position. When the movement of each axis which is X, Y and Z axis reaches to the end stop, it will be the home for the 3D printer. The limit switch is normally close (NC) and turn off the current when it is triggered.

There are many types of sensing which are mechanically, magnetically and optically. Table 3.3 summarize the features for each type of end stop.

Table 3.3 Summarization of features for different types of end stop.

Type of end stop	Features	Weakness
Mechanical end stop - determine distance in between through **the physical collision of two objects** (Meijer, 2014)	-High accuracy with high degree of repeatability -Easily purchase (Lower price; RM 2.00 (Lazada)	-Will physical worn out -High maintenance needed
Optical end stop - determine distance in between through **path of emitted light**	-Using infrared or other forms of electromagnetic radiation -Not using moving parts -Operate longer than mechanical counterparts (Low maintenance needed)	-Less accuracy and difficult to be configured - High cost; RM43.90 (Lazada)
Magnetic end stop (Half Effect Switches) -Measure **the intensity of the nearby magnetic field** when it exceed certain polarity	-Highly precise and repeatable -Extremely resistant to noise and environmental condition	-Highest cost ; RM52.50 (Lazada) -Difficult to be triggered by hand during troubleshooting

Based on the features above, mechanical end stop is selected due to the lower cost and high accuracy accompany with higher degree of repeatability.

3.2.1.6 Type of Filament Used for 3D Printer

The properties of thermoplastics is taken into consideration in comparison of the material used in 3D printing. Two of materials, PLA and ABS are used in this project.

Table 3.4: Properties of 3D filaments in 3D Printing (Akaslan et al., 2017).

Properties	PLA	ABS	PC	Nylon

Colour	H+			H+
Environment Friendly	H+			L-
Harmful Fumes	L-	H+		
Print Speed	H+			
Resolution	H+			
Strength		H+	H+	
Flexibility	L-	M		
Heat Resistance	L-	H+	H+	
Melting point		H+		
Easy Extrusion		H+		
Brittleness	M+			
Cooling Speed	L-			
Durability			H	

Most of the 3D printing in this project use ABS as material such as base corner support and hotend mounting plate due to its high strength properties. From comparison in Table 3.4, ABS and PC have higher strength in material as compared to the other material, which made it more unbreakable. The high heat resistance and melting point of ABS also enable it to withstand the higher heated part in portable 3D printer such as hotend mounting. It is easier to be extruded which cost less maintenance on the used 3D printer. However, extra care need to be given as harmful gases will released during the 3D printing. Therefore, a cover is assembled of the printing 3D printer with the fan behind to remove the harmful gases out of the room.

3.2.2 Conceptual Design

3.2.2.1 Z-axis Folding with Double Shaft Support

The portable 3D printer is a gantry type printer where the Z-axis is formed by a gantry shape with column and beam where X-axis shaft is able to slide in Z. The built plate of the 3D printer is movable in Y direction. Under foldable Z-axis, there are many locking mechanisms proposed, which are different in mechanisms utilised, the folding direction, and the support to enforce the stability of the folding parts. The design was drafted by referring to the design found in Emmanuel in year 2017, the foldable part uses concept of ball plunger spring that is implemented in the concept of locking mechanism of luggage bag.

3.2.3 Detail Design

3.2.3.1 Hardware Design

The screenshots of overall design of the prototype for the portable 3D printer are shown in Figure 3.2 (upright position) and Figure 3.3 (folding position). The base assembly of the 3D printer consists of Y-axis rail, built plate and foldable part. The support assembly consists of Z-axis rail supports Z-axis stepper motor, Bowden tube assembly and X-axis rail with extruder assembly.

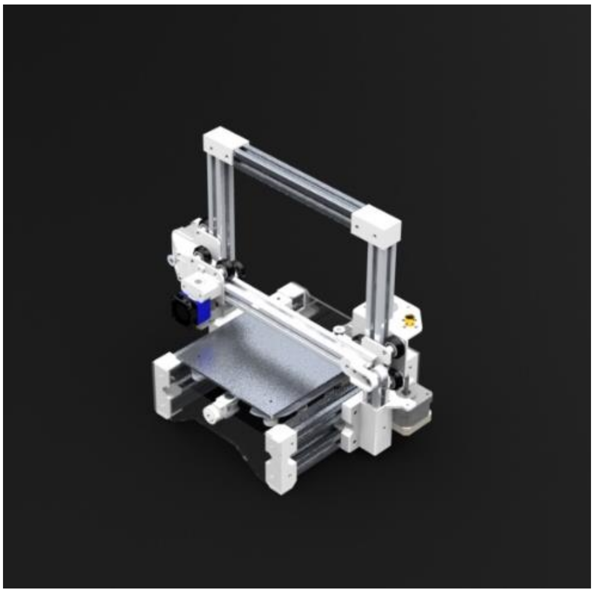

Figure 3.2: Portable 3D printing during upright position.

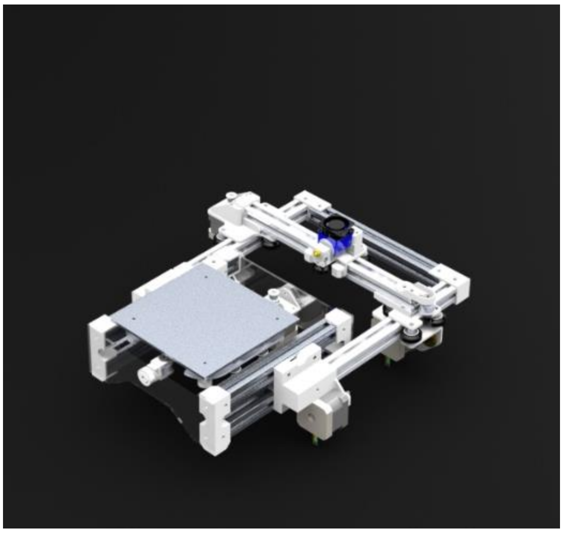

Figure 3.3: Portable 3D printer during folding position.

3.2.3.1.1 Structure of the Portable 3D Printer

The structure design of the 3D printer mainly consists of aluminium profile, 3D printed part and acrylic sheet. The rigidity and strength of the 3D printer is the most critical specification of the frame as it will directly affects the 3D printing. 20 mm x 20 mm aluminium profiles are used as the one of the frame material because of the properties of lightweight. The material and the extrusions geometry of the profile allow the printer to remain rigid over a distances. The base of the 3D printer is designed as in Figure 3.4.

Figure 3.4: Base assembly of the 3D Printer.

The 3D printed parts are located at the four corners of the base assembly. Each of the corner is extruded 27 mm from the ground to avoid the collision of the foldable part during unfold stage. Besides, a cast acrylic base plate is attached at the bottom of the base assembly and connected to the lower part of the aluminium profile and the 3D printed corner by M4 bolt. This will increase the rigidity as base plate avoid the shearing of the base assembly. This concept goes as well to the front and back acrylic plate. The front plate and the back plate also serve as the counting for Y belt tensioner and Y Stepper Motor mounting and is attached to aluminium profile by using M6 bolts. The space between two 20 mm x 20 mm aluminium profiles are attached with the folding support of the foldable part.

The Z axis of the 3D printer is in gantry and made up of aluminium profile and 3D printed parts. It is also connected to the foldable part as the Z-axis will become be unfold to achieve the optimization of the space usage during non-usage period of the 3D printer. Aluminium profile 20 mm x 20 mm L-brackets are attached at top of the gantry to maintain the 90° alignment. The Z-axis gantry during printing period and non-printing period is as shown in Figure 3.5 and Figure 3.6.

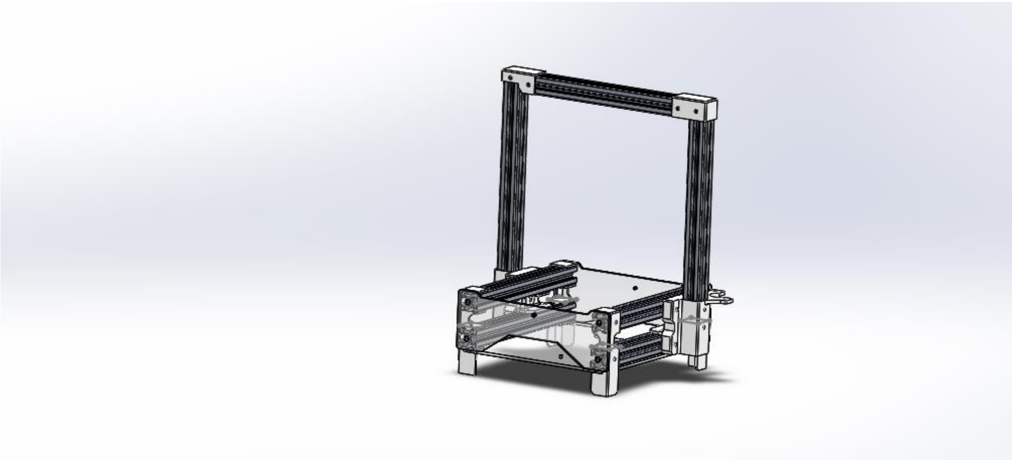

Figure 3.5: 3D printer during printing period.

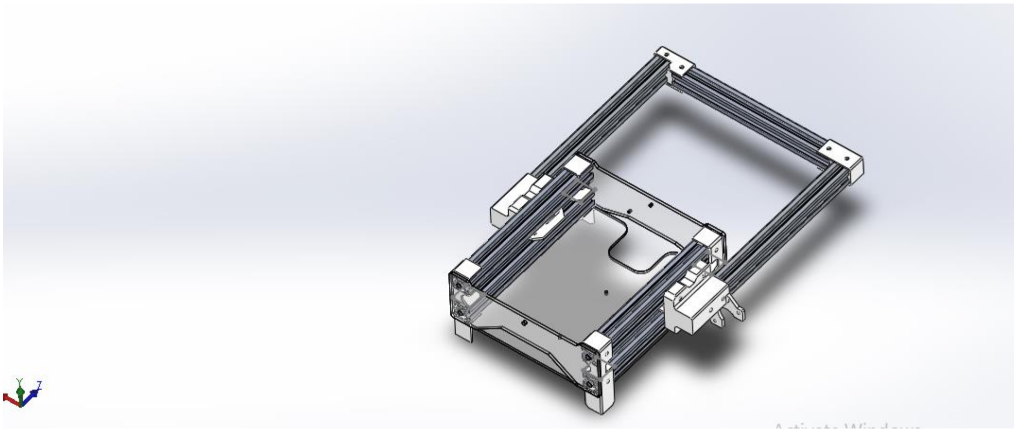

Figure 3.6: 3D printer during non-usage period.

3.2.3.1.2 Foldable Assembly

The folding mechanism of the 3D printer involved the foldable part of Z-axis gantry. When the use of 3D printer, Z-axis is pulled up and rotated 90 degree along the axis of foldable support which implemented the design idea from Emmanuel (2017) by using ball plunger spring for the folding mechanism. The ball plunger spring consists of a cylinder in which a sphere is pushed outside by a spring. It is normally apply in mechanisms of the folding handle of a luggage at the locking position when it is extended.

Figure 3.7: The mechanism of ball plunger spring (Emmanuel, 2017).

Figure 3.7 displays the mechanism of ball plunger spring. Four of the ball plunger springs will be inserted into four corners of the main folding part of foldable part. The distance of two insertion of ball plunger spring is set to 38 mm length in Y and 37 m in X so the locking of the ball plunger can be fitted in between the aluminium profile during fold and unfold stage.

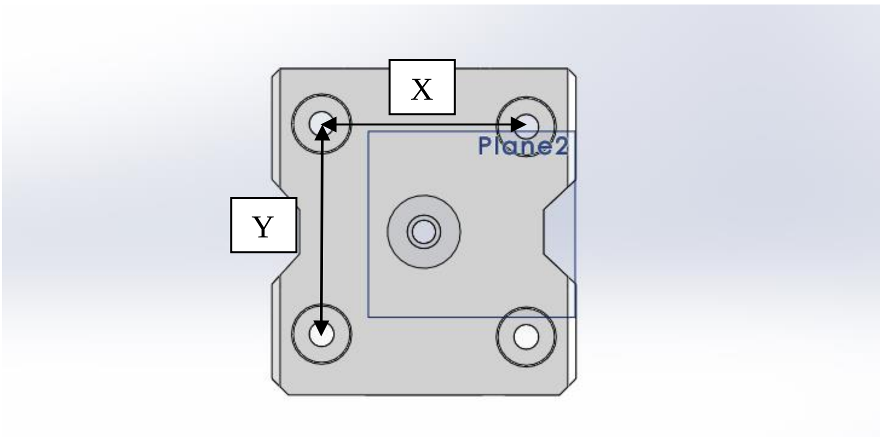

Figure 3.8: The back view of the main folding part.

The folding support and the main folding part are attached together by using M4 bolt and M4 Lock Nut to secure both of the parts in place and enable rotating mechanism at the same time. The distance between the folding support and the end of the corner is separated in 40 mm distance to maximize the printable size of the 3D printer.

3.2.3.1.3 X-Axis and Hotend Assembly

The design of X-axis assembly is designed such as the X-axis assembly in Creality Ender-3 with some modification. Figure 3.9 shows the Solidwork model of the mechanism of lateral movement. Left hand side of the X-axis assembly consists of X-axis motor mounting and X-axis limit switch while extruder stepper motor mounting, X-axis belt tensioner and brass lead screw nut are located at the right hand side.

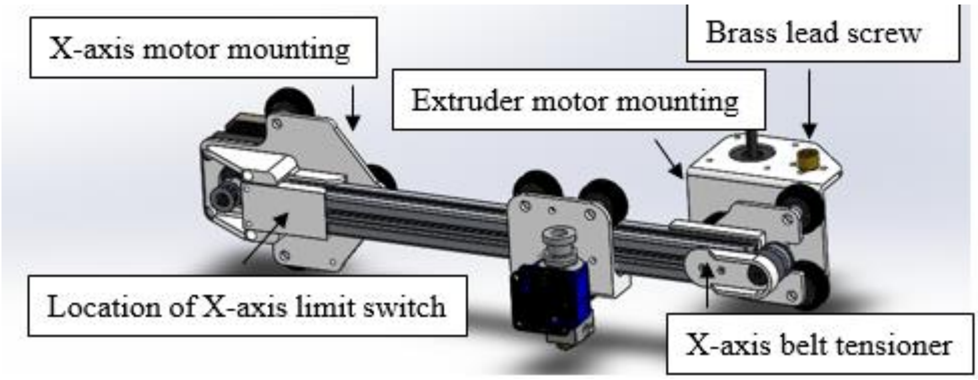

Figure 3.9: X-axis assembly of 3D Printer.

The rotary motion from the X-axis stepper motor is converted into linear sliding motion. This liner motion is transferred by GT2 pulley and flanged bearing connection. 250 mm aluminium profile serve as a guidance rail for extruder hotend assembly to enable and balance the movement of printing in X direction. . The aluminium profile is fixed at both right and left hand 3D printed part by using M5 bolt and T-nut.

The extruder hotend mounting is mounted onto the carriage. The extruder hotend assembly slides in the horizontal direction over aluminium profile using V-slot wheel bearings. The carriage is fixed to the lower timing belt of the loop. When the motor rotates in clockwise direction, the assembly will move from left to right and vice versa for anticlockwise direction.

3.2.3.1.4 Y-Axis Assembly

The printing bed is connected in Y-axis assembly to enable the movement in y-axis. The movement of the printing bed is driven by the timing belt through the rotary motion of Y-axis motor. V-slot bearings are mounted at the four corner of the printing bed support and are fixed at the both inner side of the aluminium profile. Figure 3.10 shows the bottom view of the 3D printer with v-slot bearing mounting. Eccentric nuts are fixed at two holes in one side of the plate support to hold the printing bed in position.

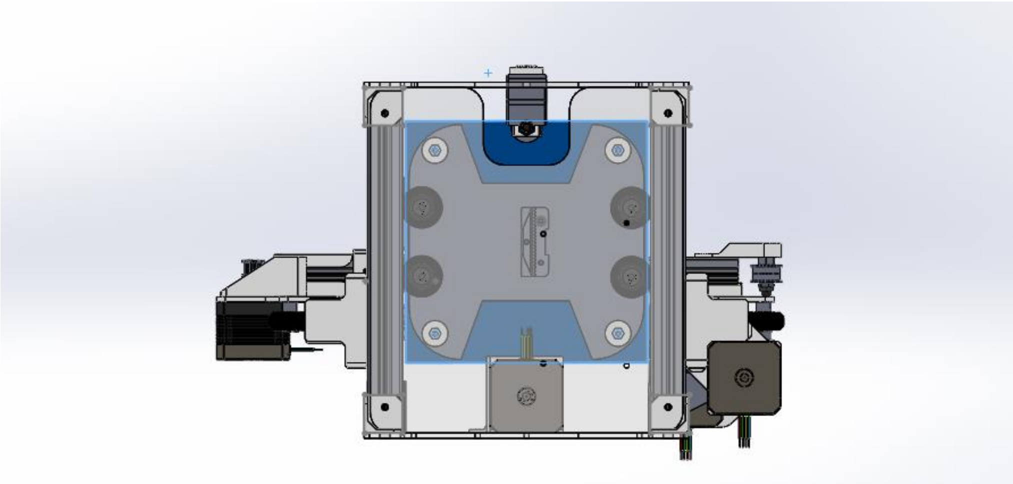

Figure 3.10: Bottom view of the 3D Printer.

The belt grabber is fixed under the printing bed support to hold the GT2 belt at the printing bed part. The Y-axis stepper motor is located at the back plate of the 3D printer and the Y-axis belt tensioner is at the front plate of the 3D printer. The Y-axis belt tensioner is designed to adjust the tightness of the belt to avoid the imperfect printing. The clockwise turning of the knob for Y-axis belt tensioner will pull the belt to tighten and loosen during anticlockwise turning. Figure 3.11 shows the assembly of the Y-axis belt tensioner.

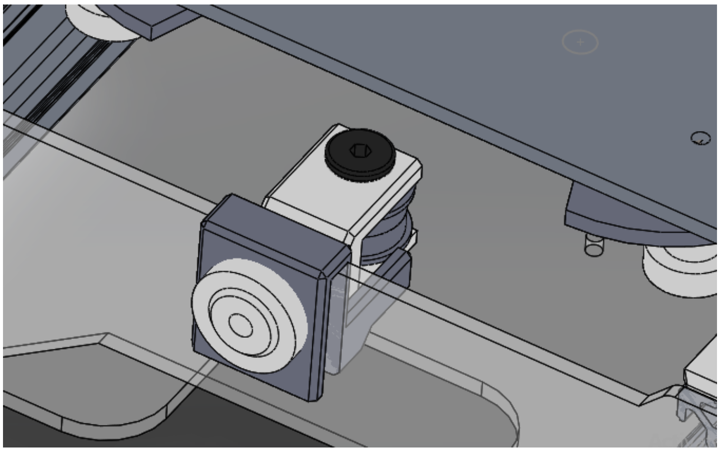

Figure 3.11: Y-axis Belt Tensioner.

3.2.3.1.5 Z-Axis Assembly

The Z-axis assembly is as shown in 3.2.3.1.1 part where the Z-axis consists of aluminium profiles and 3D printed parts. The vertical 250 mm aluminium profiles are fixed at main folding parts at both side. Besides, horizontal 200 mm aluminium profile connects to the vertical part of aluminium profiles with 3D printed parts and aluminium profile L-bracket.

The whole X-axis assembly move in vertical direction, which is Z direction through lead screw drive. The mounting of the brass lead screw nut is located at the right back plate of X-axis assembly. There is only one Z-axis stepper motor and the motor is mounted at the right hand side of the main folding part. The torque produced by the motor is transmitted to the lead screws by using shaft coupler and brass lead screw nut. When the motor rotates in clockwise direction, the X-axis assembly will move upward and vice versa in anticlockwise direction. Extruder feeder and extruder stepper motor are fixed at the right hand side assembly.

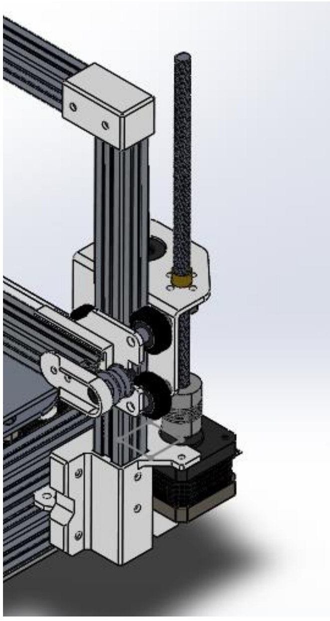

Figure 3.12: Right hand side Z-axis assembly.

3.2.3.2 Electronic Design

In this project, RAMPS 1.4 is used as control board together with Arduino Mega 2560 board and A4988 Stepper Motor Driver. It can control up to 5 stepper motors with 1/16 stepping precision. Interface of RAMPS 1.4 are available for hotend, heatbed, fan, 12V power supply, three thermistors and three end stoppers. Table 3.5 shows the current electronics used in the project.

Table 3.5: The current electronics for Portable 3D Printer.

Electronics	Amount
Nema 17HS3401-S	4 units
RAMPS 1.4	1 unit
Arduino Mega 2560	1 unit
Micro Limit Switch	3 units
E3D J6 Hotend Extruder with fan	1 unit
A4988 Stepper Motor Driver	4 units

The following procedures were carried out to complete the RAMPS 1.4 assembly:

1) Jumpers were inserted to control the precision of the motor movement to 1/16 micro stepping.
2)

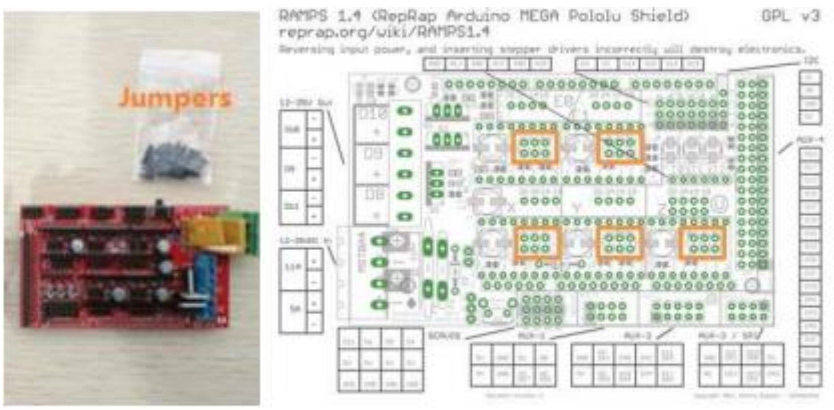

Figure 3.13: Connection of Jumpers on RAMPS 1.4 shield (3D Printer Czar, n.d.).

3) RAMPS 1.4 shield was stacked on top of Arduino Mega 2560 board where the RAMPS 1.4 shields “D8 D9 D10” area is on top of Arduino Mega 2560’s USB side.

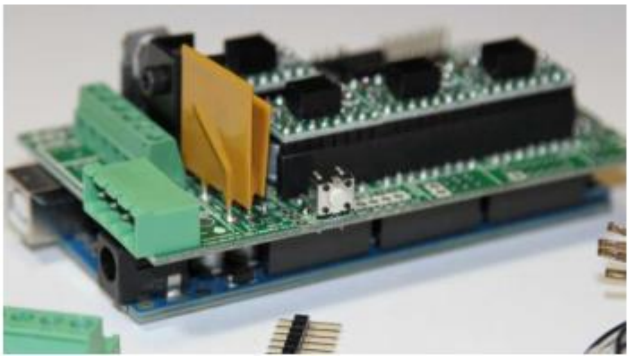

Figure 3.14: Connection of RAMPS 1.4 shield and Arduino Mega 2560 (3D Printer Czar, n.d.).

4) The A4988 stepper motor drivers were stacked on top of RAMPS 1.4 shield with the potentiometer of driver face away from the "D10 D9 D8" side of shield.

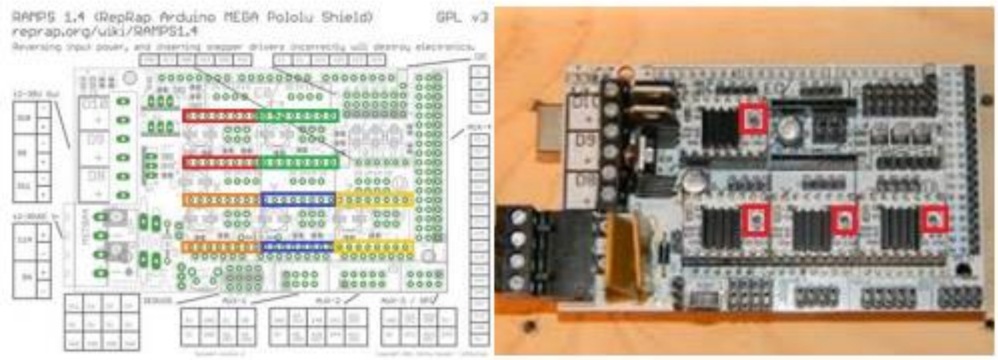

Figure 3.15: Connection of A4988 stepper motor driver to RAMPS 1.4 shield (3D Printer Czar, n.d.).

5) Three wires of the power plug (Brown, Blue and Green) connect to the power supply unit's L, N and G nodes respectively. Four spare wires were connected from two Com (V-) and two V+ nodes to the other ends of RAMPS 1.4 shield's power input nodes.

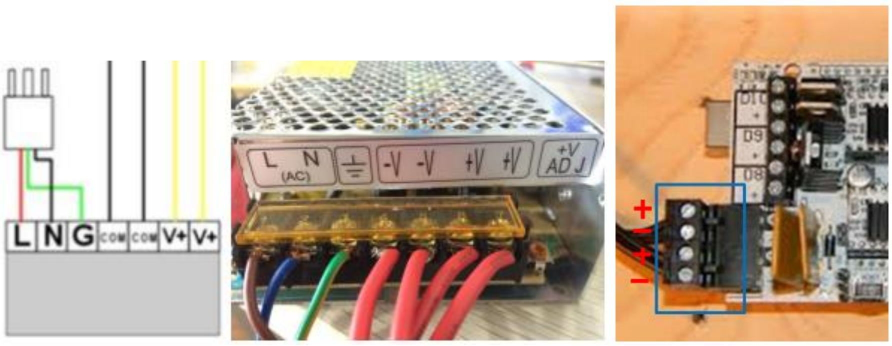

Figure 3.16: Connection between power supply and RAMPS 1.4 shield (3D Printer Czar, n.d.).

6) Nema 17 stepper motors, thermistors, hotend and fan were connected to RAMPS 1.4 shield in Figure 3.17.

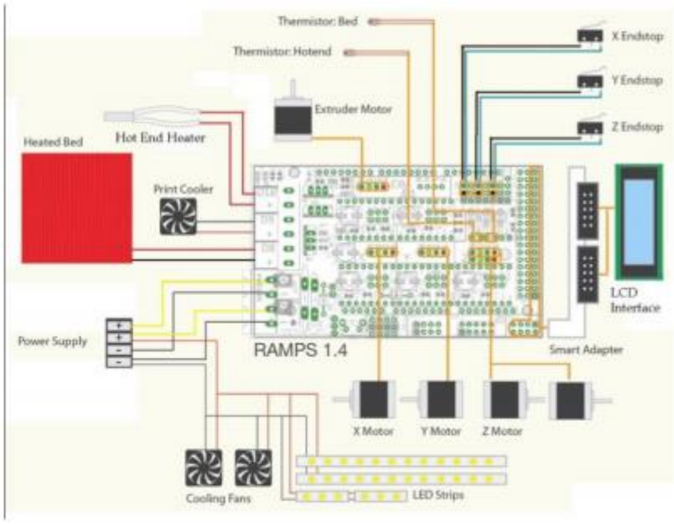

Figure 3.17: Connection of stepper motor, hotend, thermistor, fan and endstop with RAMPS 1,4 shield (3D Printer Czar, n.d.).

3.2.3.3 Firmware Design

Marlin firmware is chosen as the firmware of the project. Modifications were made to match the settings for the current design of portable 3D printer. The software that used to upgrade and renew the firmware to the motherboard is Arduino IDE software. According to Peter (2017), the following adjustments were made in the firmware:

1) **Communication speed:**

   This defines the communication speed between the electronic board and the computer. The two commonly used speed by 3D printer software are 250000 and 115200 baudrate. In this project, the speed is set to 115200.

```
#define BAUDRATE 115200
```

2) **Motherboard:**

   The motherboard RAMPS 1.4 is selected and power outputs was set as extruder, fan and bed.

```
#define BOARD_RAMPS_14_EFB
```

3) **Number of extruder**

```
#define EXTRUDERS 1
```

4) **Temperature sensor**

TEMP SENSOR 0 is used for the first hotend and TEMP SENSOR BED is used to connect the heat bed. 1 is to enable it and 0 is to disable it

```
#define TEMP_SENSOR_0 1
#define TEMP_SENSOR_BED 0
```

5) **Minimum and maximum temperature**

Minimum temperature is set to check whether the thermistor is working and prevent the controller from heating the hotend at maximum power indefinitely. Maximum temperature is set to prevent the temperature to overshoot the target temperature.

```
#define HEATER_0_MINTEMP 5
#define HEATER_0_MAXTEMP 215
```

6) **Pull-ups resistance**

Pull-ups resistance are needed for direct connection between the mechanical end switch between the signal and ground pins. There is a pull-up resistor integrated in Arduino to be activated by the software.

```
#ifndef ENDSTOPPULLUPS
   #define ENDSTOPPULLUP_XMAX
#endif
```

7) **Axis steps per unit**

The stepper motor receives step by step moving command from the controller. The correct amount of steps/mm is set to send the appropriate steps to reach the required distance.

The NEMA 17HS3401-S stepper motor used has 200 steps per revolution (1.8° step angle). The configured micro stepping of the stepper motor driver used, A4988 motor driver is 1/16.

The designed portable 3D printer used M8 threaded rod on the z-axis. The M8 rod used has thread pitch of 2 mm per revolution. First rough setting for step per mm for z-axis is obtained through the calculation below:

Steps_per_mm = (motor_steps_per x driver_microstep)/thread_pitch

= (200 steps/rev x 16 micro steps) / 8 mm

= 400

X-axis and Y-axis of 3D printer are driven through belt and pulley. The step per mm can be calculated through the pitch of the belt. The GT2 timing belt with a pitch of 2 mm and pulley with 20 teeth will drive the belt to move 20 x 2 mm per revolution. In reality, the effective circumference of the pulley will overrule. For 20 teeth pulley, it has diameter of 12.23 mm. With multiplication with π (3.14159..), a circumference value of 38.4216 mm will be obtained and the value is used to calculate the value for step per mm for a more accurate reading before minor calibration.

Steps_per_mm = (motor_steps_per_rev x driver_microstep)/

(circumference of pulley x π)

= (200 steps/rev x 16 micro steps) / (12.23 mm$x$ 3.14159)

= 83.2864

For step per mm of extruder drive, the feed rate of the filament is influenced by the effective circumference of the filament screw. For MK8 extruder filament screw, the effective diameter will be 7 mm as hobbing will reduce the diameter.

Steps_per_mm = (motor_steps_per_rev x driver_microstep)/

(effective_diameter x π)

= (200 steps/rev x 16 micro steps) / (7 mm x 3.14159)

= 145.5131

After calculation, the value is inserted according to brackets set value {x-axis, y-axis, z-axis, extruder}

```
#define DEFAULT_AXIS_STEPS_PER_UNIT {83.2864, 83.2864,
1600, 145.5131}
```

8) Maximum feed rates

The tuning of feed rate is to ensure that the printer able to stay within its physical capabilities even when G-code advice a higher rates. The value is affected by the physical setup such as stepper motor current and moved masses of the bed and extruder. Low federate may result in humming sound of the motor or the axis is not able to move. High motor current will cause overheat of stepper driver and even damage the stepper motor as it runs over its current specification. First, the value is set as below:

```
#define DEFAULT_MAX_FEEDRATE {300, 300, 5, 25}
```

3.3 Project Planning

3.3.1 Flow Chart

Figure 3.18 shows the flow chart of the overall development of portable 3D printer.

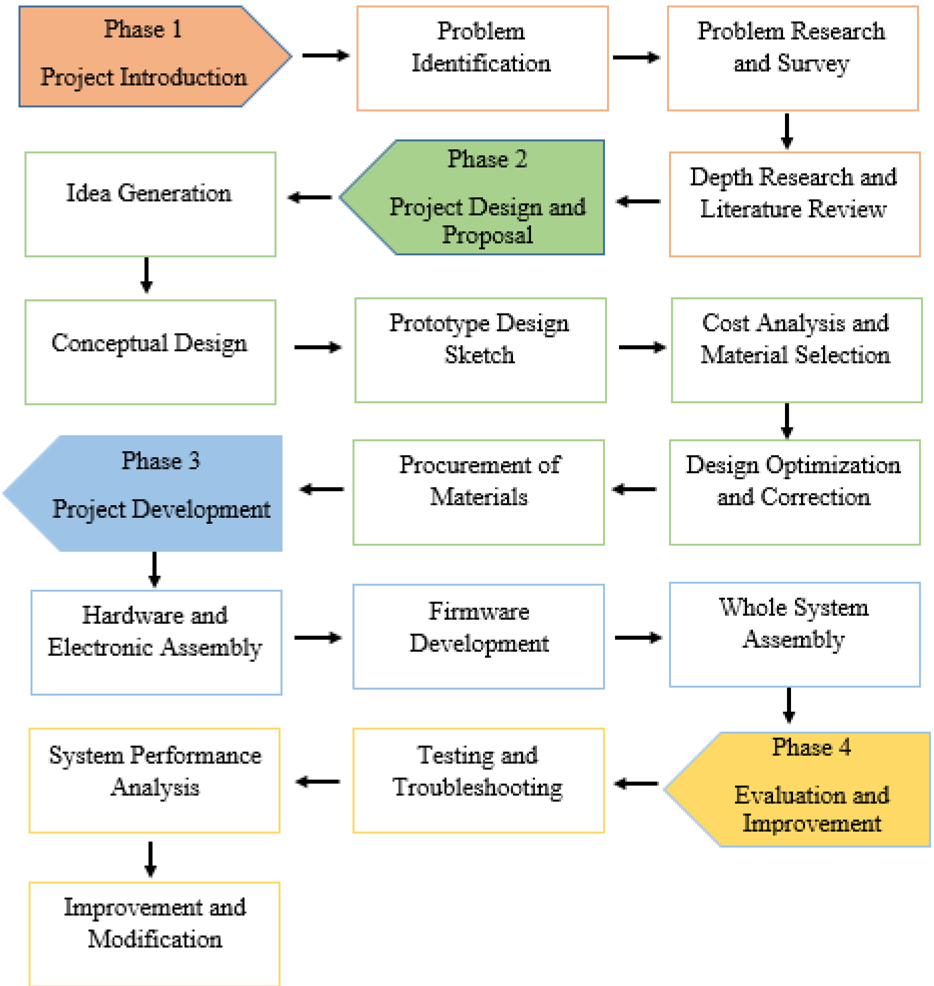

Figure 3.18: Flow Chart of the Project Planning.

In Phase I, the problem of the heavy and bulky size of 3D printer that decrease the mobility and larger space usage had been identified and the research on portable 3D printer was conducted. In Phase 2, the implementation of ball plunger spring mechanism had been included in the design of the portable 3D printer and the prototype design is illustrated in Solidwork. Besides, the materials of the components were searched and purchased. In Phase 3, after the materials purchased reached, the hardware assembly was started and modification was made throughout the assembly process. The electronics were tested out with the adjustments of firmware settings. The electronics were then assembly together with the hardware structure of the developed portable 3D printer. In Phase 4, the developed 3D printer was tested out and modification was made in order to obtain the best quality of printing.

3.4 Gantt Chart for FYP 1 and 2

The tables below show the Gantt Chart for FYP Part 1 and 2.

Table 3.6: Gantt Chart for FYP Part 1.

No.	Project Activities	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
M1	Problem identification &project planning														
M2	Suryeying on Information of 3D Printing Industrial														
M3	Literature Review														
M4	Prototype Design of 3D Printer														
M5	Report writing & presentation														

Table 3.7: Gantt Chart for FYP Part 2.

No.	Project Activities	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
M1	Material Purchasing and Prototype Design Adjustment														
M2	Prototype Assembly of 3D Printer														
M3	Electronic Assembly and Firmware Tuning														
M4	Algorithm testing and Troubleshooting														
M5	Report writing and presentation														

3.5 Summary

In summary, the portable 3D printer is a gantry type FDM 3D printer with foldable Z-axis that apply the concept of ball plunger spring. The components for the hardware is mainly consist of cast acrylic, 3D printed part and aluminium profile whereas the electronic components include NEMA 17 stepper motor, RAMPS 1.4 shield, Arduino Mega 2560 and A4988 motor driver. The tuning of the configuration for firmware is made through Arduino IDE program and test out in Pronterface.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

After the design for portable 3D printer, the 3D printed parts were fabricated through 3D printing from Creality Ender-3 with ABS filament and the acrylic parts were cut. The parts were assembly and correction and adjustment was made during the assembly period with hardware and electronics. After the assembly and correction was done, the movement of the stepper motor and extrusion of filament is test with printing process as well through Pronterface. The firmware was fine-tuned until the first prefect printing was performed.

4.2 Hardware Assembly

4.2.1 Output Results

As designed in Solidwork, the basic frame of the 3D printer is constructed by using aluminium profile, acrylic sheet and 3D printed parts. The Z gantry with foldable parts are attached to form Z gantry as well. Figure 4.1 and Figure 4.2 show the folding and unfolding stage of the 3D printer.

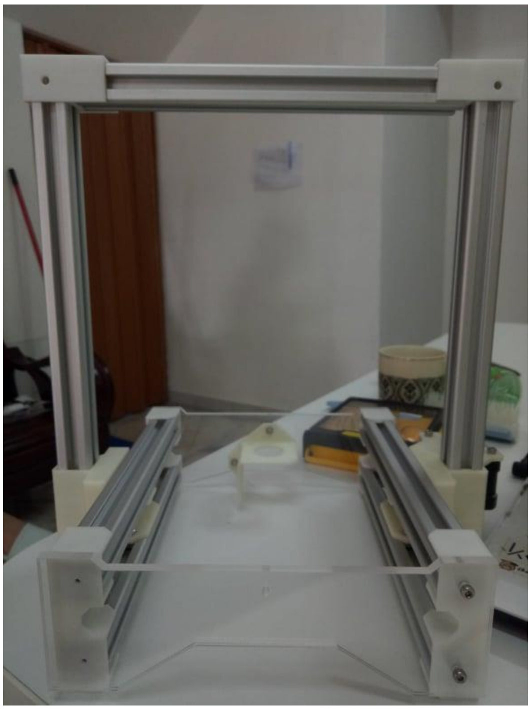

Figure 4.1: The frame of 3D printer during upright position.

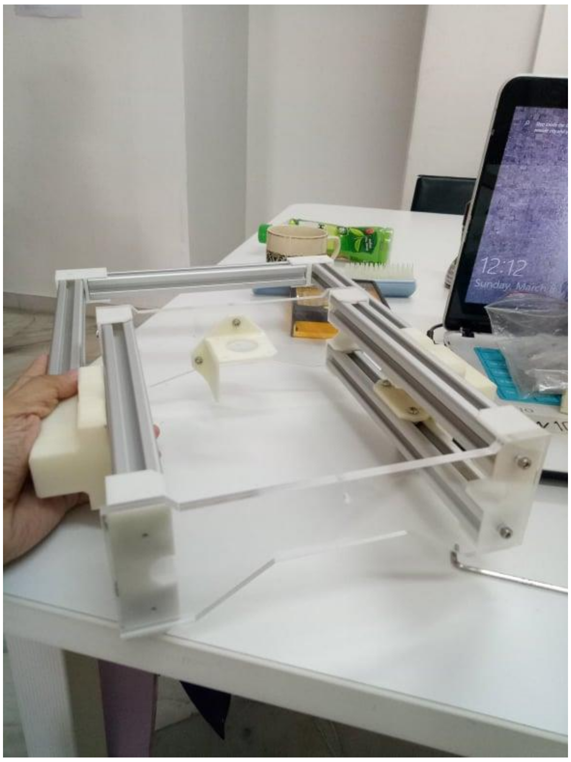

Figure 4.2: The frame of 3D printer during folding stage.

Figure 4.3 shows the completed assemble 3D printer with power supply unit (PSU).

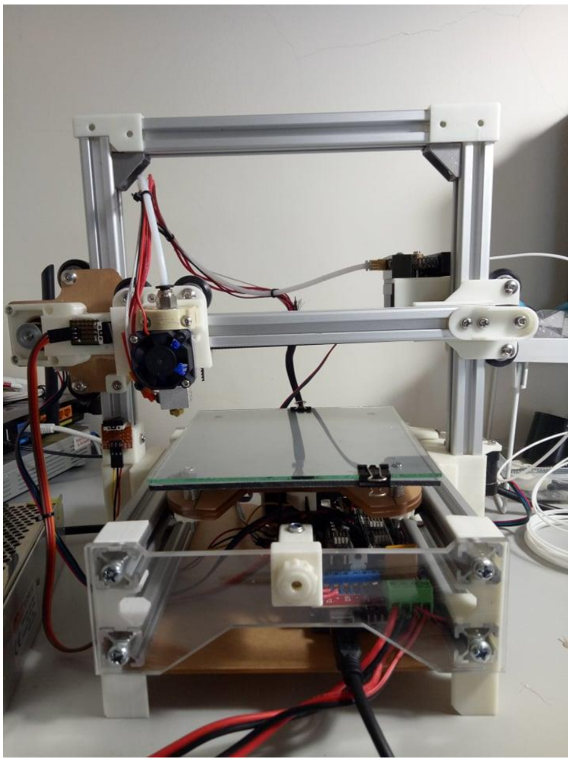

Figure 4.3: The complete assembled portable 3D printer.

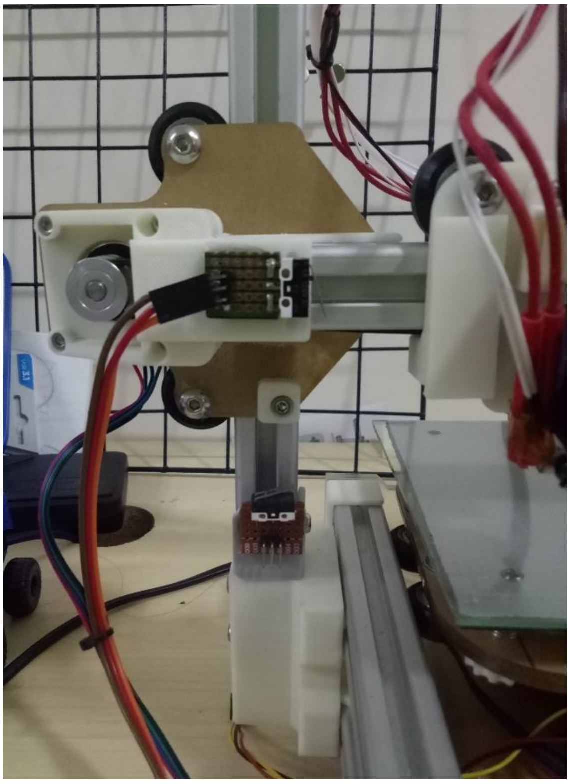

Figure 4.4: Left side view of X-axis assembly.

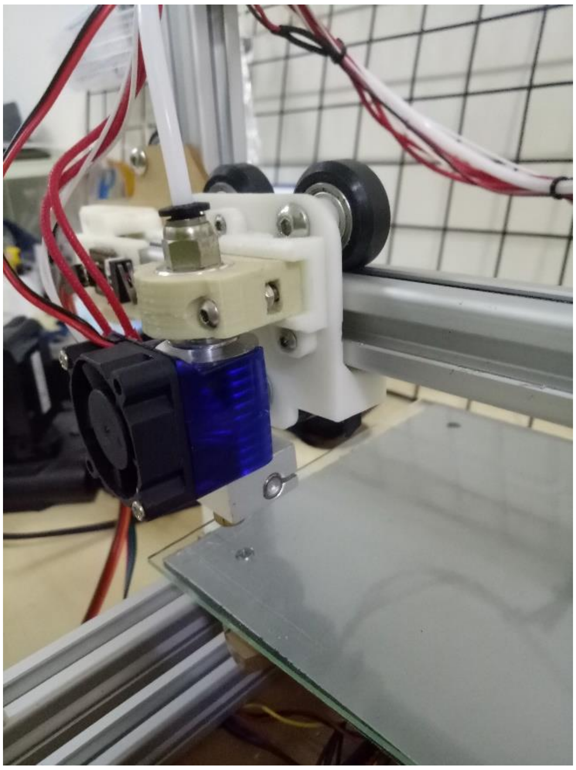

Figure 4.5: Hotend assembly.

Figure 4.6: Right side view of X-axis assembly.

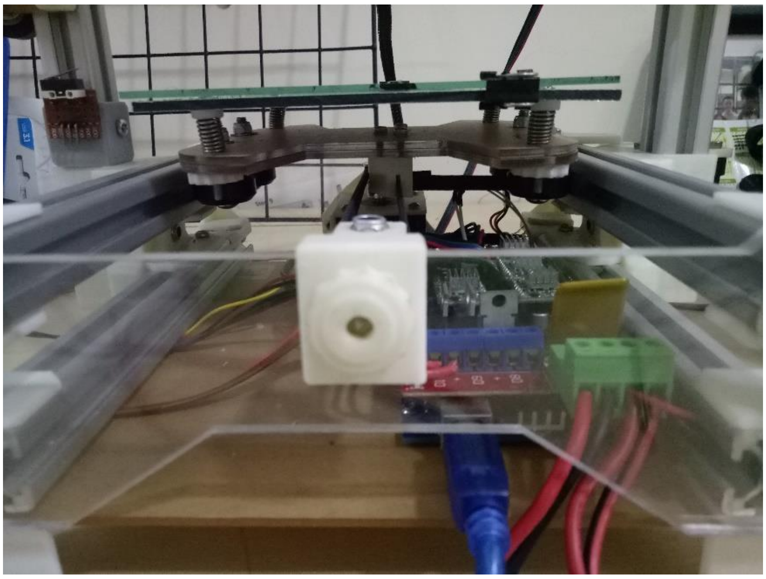

Figure 4.7: Front view of built plate.

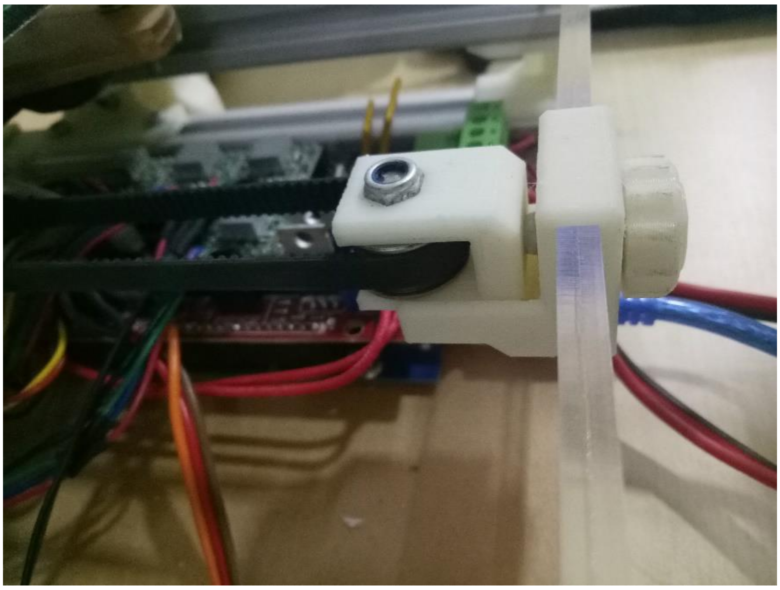

Figure 4.8: Y-belt tensioner.

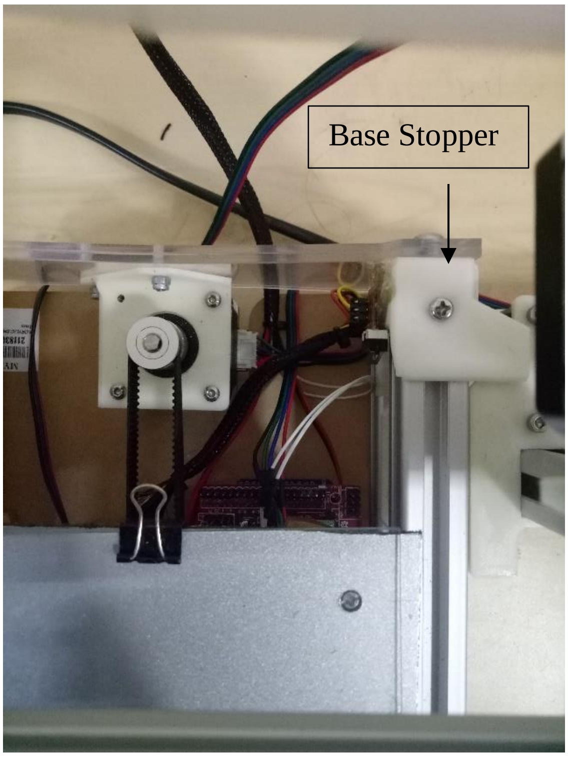

Figure 4.9: Top view of back side.

4.2.2 Problem Faced and Solutions

Firstly, Z-axis gantry faced misalignment in vertical orientation due to the limitation of folding assembly with minor gaps between aluminium profile and 3D printed main folding part. The misalignment of Z-axis gantry cause shifting and unstable structure that will eventually effect the result and quality of the printing. To overcome this problem, aluminium profile L-bracket is used to align the top part of Z-axis gantry to reinforce the alignment between the horizontal and vertical aluminium profile and thus reduce the minor gaps between foldable assembly and aluminium profile at base assembly.

Besides, in the folding assembly, there is difficulty in fixing the folding part at vertical and horizontal position. The plastic ball of ball plunger spring (PFPPN10) cannot tight fit into 6 mm gap at the aluminium profile and the gaps between both will cause unstable structure especially in upright position when printing is on-going. This is solved by adjusting the position of the hole at the main folding part. Initially, the hole to fit the ball plunger spring is located 10 mm away from the top and bottom of the aluminium profile. After the adjustment, the position of hole is shifted away the top and bottom of the aluminium profile by 1.5 mm. Thus, it provide grabbing force to tighten the 3D printed part. The shifting of the holes position enable a slight forward motion that enable the folding part to turn further from the 90 degree position. Therefore, a 3D printed part which is the base stopper is created to avoid further movement of the Z-axis gantry.

The initial design of portable 3D printer for base assembly only consist of 3D printed part which is the corner connector and the front and back acrylic plate. However, there will be shifting to left and right and thus create an unstable structure. An acrylic plate is added to the base assembly with mounting for RAMPS 1.4 shield and Arduino Mega 2560 to avoid shifting and increase the stability.

Apart from that, there is also difficulty in bolt and nut fixing for folding support to aluminium profile. The initial design will require the fixing of bolt and nut at the top and bottom of the aluminium profile. However, it is difficult to fix either top or bottom part of the folding support as the screw unable to fit in the small gap to fix the bolt into the nut. Therefore, it is solved by changing the design of the folding support. The top hole of the folding support is replaced with an additional 3D printed part, a bar that tight fit in the gap of aluminium profile. Thus, this eliminates the difficulty in fixing of bolt and nut. The initial and final design of the folding support is as shown in Figure 4.10.

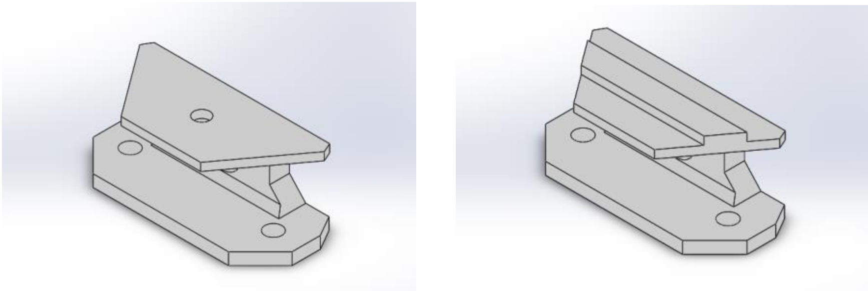

Figure 4.10: Initial (Left) and Final (Right) design of folding support.

4.3 Electronic and Firmware Adjustment

4.3.1 Output Results

The 3D printer is connected to Pronterface and a series of trial are tested to initiate the printing. Figure 4.11 shows the interface of Pronterface.

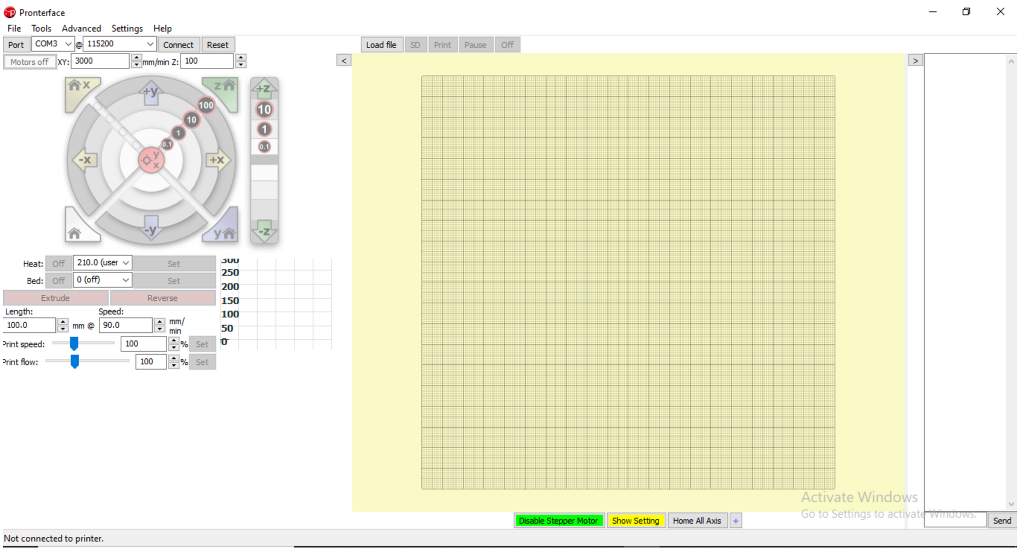

Figure 4.11: Interface of Pronterface.

Firstly, the preheat process was tested out by preheating the nozzle to PLA temperature. The portable 3D printer is designed for PLA printing only. Heated bed is not applied and glass bed is used instead. Before the printing, hairspray is sprayed on top of the glass bed to increase the viscosity between the glass bed and the printed bed and allow the printed bed to fix at the glass bed during printing. As mentioned in 3.2.3.3, the temperature sensor for nozzle is enable and the minimum and maximum temperature which are 5°C and 215 °C are set. After the connection between the Arduino Mega 2560 and Pronterface software, the “SET” button for Heat is pressed and the heat block is able to be heated up to the desired set temperature which is 210 °C after 8 times of fluctuation. The graph of the temperature over the time can referred to Appendix C that shows the temperature graph.

Next, PID tuning was performed. According to Th3D Studio, PID tuning refers to the parameters adjustment of a proportional-integral-derivative control algorithm used for the hotend. P, I and D values are needed to be defined in order to control the nozzle temperature. Therefore, PID Autotune was ran with G-code when the nozzle is cold by enter command of M303 E0 S200 C8. It will heat up the first nozzle (E0) to 200 °C (S200) and cycle the target temperature 8 times (C8). The new P, I and D values will be returned and the Kp, Ki and Kd constants which are 32.37, 2.95, 88.83 respectively were then replaced the old Kp, Ki and Kd constants which are 22.20, 1.08, 114.00 in the configuration.h in Marlin firmware.

Besides, the homing of each axis was tested, the direction of the stepper motors for each axis were set to TRUE while the motor connector for the extruder and X-axis stepper motor were reversed as the direction is inverted. The line for #define Z_HOMING_HEIGHT 4 was enable to minimal Z height to be raised before homing (G28) for Z clearance above the glass bed or clamps.

There are some changes on the axis step per unit calculated at section 3.2.3.3. The axis step per unit is changed from to 145.5131 to 103.09. Adjustment was made by calculating the distance travelled with the set value of 100 mm with 90 mm/sec feed rate. Below is the step for process of calibrating axis step per mm for extruder:

1) 150 mm of marking was labelled on the filament. Command of G90 was sent to the printer to absolute the position of extruder stepper motor.
2) G92 E0 was sent to indicate the stepper motor as 0 in its position.
3) G1 E100 F90 was sent to enable the extruder stepper motor to move 100 mm with 90 mm/sec speed.
4) As the filament was over extruded, the value was set to 100 for axis step per unit for testing. The process was repeated and the distance to the mark was measured again and subtracted that from the original 150 mm.
5) The new axis step per mm was obtained by multiply the old step per mm with 100 mm and divide with the actual length extruded.

The subtracted value from the distance from the marking and 150 mm is the length that the extruder actually pushed through which is 141.5 mm. In order to compensate the 8.5 mm offset, the axis step per mm value is calculated as stated in Step 5 and new value of 103.09 is obtained. The new axis step per mm in firmware by sending command of M92 E103.09 to Arduino and M503 to overwrite the value in the firmware. After the adjustment, the correct amount of filament is able to be extruded.

4.3.2 Problem Faced and Solutions

Firstly, when the Arduino Mega 2560 was connected to the Pronterface. A message of "Error:Thermal Runaway, system stopped! Heater_ID: 0" will show up after the general data pop out at the G-code session and the hotend unable to heat up. There are many possibilities that will lead to this error such as loosen thermistor, broken thermal heater, wrong PID tuning or setting for thermal protection setting in configuration_adv.h. The problem that faced is the wire of the thermistor short circuit with the bolt and cause MIN_TEMP error. This is solved by insulating between the bolt and thermistor wire.

Besides, micro limit switches were connected with the RAMPS 1.4 and tested for the connection and functionality. However, after checking the connection of endstop by using M119 command. It showed that the endstop is in TRIGGERED status which normally in OPEN status. It is noted that the micro limit switch that is used in this project consist of three pins which are Signal, Normally Close (NC) and Normally Open (NO) and is connected as shown in Figure 4.12. In this project, limit switch connection is NC where the current is running through all the time and the current will cut off when the arm on the switch is depressed that will indicate TRIGGERED status when M119 command is sent. After troubleshooting, the female pins that are connected between the RAMPS 1.4 and limit switch is found wrongly connected as the wire connected is to pin Signal and NO instead of Signal NC. This is solved by switched the pin of female head from NO to NC.

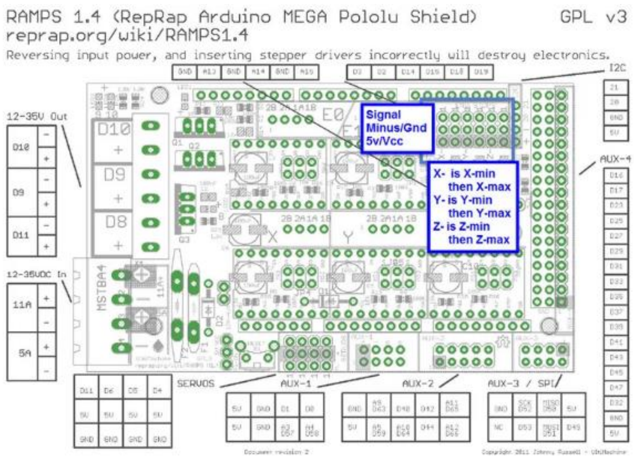

Figure 4.12: Connection of endstop to RAMPS 1.4. (Dintid, n.d.)

4.4 Print output

For first trial of the 3D printing before the fine tuning of the firmware setting, 20 mm calibration cube was printed out. Figure 4.13 shows the printing result of 20 mm calibration cube. After the calibration cube is finished printed, online source of tooth model is printed out as shown in Figure 4.14 and the result of the 3D printed tooth model is shown in Figure 4.15. The printing does not meet the resolution of the original printing as the aluminium coated plastic build plate support is not proper constructed, therefore cause the build plate is not stable. Besides, layer separation is happened where in Z direction of the printing as well as problem of under extrusion that lead to incomplete printing. This is because the assembly at extruder motor is not properly constructed.

Figure 4.13: The X (left), Y (middle) and Z (right) face side of the calibration tube.

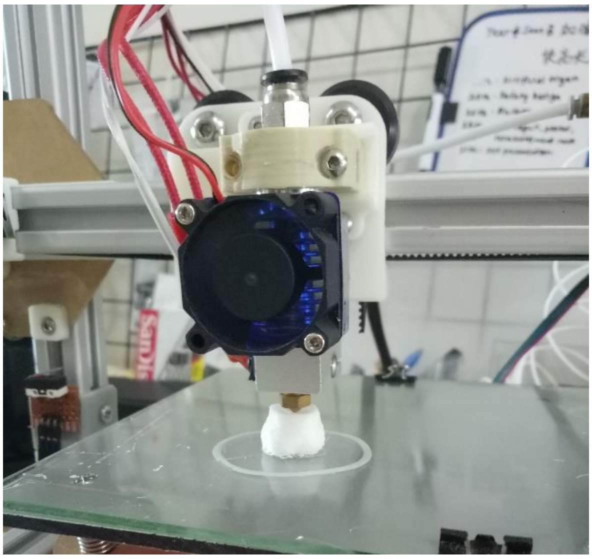

Figure 4.14: Printing process of tooth model.

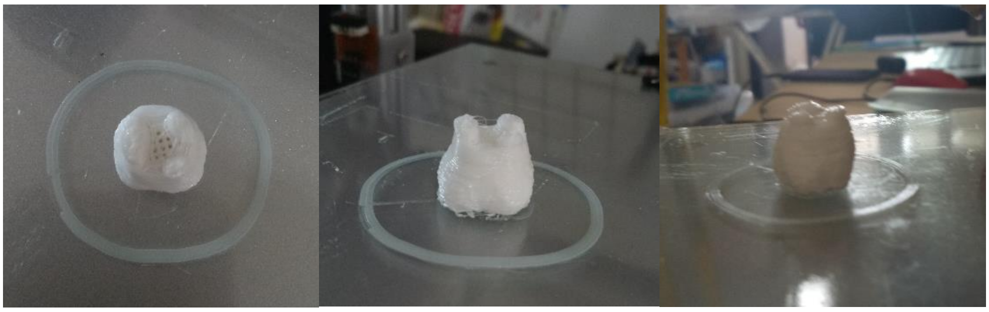

Figure 4.15: The top (left), front (middle) and side (right) view of the tooth model.

4.5 Summary

The prototype of the portable 3D printer was assembly while fine adjustment was made to achieve the stability of the printer such as addition of base acrylic plate and aluminium profile L-bracket. The firmware was updated and adjusted to achieve the best printing profile setting. PID tuning and jerk setting adjustment were made. The best achievable printing quality is reached despite of some limitations.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

With the use of portable 3D printer, it is definitely can optimize the space usage during the non-usage period of 3D printer. Besides, portable 3D printer can be brought out easily which increase the mobility of the printer. As compared to gantry FDM 3D printer, which bulky and heavy, the portable 3D printer is smaller and easier, in terms of usage and carry.

In this research, foldable Z-axis gantry was proposed for the portable 3D printer. The portable 3D printer is 390 mm x 320 mm x 115 mm during folding stage and 220 mm x 323 mm x 329 mm during unfolding stage with printing volume 90 mm x 90mm x 90 mm. The weight of the portable 3D printer is 3.90 kg, where the power supply unit has a weight of 0.7 kg. The foldable assembly apply the concept of ball plunge that normally applied in the mechanism of folding handle of luggage. The benefit of the folding mechanism is to reduce the folding procedure and time from several minutes to within 5 seconds period. Lastly, the best printing quality is achieved after hardware and firmware adjustment.

5.1.1 Recommendations for future work

Several improvements can be made to improve the hardware and firmware of the portable 3D printer to achieve the best printing quality.

The current design for the X-axis gantry of the 3D printer is designed in such that the stepper motor for X-axis is placed at the left hand side of the 3D printer and the extruder stepper motor is placed at the right hand side of the Z axis gantry with the support of lead screw. This will cause a slight slant to the left X-axis rail that cause minor unbalance and delay of movement at the left side rail. In order to avoid this problem, the X-axis stepper motor is better to allocate at the right hand side with lead screw or add in lead screw at the left hand side.

On the other hand, the developed 3D printer is powered by PSU unit and the printing is controlled by Pronterface which require the aid of computer. In order to increase the mobility and accessibility, the PSU unit can be replaced by using Lipo battery with the correct rated power. LCD screen can also be added to eliminate the usage of Pronterface that control every printing. The stepper motor used in this research is NEMA 17, however this can be replaced with stepper motor with lower torque such as pancakes stepper motor or stepper motor with lower torque such as NEMA 11. This is because the torque needed by the portable 3D printer is lower. In result, with the recommendation above, the printer will achieve lighter weight, higher mobility and accessibility.

Besides, the printing volume for the portable 3D printer is 90 mm x 90mm x 90 mm as the maximum travel distance of print head and printed bed is restricted by the aluminium profile and acrylic sheet. A new idea can be researched and implemented by applying the concept of telescopic arm. Telescoping refers to the movement of one part sliding out from another, lengthening an object from its rest state. It can effectively increase the printable volume in either X or Y direction. The limitation in this design will be the stability of each axis, therefore more detailed design will needed to be brainstormed and drafted.

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APPENDICES

APPENDIX A: Datasheet for NEMA 17HS3410-S

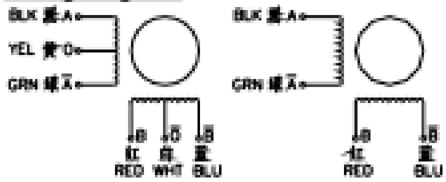
MotionKing

HB Stepper Motor Catalog

MotionKing (China) Motor Industry Co., Ltd.

2 Phase Hybrid Stepper Motor
17HS series-Size 42mm(1.8 degree)

Wiring Diagram:

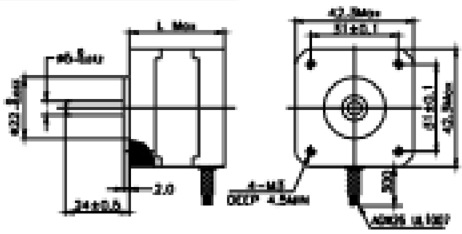


Electrical Specifications:

Series Model	Step Angle (deg)	Motor Length (mm)	Rated Current (A)	Phase Resistance (ohm)	Phase Inductance (mH)	Holding Torque (N.cm Min)	Detent Torque (N.cm Max)	Rotor Inertia (g.cm²)	Lead Wire (No.)	Motor Weight (g)
17HS2408	1.8	28	0.6	8	10	12	1.6	34	4	150
17HS3401	1.8	34	1.3	2.4	2.8	28	1.6	34	4	220
17HS3410	1.8	34	1.7	1.2	1.8	28	1.6	34	4	220
17HS3430	1.8	34	0.4	30	35	28	1.6	34	4	220
17HS3630	1.8	34	0.4	30	18	21	1.6	34	6	220
17HS3616	1.8	34	0.16	75	40	14	1.6	34	6	220
17HS4401	1.8	40	1.7	1.5	2.8	40	2.2	54	4	280
17HS4402	1.8	40	1.3	2.5	5.0	40	2.2	54	4	280
17HS4602	1.8	40	1.2	3.2	2.8	28	2.2	54	6	280
17HS4630	1.8	40	0.4	30	28	28	2.2	54	6	280
17HS8401	1.8	48	1.7	1.8	3.2	52	2.6	68	4	350
17HS8402	1.8	48	1.3	3.2	5.5	52	2.6	68	4	350
17HS8403	1.8	48	2.3	1.2	1.6	46	2.6	68	4	350
17HS8630	1.8	48	0.4	30	38	34	2.6	68	6	350

*Note: We can manufacture products according to customer's requirements.

Dimensions: unit=mm

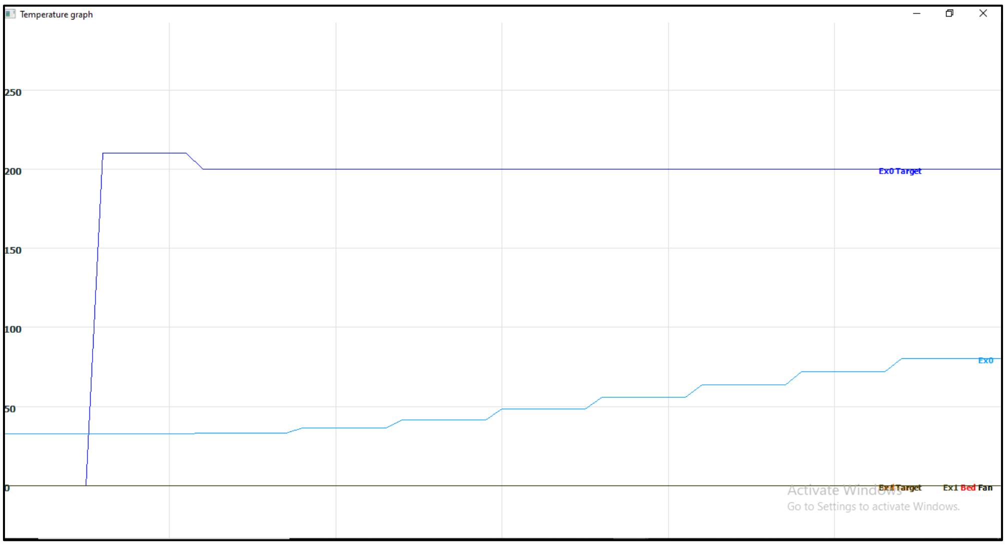


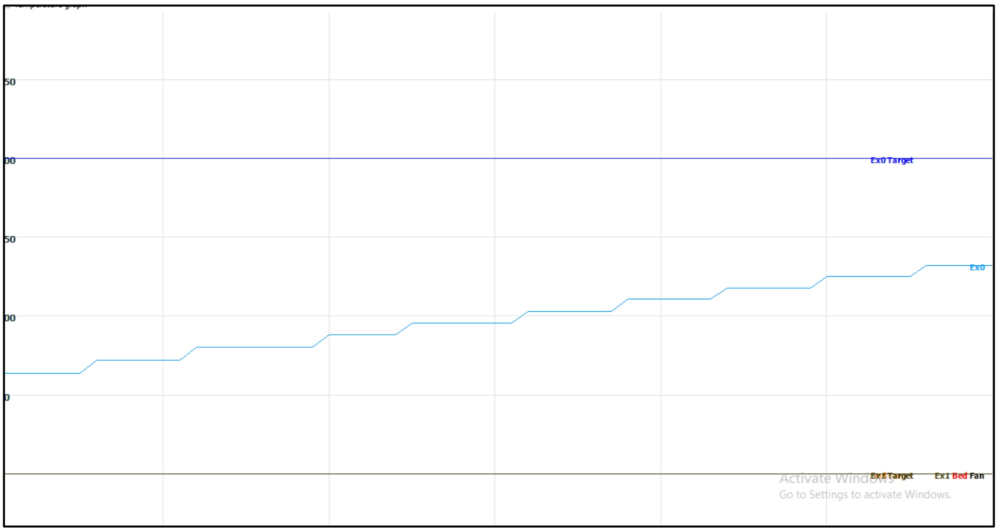
Motor Length:

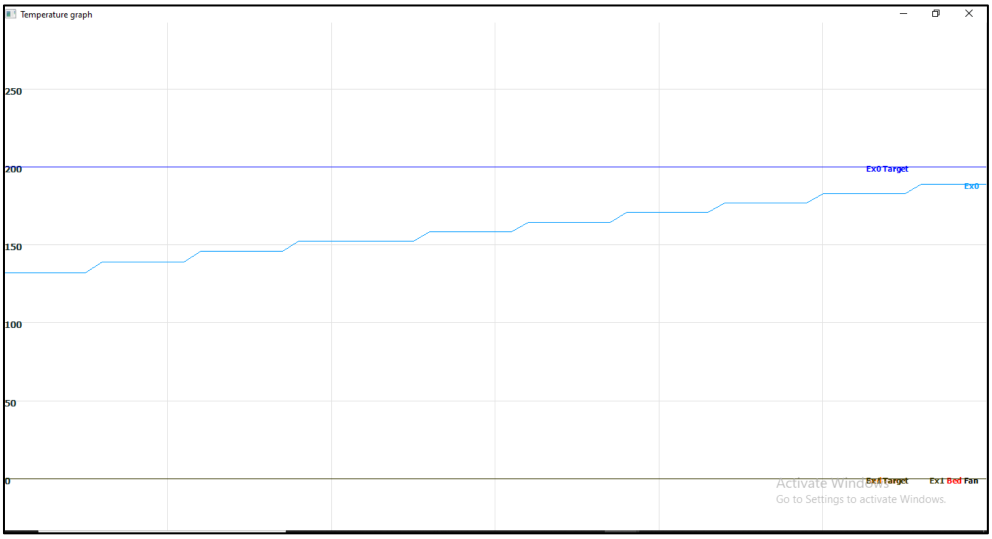
Model	Length
17HS2XXX	28 mm
17HS3XXX	34 mm
16HS4XXX	40 mm
16HS8XXX	48 mm

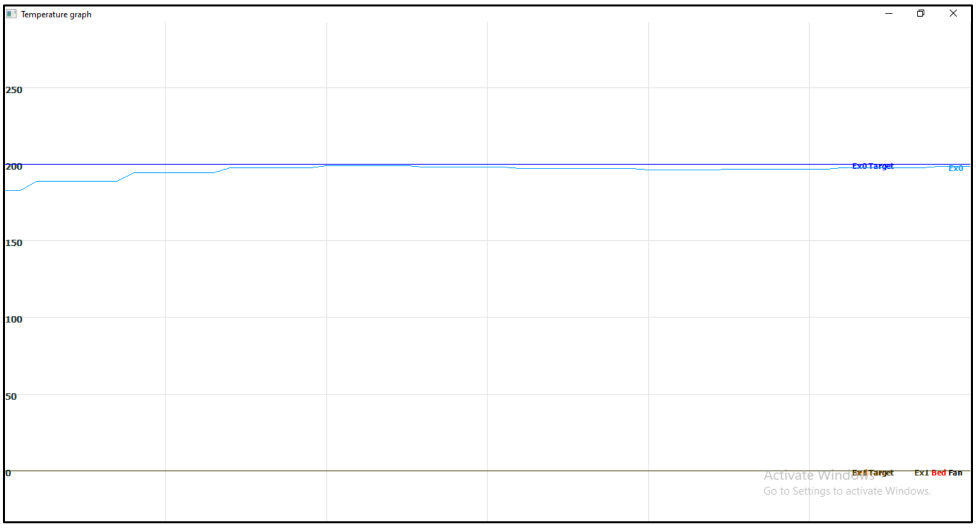
9 www.MotionKing.com MK1106, Rev.04

APPENDIX B: Temperature Graph during Preheat PLA.








Temperature graph
250
200
150
100
50
0
Ex0 Target
Ex0
Ex1 Target
Ex1
Bed
Fan
Activate Windows
Go to Settings to activate Windows.