## Faculty of Mechanical Engineering

# DEVELOPMENT AND ANALYSIS OF LOW COST 3D PRINTING MACHINE

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**Bachelor of Mechanical Engineering**

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# DEVELOPMENT AND ANALYSIS OF LOW COST 3D PRINTING MACHINE

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**A thesis submitted**
**in fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering**



**Faculty of Mechanical Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2018**

**STUDENT'S DECRATION**

I declare that this thesis entitled "Development and analysis of low cost 3D printing machine" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ..........................................

Name `` : ..........................................

Date : ..........................................

**APPROVAL**

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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| Supervisor's Name | : | ......................................... |
| Date | : | ......................................... |

# DEDICATION

This thesis is dedicated to my beloved parents, Lim Chee Ming and Chua Siew Hoon who have always loved me unconditionally and whose good examples have taught me to work hard for the things I aspire to achieve. Also to all my lecturers and lab assistants who have increased my wisdom and giving me guidance whenever I meet difficulties. Moreover, this project also dedicated to all my friends who have always been a constant source of support and encouragement during the challenges of my whole college life.

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Last but not least, many thanks to my parents, siblings and friend for their endless support in completing this degree.

# ABSTRACT

Additive manufacturing which also well known as 3D printing have been growing as a new trend in manufacturing technology and one of the main element in Industrial Revolution 4.0. However, the cost of the commercial 3D printers is expensive and mostly affordable by industries only. Hence, open source 3D printers have provided a low-cost alternative for the public to own a personal 3D printer. The objective of this project is to develop and construct a low-cost 3D printer. Besides, this project also aims to compare the performance of the developed 3D printer with the commercial 3D printer. Therefore, sample cubes are printed by both 3D printers as the specimens to be analysed. Several analyses have been conducted including surface roughness analysis, dimensional accuracy analysis and porosity analysis. The results shown the developed 3D printer is superior to the commercial 3D printer in term of surface roughness and porosity while inferior in dimensional accuracy. This shown the developed 3D printer have the potential to outperform the commercial 3D printer at a lower cost. Lastly, the improvement in dimensional accuracy is reported.

# ABSTRAK

*Pembuatan tambahan yang juga dikenali sebagai percetakan 3D telah berkembang sebagai trend baru dalam teknologi pembuatan dan salah satu elemen utama dalam Revolusi Industri 4.0. Bagaimanapun, kos pencetak 3D komersial amat tinggi dan kebanyakannya hanya mampu dimiliki oleh industri sahaja. Oleh itu, pencetak 3D sumber terbuka telah menyediakan alternatif yang murah untuk orang ramai untuk memiliki pencetak 3D peribadi. Objektif projek ini adalah untuk membangun dan membina pencetak 3D yang berkos rendah. Selain itu, projek ini juga bertujuan untuk membandingkan prestasi pencetak 3D yang dibangunkan dengan pencetak 3D komersial. Oleh itu, sampel bentuk kubus dicetak oleh kedua-dua pencetak 3D sebagai spesimen yang akan dianalisis. Beberapa analisis telah dijalankan termasuk analisis kekasaran permukaan, analisis ketepatan dimensi dan analisis keliangan. Keputusan telah menunjukkan pencetak 3D yang dibangunkan memiliki kelebihan dari segi kekasaran permukaan dan keliangan serta kelemahan dalam ketepatan dimensi berbanding dengan pencetak 3D komersial. Ini menunjukkan pencetak 3D yang dibangunkan mempunyai potensi untuk mengatasi pencetak 3D komersial dengan kos yang lebih rendah. Akhir sekali, peningkatan dalam ketepatan dimensi adalah dilaporkan.*

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## LIST OF ABBREVIATION

| | |
|---|---|
| 3D | Three Dimension |
| ABS | Acrylonitrile Butadiene Styrene |
| AM | Additive manufacturing |
| BOM | Bill Of Material |
| CAD | Computer-Aided Design |
| CATIA | Computer Aided Three-dimensional Interative Application |
| CNC | Computer Numerical Control |
| DLP | Digital Light Processing |
| FDM | Fused Deposition Modelling |
| FOSS | Free and open source software |
| LCD | Liquid Crystal Display |
| PLA | Polylactic acid |
| RepRap | Self-replicating Rapid Prototypers |
| SLA | Stereolithography Apparatus |
| SLSL | Selective Laser Sintering |
| STL | Standard Tessellation Language |
| UV | Ultra Violet |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

In the past few decades, additive manufacturing has been emerged as a new and advance technology which also act as a driven to the Industrial Revolution 4.0. According to Obama in his speech at the National Additive Manufacturing Innovation Institute, additive manufacturing has the possibilities to revolutionize the methods we make almost everything. (Doug Gross 2013). Additive manufacturing which is also well known as 3D printing is a cutting-edge technology where the product is fabricated through layer by layer manufacturing technology (Wong & Hernandez, 2012). The additive manufacturing process starts with the modelling of 3D model through computer-aided design (CAD) software and being converted into STL file before proceeding to be printed by a 3D printer. 3D printing technology is formerly known as rapid prototyping since three decades more ago. However, as the 3D printing technology have been evolved and applied more widely to the small mass production recently, it is more commonly known as additive manufacturing in the present. Nowadays, 3D printing technology have been applied widely in various fields such as research, engineering, medical industry, military, construction, architecture, fashion, education, computer industry and many others (Pîrjan & Petroşanu, 2013). The availability of the material also has been expanded where metal, plastic, ceramic and cement product as shown in Figure 1.1 can now be fabricated by using 3D printer.

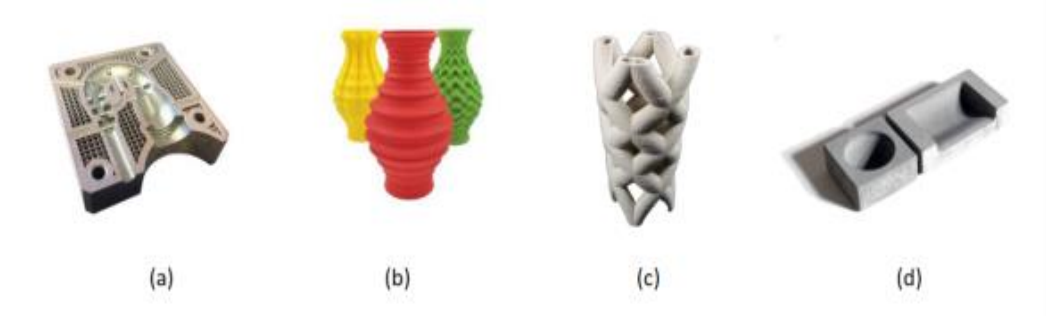



Figure 1.1: 3D printing product manufacturing in the material of

(a) metal (b) plastic (c) ceramic (d) cement

Previously, 3D printing is a technology which was costly and only affordable by large-scale manufacturing industry (Kostakis, Niaros, & Giotitsas, 2015). However, the 3D printing is now more user-friendly and can be available at a lower price. People can also build up their own 3D printer through various open source information provided by some volunteer organization and community. One of the most famous open source 3D printer is RepRap which core on inventing self-replicating manufacturing machine as shown in Figure 2 (RepRap.org, 2017). Besides, there are also other communities who committed to contribute in open source 3D printer such as Make Your Own Ceramic 3D Printer community which focus on designing Delta 3D printer for ceramic and other paste material (Jonathan Keep, 2017).


Figure 1.2: RepRap 3D printer

## 1.2 Problem statement

Open source 3D printer had provided a low-cost alternative for user to own a personal 3D printer. However, commercial 3D printers as shown in Figure 1.3 are claimed to have a better performance at a higher cost. Hence, low cost open source 3D printer with performance close or better than commercial 3D printers have to be developed. Detail analysis also should be conducted to compare the performance between the developed 3D printer and commercial 3D printer.



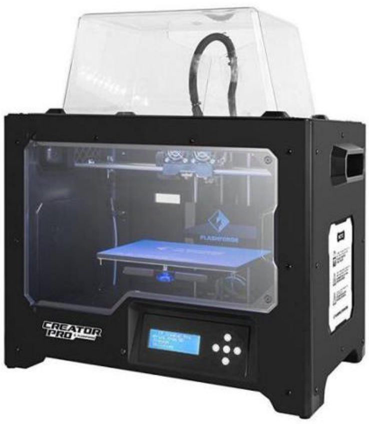


Figure 1.3: Commercial 3D printer

## 1.3 Objective

The objectives of this project are as follows:

1. To develop and construct a low-cost 3D printer based on Fused Deposition Modelling (FDM) technology.

2. To analyse the performance of the 3D printer developed through comparison with the commercial 3D printer.

## 1.4 Scope of project

The scopes of this project are:

1. The 3D printing machine utilized open source system and capable to print plastic material.
2. Compare the performance of developed 3D printer and commercial 3D printer in term of surface roughness, dimensional accuracy and porosity.



## 1.5 Summary

In short, development of low cost open source 3D printer with performance close or better than the existing commercial 3D printer are the main idea of this project. By conducting this project, users can own a 3D printer with better performance at a lower cost. The next chapter will describe the literature review of this study.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

This chapter described the literature review done related to this project. Firstly, additive manufacturing which is the main core of this project is introduced. Next, the information related to open source 3D printer is searched and studied to acquire the relative knowledge in development of a 3D printer. After that, the background, process and advantages of Fused Deposition modelling (FDM) technology is elaborated. Finally, the relevant researches carried out by other researchers is studied and described.



## 2.2 Additive Manufacturing

Nowadays, additive manufacturing (AM) which also well known as 3D printing have been growth as a new and popular technologies in the field of design and low volume production (Galantucci et al., 2015). The ASTM International Committee ASTM F2792-12a on AM technologies defines AM as the process of joining materials to make objects from three-dimensional (3D) model data, usually layer by layer as opposed to subtractive manufacturing technology (ASTM, 2012). It is firstly known as direct digital fabrication as it determines how each layer will be constructed directly from the CAD file and build up the product by fusing a wide variety of material (Hwa, Rajoo, Noor, Ahmad, & Uday, 2017).

AM is initially recognized as rapid prototyping while it undergoes outstanding progress within this last 30 years because of some of its benefits against other manufacturing technologies. For example, AM have the advantages of capable to manufacture complex geometries, less material wastage, considerably less time consumption and more user friendly (Banoriya, Purohit, & Dwivedi, 2015). Recently, AM has been applied in manufacturing of functional products in low volume while the precision and surface quality is usually inferior as compared to those manufactured by machining. However, there are advance machines which are already capable to fabricate parts that is close or exactly the shape of the final product. Through some appropriate post processing, the differences of material qualities and properties between the parts produced and the final products will be further narrowed or eliminated (Chua, Leong, & Lim, 2003).

AM can be subdivided into several subcategories. According to American Society for Testing and Materials (ASTM) in 2010, AM can be classified into 7 main categories which are VAT photo polymerization, material jetting, binder jetting, material extrusion, powder bed fusion, sheet lamination and directed energy deposition. On the other hand, the material for AM also can be divided into four main types which are plastic, metal, composites and ceramic (Bourell et al., 2017).

## 2.3 Open source 3D printer

In the past, owning a 3D printer is costly and only available at industrial level (Petrovic Filipovic et al., 2011). However, the development of free and open source software (FOSS) have given an alternative way to expensive and proprietary system which greatly reduce research and development cost of 3D printer (Zhang, Anzalone, Faria, & Pearce, 2013). RepRap, Fab@home and Ultimaker are some example of open source websites that provides design of small scale 3D printer. These websites are begun at the universities level and supported by a large group of community for its continuous improvement (Sells, Smith, Bailard, Bowyer, & Olliver, 2010). Among all the 3D printers used around the world, RepRap is the most popular 3D printer as shown in Figure 2.1 and it is awarded with the most significant 3D-printed object in 2017 (RepRap.org, 2017). The increasingly uses of open source software had helped to reduce the software cost and cost of experimental science.



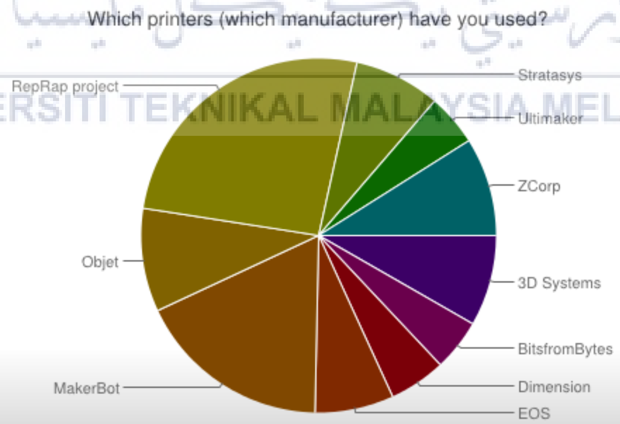



Figure 2.1: Survey on the 3D printing community (RepRap.org, 2017)

The RepRap community have successfully increased the popularity of 3D printing technologies due to its low cost and medium to high quality 3D printer (Jones et al., 2011).

The growth of the RepRap community had made the cost of owning a 3D printer become much lower and more affordable by the public. Acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA) are the main materials used by the RepRap 3D printer as they have lower melting point and more easily shaped (Tymrak, Kreiger, & Pearce, 2014). Nowadays, a Prusa type 3d printer developed by RepRap can be available at a price below $1000 and even cheaper if the users build the 3D printer themselves. This greatly increase the user based of 3D printer owner (Gibson, Rosen, & Stucker, 2010).

The objectives of RepRap community are to encourage the public to design and build 3D printers by themselves. The RepRap 3D printer can be defined as a mechatronic device which made up of a combination of stepper motor for 3D motion, frame and printed parts as the support of the structure and an extruder used for melts the material to form the product. It is designed to have the ability to self-duplicate as most of the parts can be printed by another RepRap 3D printer. The operation of all the components of the RepRap printer is coordinated and controlled by an open source micro-controller which is called Arduino (Kentzer, Koch, Thiim, Jones, & Villumsen, 2011). Most of the RepRap 3D printers are applying Fused Deposition Modelling (FDM) techniques where the thermoplastic filament is heated and extruded through a nozzle to build up a part by using layer by layer manufacturing technology (Romero et al., 2014).



In a nutshell, RepRap had provided the possibilities for the individual or public to develop high value object produced at the mass production facilities (Gershenfeld, 2005). The RepRap 3D printer are now already applied for many fields such as art, toys, tool, household items and scientific instruments (Tymrak et al., 2014). It is also proved to be useful in standard engineering, education, customizing scientific equipment, chemical reaction ware, electronic sensors, wire embedding, tissue engineering and appropriate technology-related product manufacturing for sustainable development (Wittbrodt et al., 2013).

## 2.4 Fused Deposition Modelling

The FDM process was invented and patented by Scott Crump in 1988. After the expiry of patents by Stratasys, the FDM become high accessible and adopted by most of the users due to its lower cost of ownership as compared to other laser based AM technology (Alabdullah, 2016). The FDM technology also has the benefit of simple maintenance and a wide variety of materials with different mechanical properties available. FDM process offer a lower economic and technological entry barrier to manufacturing one-off or small lots as compared to traditional manufacturing such as injection moulding or machining (Mahmood, Qureshi, & Talamona, 2018).

The FDM process start with the preparation of 3D drawings of the model by using any computer aided design (CAD) software followed by slicing of CAD file to calculate a path to extrude thermoplastic and generate the support material if necessary. The 3D printer will then heat the thermoplastic to a semi-liquid state and deposits it in ultra-fine beads along the extrusion path. After the part is completely built, the users will remove it from the platform and post process will be applied to remove the support or improve the surface finish (Surange & Gharat, 2016). The schematic diagram of the FDM process are shown in Figure 2.2.

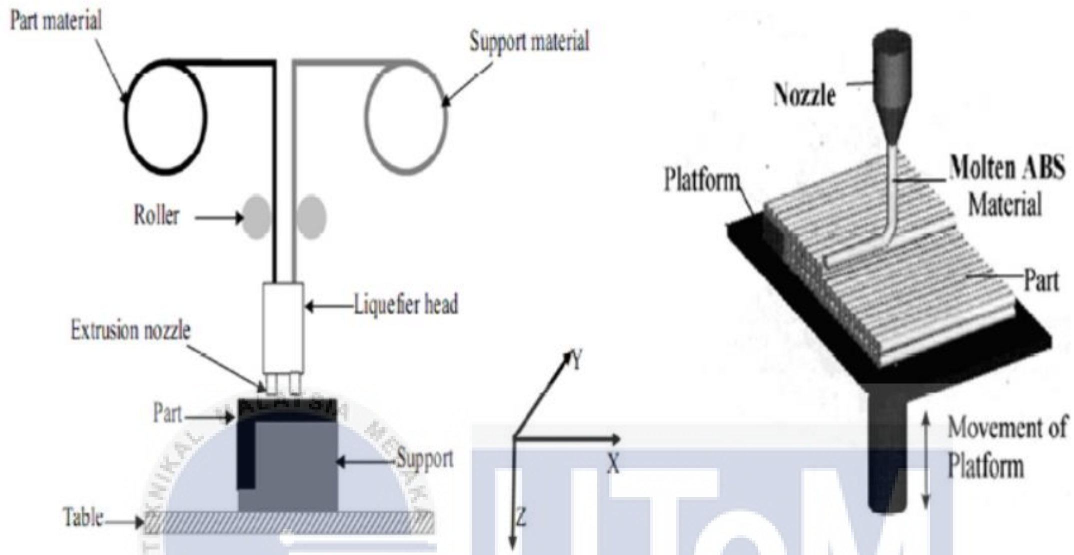



Figure 2.2: Schematic diagram of FDM process (Schmitt et.al., 2016)

According to Kuo et al. (2016), FDM technology have the advantages of clean, simple-to-use, high processibility, low cost and facile manipulation which is suitable for both household and industrial application. Besides, FDM process also have the advantages of easy material change, low maintenance cost, quick production of thin parts, a tolerance equal to ±0.1 millimeters overall, no need for supervision, no toxic material, very compact size and low operation temperature (Galantucci et al., 2015). Furthermore, FDM process has lower energy consumption and lower total life cycle environmental impact as compared to SLA and Polyjet printing (Schmitt et al., 2016).

## 2.5 Relevant studies

Several studies have been conducted to analyse the performance of open source and personal 3D printer. Yalun et. Al. (2016) had conducted researches to study the best AM technology in personal 3D printer in terms of cost, sustainability, surface roughness and human perception. The AM technologies compared in this research are Fused Deposition Modelling (FDM), Stereolithography apparatus (SLA), and Polyjet printing. The material used for each AM technology are polylatic acid (PLA) for FDM, clear ultra-violet (UV) curing resin for SLA and translucent UV resin for Polyjet printing. The surface roughness is then measured by using a surftest SJ-210 surface roughness tester from Mitutoyo. From the result, Polyjet printing shown the best performance among all the AM technology. This research has shown a comparison between different AM technologies however the printing material is different for each technology which may be a factor of affecting the printing quality as well.

In addition, Tao Peng and Fei Yan(2018) have conducted researches in investigating the effect of process parameters on the energy consumption and surface roughness of FDM 3D printer. Comparison is made by printing the same set of process parameter on the commercial and self-developed 3D printers. The models of commercial 3D printer applied in this research are Creatbot DX and Mbot Frid II plus while the self-developed 3D printer is an open source delta type 3D printer. The material used is PLA with diameter of 1.75millimeters and 3millimeters due to its excellent biodegradable properties and easily shaped at temperature of 200℃. A portable wattmeter HOPI HP9800 was used to acquire the power consumption of each printer while roughometer TIME 3200 is used to take the measurement of surface roughness. This research had shown the most suitable process parameters in saving energy consumption and improve surface roughness but did not shown the comparison of performance between different printers.

Moreover, Galantucci et.al (2015) have conducted research to analyse and compare the dimensional performance of open source 3D printer based on FDM technique with commercial 3D printer. The open source 3D printer used in this research is Fab@Home Model 1 3D printer while the model of commercial 3D printer is Stratasys FDM 3000 3D printer. Rectangular specimen as shown in Figure 2.3 were printed by both 3D printers and the dimensional measurements is taken by using a digital microscope "Dino-Lite pro AM413-T" which having an accuracy of ±0.01 millimeters. The specimens printed by the commercial 3D are using filament of ABS-P400 material with outer diameter of 1.75millimeters and a density of 1000 $kg/m^3$ while the open source 3D printer use filament of ABS material with outer diameter of 3.00 millimeters and a density of 1060 to 1200 $kg/m^3$. This research shown an in-depth analysis and comparison between the performance of open source 3D printer and commercial 3D printer. However, the material used for both printers are not the same which may lead to the inconsistent of the test result and dimensional analysis only cannot reflect the overall performance of the 3D printer.

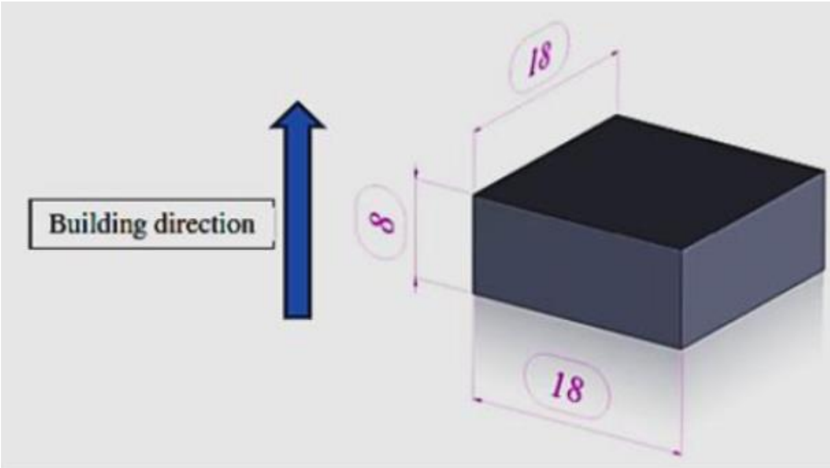



Figure 2.3: Rectangular specimen (Galantucci et al., 2015)

## 2.5 Summary

AM shown great potential not only in manufacturing field but also in other advance field such as medical and others. With the aid of various open source information available on internet, the distance between the public and this technology is shortened. One can easily access the relevant information or even build up their own 3D printers. For these reasons, more and more researches have been conducted to improve and analyse the performance of 3D printer especially open source 3D printer. After understanding the background of this study, the methodology for conducting this project is planned and described in the next chapter.

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

This chapter described the methodology used in this project to construct and analysis the performance of the low-cost 3D printing machine, This project started with the choosing of the design of 3D printer to be developed. After the design is decided, all the required components is purchased from different sources and assembled once they are collected. The programming code is then edited based on the requirements and uploaded to the mother board of the 3D printer. Next, calibration processes is carried out to ensure the machine is functioning properly as the design purpose. After the 3D printer is calibrated, specimens are printed by using the developed 3D printer for the further analysis. Lastly, the specimens are analysed and comparison is made between the developed 3D printer and commercial 3D printer. The flowchart of the methodology is shown in the Figure 3.1.

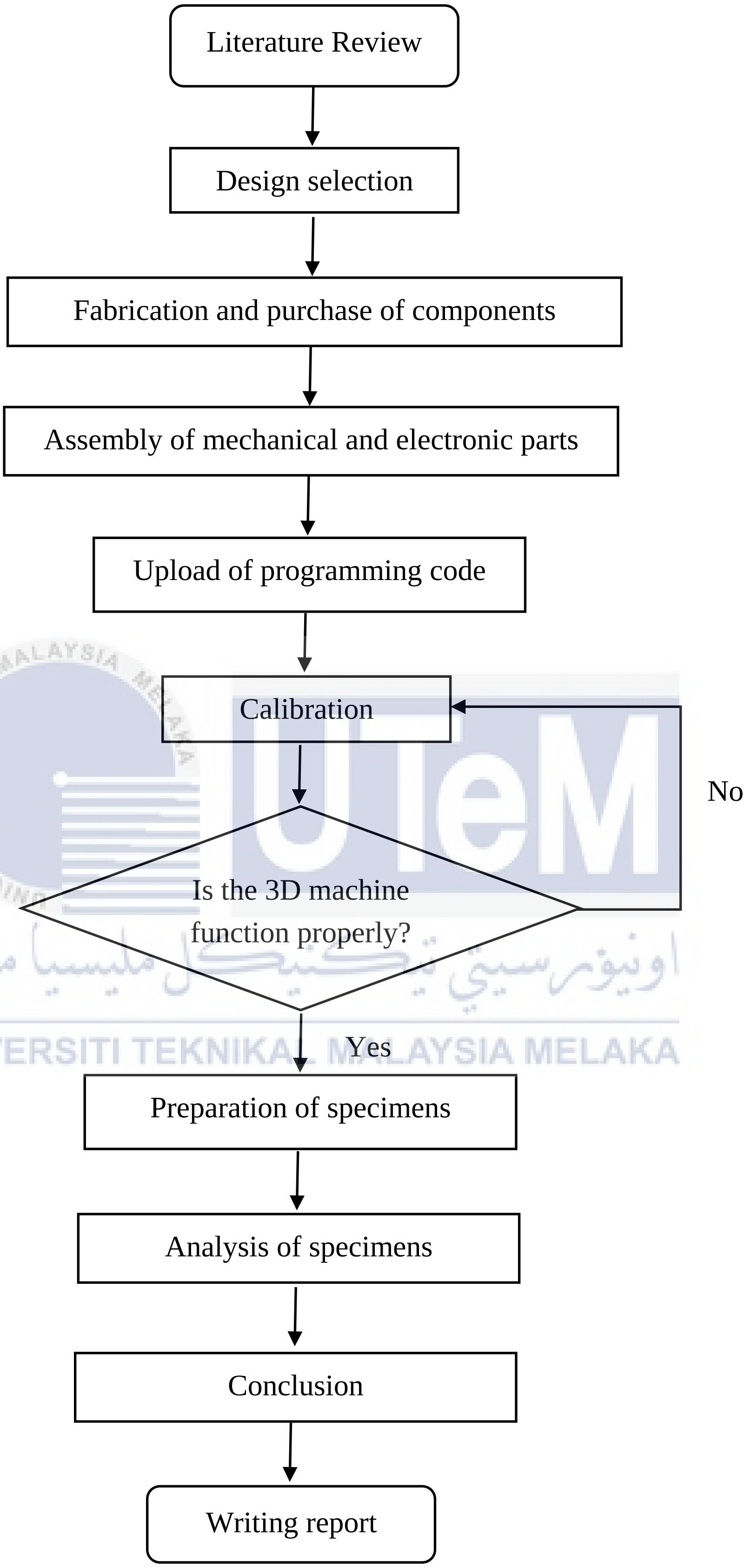


Figure 3.1: Flowchart of the methodology

## 3.2 Design selection

Surveys have been conducted to choose the most suitable 3D printer to be developed. The design of the 3D printer will be chosen from the open source websites, RepRap as it provided a various type of open source 3D printers which required a low cost of development. Several designs are then shortlisted and evaluated in term of printer size, speed, printing size, cost, stability and mofiability. The 3D printer chosen should fulfilled the requirements of low cost, high stability, high mofiability and user friendly.

## 3.3 Fabrication and purchasing of components

The components of the 3D printer can be divided into two categories which are fabricated components and standard components. The fabricated component are printed by using the Anet A8 3D printer as shown in the Figure 3.2. The STL file of the fabricated components are downloaded from the open source website, Thingiverse.com which provided by Tech2C and published under the creative commons-attribution-non-commercial license. On the other hand, the standard components are purchased from different sources and mostly from the online shopping websites such as Shopee, Lazada and Lelong as they provide a lower price. Some of the components are taken from the stock of the laboratory such as shaft and bearing to reduce the cost of development.

Figure 3.2: Anet A8 3D printer

## 3.4 Assembly of mechanical and electronic components

After all the fabricated components and standard components is readily prepared, the project is continued with the development process of 3D printer. The assembly process is divided into three stages. The first stage is the assembly of frame where the aluminium extrusion are joined together by the corner brackets, sliding nuts and screws. After that, the mechanical components such as shaft, bearing, fabricated components and timing belts are fixed and installed to the frame. The next stage of assembly process is the connection of the wires and LCD display screen to the motherboard of the 3D printer by referring to the wiring diagram obtained from the RepRap website as shown in Figure 3.3.

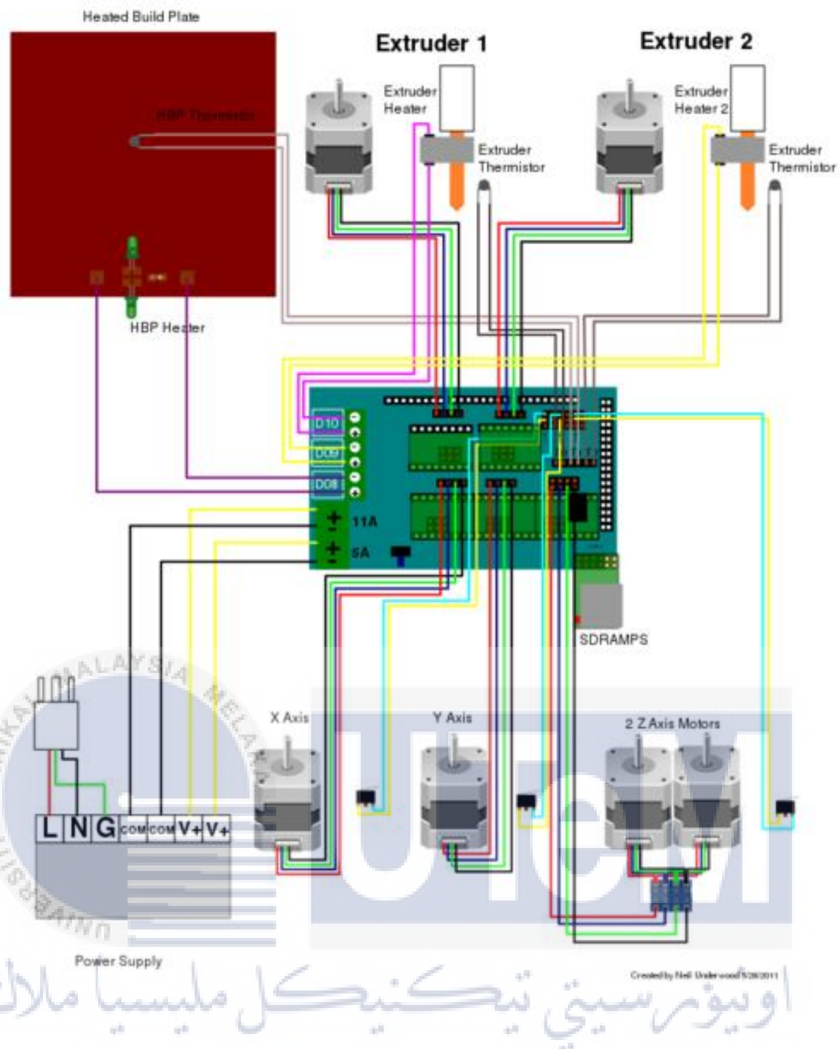



Figure 3.3: Wiring diagram (RepRap.org, 2017)



## 3.5 Upload of programming code

After the mechanical parts and electronic parts is fully assembled, the development process is continued with the upload of programming code. The programming code uploaded to the 3D printer is called marlin firmware which is a free to download from Github website. The programming code used in this project is the latest version of marlin which is Marlin 1.1x. It is then edited and compiled by using a free and open source software which is named

Arduino IDE as shown in Figure 3.4. After the marlin firmware is edited and successfully compiled, it is uploaded to the 3D printer developed by using a Type-B USB cable as shown in Figure 3.5 to enable the connection between the computer and the 3D printer.

Figure 3.4: Arduino IDE software interface



Figure 3.5: Type-B USB cable

## 3.6 Calibration process

There are two main calibration processes carried out to ensure the machine is function properly based on its design purpose which is the calibration of the motor movement and the levelling of the heat bed. The calibration is carried out with the aid of several tools such as vernier caliper, spanner and water level. Besides, a software named Pronterface as shown in Figure 3.6 is used in assisting the calibration process. Firstly, the correct baud rate and port at which the 3D printer is connected to the computer is selected. After that, connection is made between the computer and 3D printer by clicking the connect button and the users can now control the 3D printer by using the control panel or by typing the G-code.

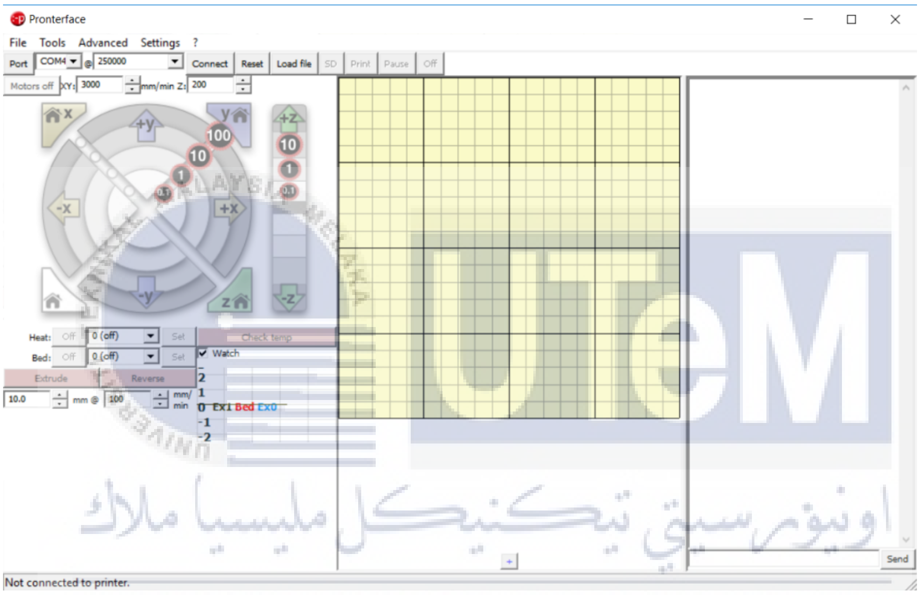





Figure 3.6: Pronterface software interface

## 3.7 Preparation of specimen

Specimens are printed by both developed 3D printer and commercial 3D printer to make the comparison between them. Same material and same printing parameters as shown Table 3.1 are applied for both the 3D printer to ensure the consistency of the analysis conducted. 2 millimetres cubes printed by using PLA material are printed by both printers as the specimens to be analysed in this project. The STL file of the 2 millimetres cube are prepared by using Computer Aided Three-dimensional Interactive Application (CATIA) software. An open source slicing software named Cura as shown in Figure 3.7 is then used to convert the STL file into G-code for developed 3D printer. On the other hand, slicing software named FlashPrint as shown in Figure 3.8 is used for the preparation of G-code for the commercial 3D printer.

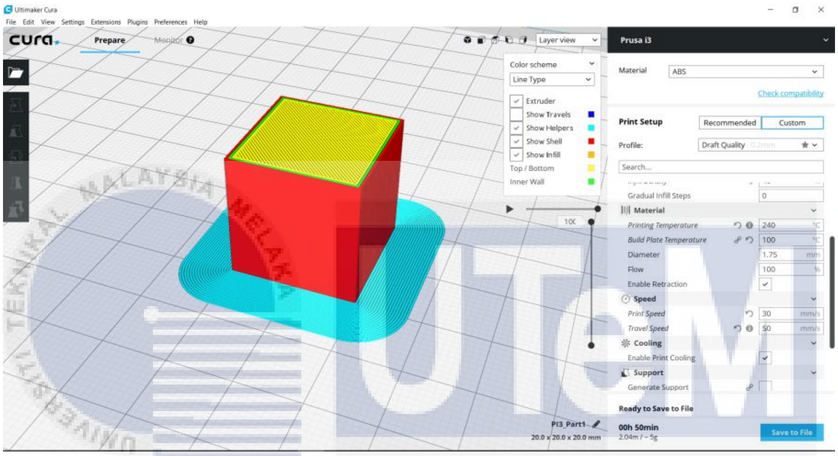



Figure 3.7: Cura slicing software



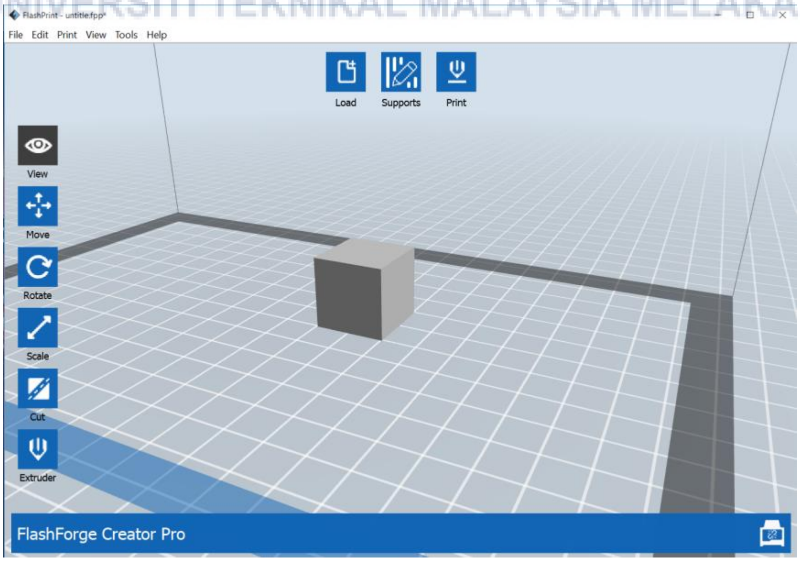



Figure 3.8: FlashPrint slicing software

Table 3.1: Printing parameters of specimens

| | |
|---|---|
| Speed, mm/s | 30 |
| Layer thickness, mm | 0.2 |
| Fill angle, ° | 45 |
| Infill pattern | Linear |
| Infill density, % | 100 |

The commercial 3D printer used in this project is CreatorPro 3D printer as shown in Figure 3.9 manufactured by FlashForge 3D printing industry at China. The specifications of Creator Pro 3D printer are tabulated in Table 3.2.

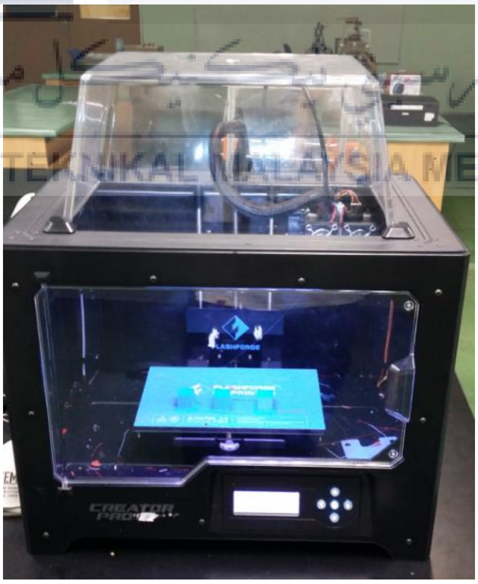


Figure 3.9: CreatorPro 3D printer

Table 3.2: Specifications of Creator Pro 3D printer

| | |
|---|---|
| Machine type | FDM |
| Build volume, mm | 225 x 145 x 150 |
| Minimum layer height, mm | 0.1 mm |
| Maximum layer height, mm | 0.5 mm |
| Extruder head | 2 |
| XY precision | 0.011mm |
| Printing speed, mm/s | 30-100 |
| Material | ABS, PLA, PVA |
| Filament diameter, mm | 1.75 |
| Connectivity | USB, SD card |



Three specimens are printed by each of the printer to obtain an average value for the analysis conducted. The 2 millimeters cubes are arranged with a distance of 20 millimeters between each other as shown in Figure 3.10.

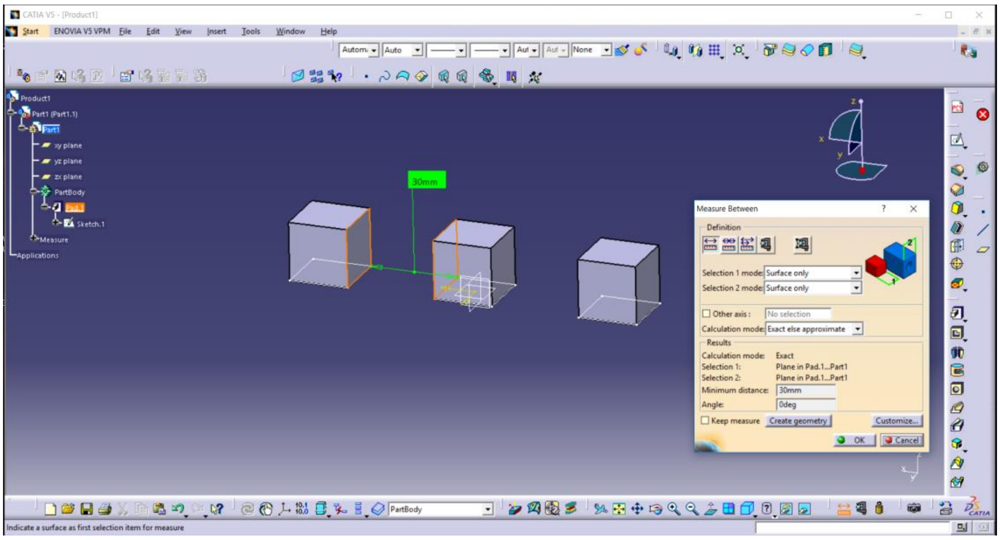



Figure 3.10: Arrangement of specimens to be printed

## 3.8 Analysis of specimens

Three analyses are conducted to compare the performance between developed 3D printer and commercial 3D printer. The analysis conducted are surface roughness analysis, dimensional accuracy analysis and porosity analysis.



The surface roughness analysis is conducted by measuring the surface roughness of the printed specimens by using the 3D non-contact profilometer as shown in Figure 3.11 The measurement is taken on nine points on the specimen surface as shown in Figure 3.12 to get the average value of the surface roughness. The specimen is placed on the platform and the microscopic power is adjusted to 45X. After that, the filter lens is changed to suitable colour and the focal length is adjusted until a clear image is seen on the display screen. The Winroff software is the generate a 3D profile from the image and the surface roughness at the particular point is determined in the unit of Ra.

Figure 3.11: 3D non-contact profilometer

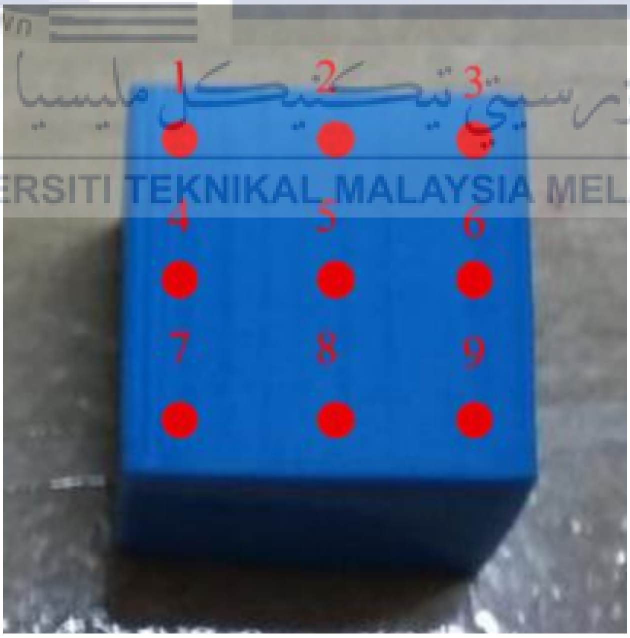



Figure 3.12: Points of measurement on the specimen’s surface

The dimensional accuracy analysis is conducted by measuring the dimension of the specimens printed by both developed 3D printer and commercial 3D printer. A digital vernier calliper with resolution up to 2 decimal points and accuracy of ±0.02mm as shown in Figure 3.13 is used to take the measurement of the dimension. The measurements is taken three times on each side of the specimens as shown in Figure 3.14 and a total of nine measurements is taken to calculate the average value.


Figure 3.13: Digital vernier calliper



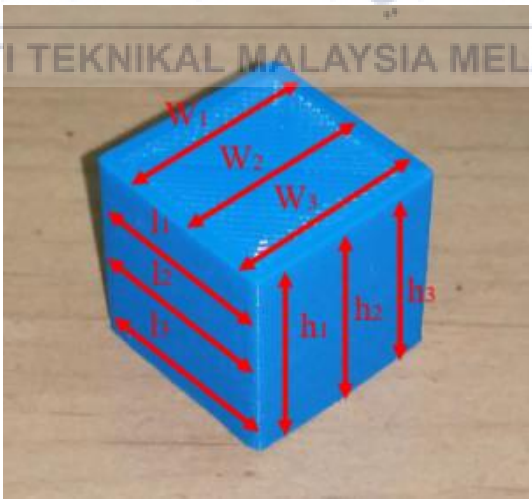



Figure 3.14: Measurements taken on each specimen

Furthermore, the porosity analysis is carried out by calculate the density of the printing material and the density of the specimens printed by both printers. The weight of the specimens is measured by using electronic balance model ATX 224 as shown in Figure 3.15. After the densities is determined, the porosity is calculated and comparison is made between developed 3D printer and commercial 3D printer.



Figure 3.15: Measurement of weights by using electronic balance

## 3.9 Summary

In short, the methodology is planned in an organized way and the project is successfully completed within the period. The results of the works conducted is discussed and evaluated in the next chapter.

# CHAPTER 4

# MACHINE DEVELOPMENT

## 4.1 Introduction

This chapter summarized and discussed all the results obtained from the development process of the machine as stated in the previous section. Firstly, the criteria considered in the design selection phase is elaborated. It is then followed by the fabrication process of the 3D printed components. Next, the price and source of the standard components is discussed in the following section. After that, the assembly process of the 3D printing process is then described followed by the edition of programming code. Lastly, the calibration process and parameters used in the preparation of specimen is evaluated.



## 4.2 Design Selection

After considerations, three models of 3D printer are shortlisted from the RepRap websites which are the Prusa, Kossel and Hypercube model. The specifications of these 3D printers are compared and tabulated as shown in the Table 4.1.

Table 4.1: Comparison between 3D printers

| Description | Prusa | Kossel | Hypercube |
|---|---|---|---|
| Picture |  |  |  |
| Type | Cartesian | Delta | CoreXY |
| Printer size | 400x450x500mm | 300x400x680mm | 340x350x380mm |
| Speed | 10-100mm/s | 20-150mm/s | 20-130mm/s |
| Printing size | 200x200x200 | 180x180x300 | 200x200x220 |
| Number of motors | 5 | 4 | 4 |
| Cost | medium | low | low |
| Cooling fan | Yes | No | Yes |
| Stability | Low | Medium | High |
| Modifiability | Medium | Low | High |



Prusa model is a cartesian type 3D printer while Kossel model is a delta type 3D printer and Hypercube is a CoreXY 3D printer. Unlike cartesian type 3D printer where the movement of each axis are controlled by different motors separately, the movement of X and Y axis of delta and CoreXY type of 3D printer are controlled through the coordination movement between motors. This can reduce the burden to the motor since the load is distributed between motors.

Among all these 3D printers, Prusa model occupy the largest space followed by Kossel model and then the Hypercube model of 3D printer. The smaller size of Hypercube 3D printer made it more portable and space saving. Besides, Kossel model can print with the highest printing speed followed by the Hypercube model and then the Prusa model. This is due to Kossel model has the lightest weight of moving platform while the moving platform for Prusa model is the heaviest as it is a combination of extruder and motor.

Furthermore, Hypercube model have the biggest printing size followed by Prusa model and then the Kossel model. This is because Hypercube model has a higher printing height as compared to Prusa model and a bigger print bed as compared to Kossel model which is circular in shape. On the other hand, Kossel model and Hypercube model share the same number of motors which is four while the number of motors for Prusa model is five. This lead to the Kossel model and Hypercube model have a lower building cost as compare to Prusa model as less of the motor, shaft, coupler and threaded rod needed.

In addition, Prusa model and Hypercube model having advantages against Kossel model by equipping with cooling fan. Cooling fan may help to improve print quality and reducing printing error such as overhang, overheat, bridging and others. Hypercube model also having the highest stability among these 3D printer as its frame are fully made of rigid aluminium profile joined together by corner bracket. The frame of Kossel is mostly composing of aluminium profile as well but its height is higher which lead to a higher centre of gravity and reduced stability. Moreover, the frame of Prusa model are mostly made of plastic part which making it less stable as compared to other models.

Next, Hypercube have the highest modifiability as the extruder can be easily detached and switch to another modified extruder. The rigid aluminium profile frame also making other improvement component made can be attached to the 3D printer easily. The Kossel model have the lowest modifiability as the moving platform is too small to be installed with modification component and the component added also may cause the imbalance of the moving platform.

In a nutshell, Hypercube model are chosen as the model to be developed due to its smaller volume, moderate printer size, large print size, low cost of development, high stability, high modifiability and installed with cooling fan.



## 4.3 Fabricated and purchased components

This section discussed the 3D printer and parameter of printing applied in the fabrication of the components. After that, the types and quantities of standard components with their respective sources are elaborated.

### 4.3.1 Fabricated components

Since Hypercube 3D printer is a self-replicating machine, most of its parts can be printed by using another 3D printer. The parts were initially printed by using CreateBot 3D printer as shown in Figure 4.1. However, the printing result is not satisfied because the warping problem occurred on most of the printed part as shown in Figure 4.2. This is due to the printed part is not adhere to the print plate firmly during the printing process.


Figure 4.1: CreateBot 3D printer

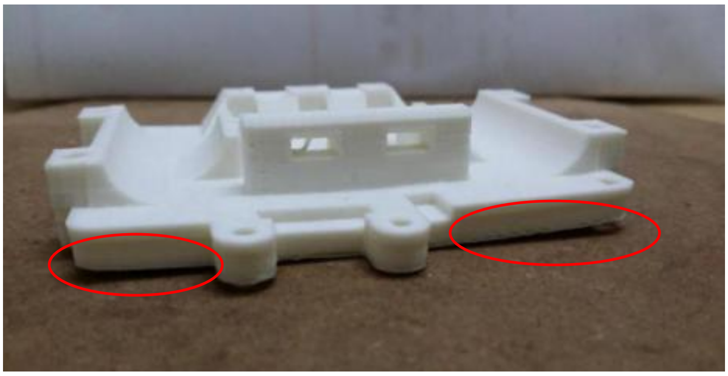


Figure 4.2: Warping problem

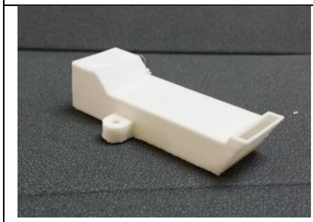
For this reason, all the parts were reprinted by using another 3D printer which is named Anet A8 with the printing parameters as shown in Table 4.2 by using ABS material. The printing quality is satisfying and all the printed parts are listed in the Table 4.3.

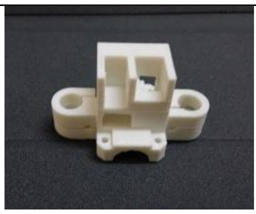
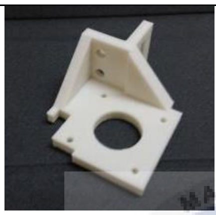
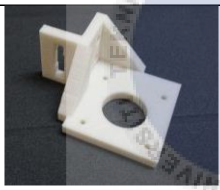
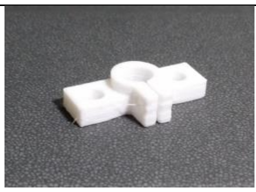
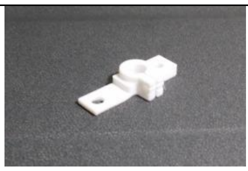
Table 4.2: Printing parameters for fabricated parts

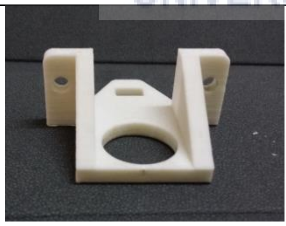
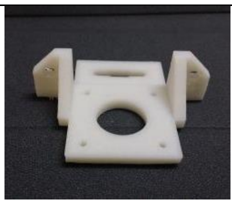
| | |
|---|---|
| Printing speed, mm/s | 30 |
| Layer height, mm | 0.2 |
| Extrusion width, mm | 0.4 |
| Shell thickness, mm | 1.2 |
| Top and bottom thickness, mm | 0.8 |
| Infill density, % | 40 |
| Infill overlap, % | 50 |
| Infill pattern | Line |
| Adhesion Type | Brim |
| Extruder temperature, ℃ | 225 |
| Bed temperature, ℃ | 100 |

Table4.3: List of fabricated parts

| Picture | Description | Quantity (pc) | Printing time (minutes) |
|---|---|---|---|
|  | Bed support<br><br>Support and hold heat bed in place. | 4 | 68 |
|  | Bowden drive mount<br><br>Attach bowden drive extruder to frame. | 1 | 16 |
|  | Dual bushing holder<br><br>Hold two 1020 bushings together. | 2 | 58 |
|  | Extruder clamp<br><br>Clamp the extruder to the extruder mount. | 1 | 22 |
|  | Extruder mount<br><br>Hold the extruder and attached to the X carriage. | 1 | 90 |

| | | | |
|---|---|---|---|
|  | Extruder sensor mount<br><br>Hold the extruder sensor in place. | 1 | 17 |
|  | <u>Fan duct</u><br><br>Direct the air blew from cooling fan to nozzle head. | 1 | 33 |
|  | <u>Spool Axle Clamp</u><br><br>Attach the spool holder to the frame | 1 | 31 |
|  | <u>X carriage clamp</u><br><br>Adjust the tension of timing belt for X and Y axes. | 1 | 4 |
|  | <u>X carriage</u><br><br>The base of the moving platform for X and Y axes. | 1 | 123 |
|  | <u>XY clamp</u><br><br>Clamp the LM8LUU bearing to XY joiner. | 2 | 66 |

| | | | |
|---|---|---|---|
|  | XY Idler<br><br>Served as a idler point for the belt system. | 2 | 64 |
|  | XY joiner<br><br>Served as connection point for X and Y axes. | 2 | 246 |
|  | XY motor left<br><br>Attach the left motor of XY system to the frame. | 1 | 93 |
|  | XY motor right<br><br>Attach the right motor of XY system to the frame. | 1 | 93 |
|  | Y end stop<br><br>Hold Y end stop in place | 1 | 5 |
|  | Y shaft clamp<br><br>Clamp the shaft and attach it to the frame. | 3 | 36 |
|  | Y shaft clamp left motor<br><br>Modification of Y shaft clamp to match the left | 1 | 12 |

| | | | |
|---|---|---|---|
| | motor. | | |
|  | Z carriage<br><br>Enable the movement of heat bed platform in Z axis | 2 | 106 |
|  | Z carriage clamp<br><br>Clamp the LM8UU bearing to the Z carriage. | 4 | 52 |
|  | Z end stop adjust<br><br>Adjust the height of the Z end stop. | 1 | 22 |
|  | Z end stop<br><br>Hold the Z end stop extruder in place. | 1 | 22 |
|  | Z leads crew support<br><br>Guide and support the Z lead crew threaded rod. | 1 | 94 |
|  | Z motor<br><br>Hold and attach the Z motor to the frame. | 1 | 112 |

| | | | |
|---|---|---|---|
|  | Z nut mount<br><br>Mount for the Z lead screw nut. | 1 | 40 |
|  | Z shaft clamp<br><br>Clamp and attach the Z shaft to the frame. | 4 | 112 |
| Total printing time (minutes) | | | 1637 |

### 4.3.2 Standard components

Hypercube 3D printer also compose of many standard components such as mechanical components and electronic components. The mechanical components are consisted of aluminium profiles, screws, nuts, shafts, bearings, bushings, gears, timing belts, pulleys and others. On the other hand, the electronic components are consisting of circuit board, end stops, motors, wires, fans and others. All the standard components purchased with their sources, quantities, and prices are tabulated in Table 4.4.



Table 4.4: List of standard components

| Items | Source | Quantity(pc) | Price/pc (RM) | Price (RM) |
|---|---|---|---|---|
| **Frame** | | | | |
| T-Slot 2020 Aluminum Extrusion Profiles | | | | |

| | | | | |
|---|---|---|---|---|
| 4 x 340mm (X) | Fabgear | 4 | 17.00 | 68.00 |
| 4 x 303mm (Y) | Fabgear | 4 | 14.00 | 56.00 |
| 4 x 350mm (Z) | Fabgear | 4 | 17.00 | 68.00 |
| 2 x 285mm (Bed) | Fabgear | 2 | 14.00 | 56.00 |
| 1 x 135mm (Bed) | Fabgear | 1 | 13.00 | 56.00 |
| | | | Subtotal | 233.00 |
| **Fixings** | | | | |
| M5x8mm button head screws | Fabgear | 70 | 0.20 | 14.00 |
| M5x10mm button head | Fabgear | 70 | 0.25 | 17.50 |
| 2020 Corner Brackets | Shopee | 30 | 0.38 | 11.40 |
| M3x10mm pan head screws | Fabgear | 55 | 0.10 | 5.50 |
| M3x20mm pan head screws | Fabgear | 55 | 0.15 | 8.25 |
| M3x6mm pan head screws | Fabgear | 5 | 0.10 | 0.50 |
| M3x35mm pan head screws | Fabgear | 5 | 0.20 | 1.00 |
| M3 Nyloc nuts | Fabgear | 40 | 0.20 | 8.00 |
| M3 hex nuts | Fabgear | 50 | 0.06 | 3.00 |
| | | | Subtotal | 84.15 |

| | | | | |
|---|---|---|---|---|
| **CoreXY + Z + Bowden Drive System** | | | | |
| 8mmx300mm linear rod | Lab | 2 | 0.00 | 0.00 |
| 8mmx350mm linear rod | Lab | 2 | 0.00 | 0.00 |
| 10mmx360mm linear rod | Shopee | 2 | 10.21 | 20.42 |
| 1012 Self Lubricating Composite Bearing Bushing | Fabgear | 10 | 5.90 | 59.00 |
| LM8UU linear bearing | Fabgear | 4 | 4.90 | 19.60 |
| LM8LUU linear bearing | Shopee | 2 | 7.97 | 15.94 |
| T8 300mm Lead Screw | Shopee | 1 | 6.14 | 6.14 |
| 5x8mm Aluminum Flexible Shaft Coupler | Fabgear | 1 | 6.90 | 6.90 |
| F623ZZ Flange Bearing | Fabgear | 20 | 1.77 | 35.40 |
| GT2 Belt +2 x 20 Tooth Pulleys | Shopee | 1 | 31.91 | 31.91 |
| MK7 Extruder Gear | Fabgear | 1 | 10.00 | 10.00 |
| | | | Subtotal | 205.31 |
| **Motors, Electronics and Accessories** | | | | |

| | | | | |
|---|---|---|---|---|
| NEMA17 Stepper Motor | Lazada | 5 | 25.70 | 128.5 |
| End stop Switch | Jit Seng | 3 | 3.00 | 9.00 |
| RAMPS 1.4 Controller + MEGA2560 R3 + A4988 With Heat Sink+MK2 Heat Bed Kit | Shopee | 1 | 130.00 | 130.00 |
| 12V Blow Radial Cooling Fan | Fabgear | 1 | 12.00 | 12.00 |
| 12V 30A 360W Power Supply | Shopee | 1 | 54.80 | 54.80 |
| Thermistor 100K with 1M Cable for Heat Bed | Fabgear | 1 | 8.00 | 8.00 |
| DC power wire for heat bed | Fabgear | 1 | 3.60 | 3.60 |
| 10M Tinned Copper 22AWG 2 Pin Red Black | Fabgear | 10 | 0.50 | 5.00 |
| Metal J-head hot end extruder | Shopee | 1 | 30.00 | 30.00 |
| | | | Subtotal | 380.90 |
| | | | Total | 903.36 |



## 4.4 Assembled 3D printer

The 3D printer is developed and constructed after all the mechanical and electronic components are readily prepared. The construction of the 3D printer began with the assembly of the frame as shown in Figure 4.3. The frame assembled have height of 350 millimeters, width of 303 millimeters and length of 340 millimeters. Thus, the total volume occupied by the 3D printer is about 0.036 $m^{3.}$

Figure 4.3: Assembled frame

After the frame is assembled, the development process is continued with the installation of mechanical parts which including the printed components, linear shaft, threaded rod, bearing, timing belts and others as shown in Figure 4.4. Since the machine developed is a core XY 3D printer, the printer head will be move in the top section which controlled by the rotation of X and Y motors. The heat bed which is attached to the threaded rod moving up and down in Z axis by the rotation of Z motor.

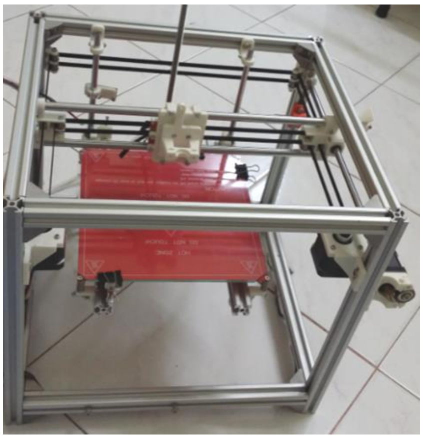


Figure 4.4: Assembled frame with motors and mechanical parts

After that, it is followed by the connection of wires of the motors and other electronic components to the Ramp 1.4 motherboard as shown in Figure 4.5. The connection of wire is carried out by referring to the wiring diagram available from the RepRap website as shown in Figure 3.3. The connection of motor wire is reversed if the motor is rotating in the wrong direction and vice versa.



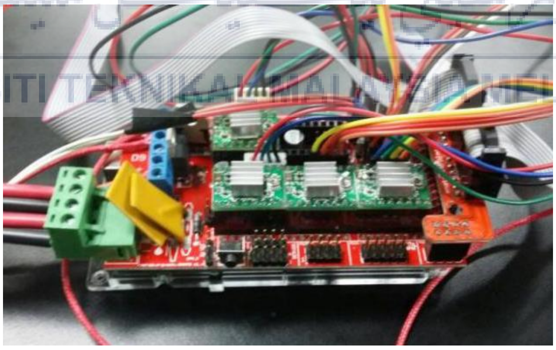


Figure 4.5: Connection of wire to Ramp 1.4 board

The last step is the installation of the LCD display controller board. The main function of LCD display controller board is to display the current information of the 3D printer including the temperature, feed rate, completing percentage, and others as shown in Figure

4.6. Furthermore, it can also enable the user to control the 3D printer without the need of computer and let the user to directly print the file from SD card. The LCD display controller board used is 12864 version which has a bigger screen and can display more detail. The completed 3D printer with mechanical parts, electronic parts and LCD display is shown in the Figure 4.7.

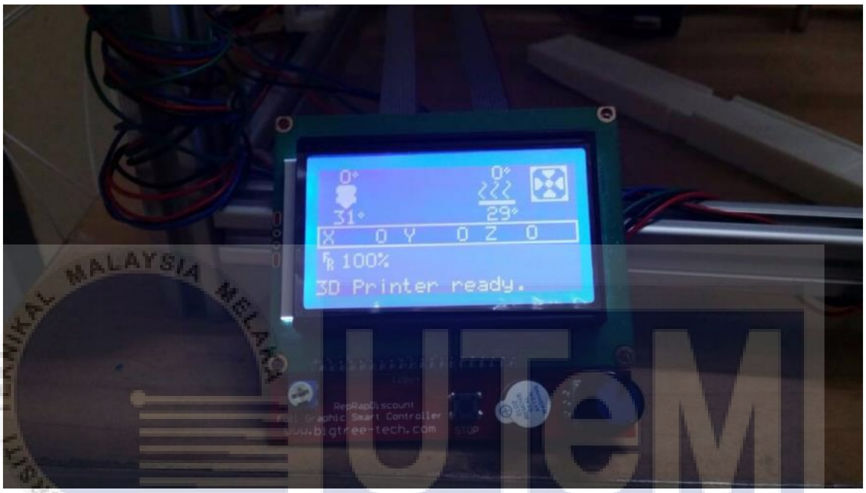



Figure 4.6: LCD display controller board



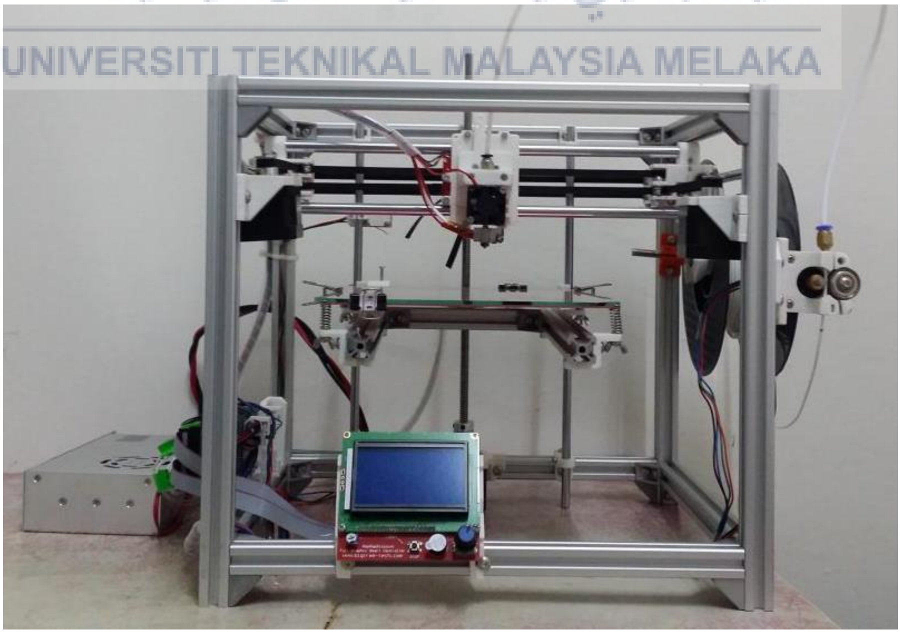


Figure 4.7: Completed 3D printer

## 4.5 Edition of programming code

There are several sections in programming code for different settings such as thermal setting, mechanical setting, end stop setting, movement setting, LCD and SD support setting. Each of them have to be modified to match the requirements of the current 3D printer developed.

In the thermal setting, the temperature sensors must be defined based on the model of temperature sensors applied in the 3D printer. In this project, 100k thermistor which is recognized as category 5 in marlin firmware is used for both heat bed and extruder. After that, the minimum temperature for both heat bed and extruder is set to be 5°C, so the machine will stop working if temperature detected is below these temperatures. On the other hand, the maximum temperature for head bed and extruder is set to be 150°C and 275°C respectively based on their capability.

The mechanical setting is crucial to define the type of the 3D printer machine developed. Since the Hypercube 3D printer is a CoreXY machine, the string #define COREXY is uncommented to activate it while others is deactivated as shown in Figure 4.8.

```
//===========================================================================
//============================= Mechanical Settings =========================
//===========================================================================

// @section machine

// Uncomment one of these options to enable CoreXY, CoreXZ, or CoreYZ kinematics
// either in the usual order or reversed
#define COREXY
//#define COREXZ
//#define COREYZ
//#define COREYX
//#define COREZX
//#define COREZY
```

Figure 4.8: Mechanical setting

In the end stop setting, there are only minimum end stops used for X, Y and Z axis, hence the maximum end stop option is deactivated. Besides, the end stop logic also have to be defined by alternating the true and false option. This is to ensure the end stop is in open state when it is not activated and vice versa.

Furthermore, the main criteria in the movement setting is the step per unit for each axis movement and also the extruder. The step per unit defines how many steps will stepper motor have to make in order to move the axis for distance of one unit. The units can be in millimetres or in inches. The correct step per unit value can be calculated by using the equation of ratio as shown in Equation 4.1.

$$Correct\ step\ per\ unit = \frac{Current\ step\ per\ unit}{Distance\ measured} \times Entered\ distance \quad (4.1)$$

The Z probe setting is used to control the direction in which each axis will moving and also defined the print size of the 3D printer, the direction of the axis can be inverted by changing the value of home direction to be positive or negative value. On the other hand, the X and Y bed size are both set be 220 millimeters based on the shape of the heat bed which is a 220millimeters square while the Z maximum position is set to be 250millimeters based on the maximum height the extruder can reach.

The LCD and SD support setting is used to define the type of LCD display used and active the SD support if available. Since the model of LCD display used is RepRap 12864 full graphic smart controller which is different to the default LCD display, an additional library named U8glib library have been downloaded and added to the firmware to ensure the

LCD display function properly. In addition, the 12864 LCD display also come with a SD card slot, Thus, the SD support is activated in the firmware.

After the edited firmware is successfully compile, it is uploaded to the circuit board through the connection of USB type-B cable. Before the upload process, the model of board and port number are checked to match the actual condition. The model of the board used in this project is Atmega 2560 while the port number can be checked through the device manager under the port option.

## 4.6 Calibration

Calibration process is important to ensure the dimensional accuracy and the material extruded at the correct rate. The calibration of motor movement and levelling of heat bed done is discussed in the following section.



### 4.6.1 Calibration of motor movement

Calibration of motor movement is carried out for every motor installed on the 3D printer. The calibration process for X and Y motors are carried out by instruct the extruder to move a distance of 10 millimeters and measure the actual distance travelled as shown in Figure 4.9. The difference between the entered distance and measured distance is then used to calculate the correct step per unit from current step per unit by using the Equation 4.1.

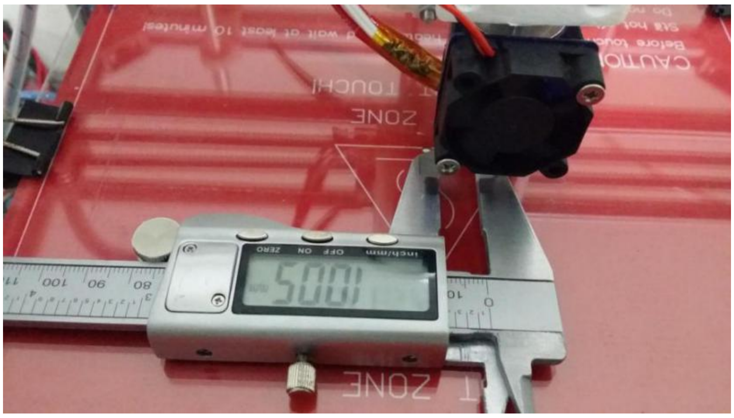


Figure 4.9: Measurement of actual distance travelled by the extruder

Similarly, the calibration for Z motor is carried out by instruct the heat bed to move a vertical distance of 10 millimeters and measure the actual distance traveled as shown in Figure 4.10. The correct step per unit for Z motor is then determined by using Equation 4.1.

Figure 4.10: Measurement of actual distance travelled by the heat bed

On the other hand, the calibration for extruder motor is carried out by inserting a filament into the extruder and making a mark on the filament. After that, the extruder motor is instructed to extrude the filament backward at a distance of 10 millimeters. The distance between the initial and final position of the mark is then measured as shown in Figure 4.11 and the correct step per unit value is determined by using Equation 4.1 as well.

Figure 4.11: Measurement of actual distance travelled by the mark on filament

After all the correct step per unit value for each motor is determined. The final value is keyed into the original programming code and reuploaded to the Mega 2560 board by using IDE Arduino software.

### 4.6.2 Leveling of heat bed

Leveling of heat bed is an important calibration process to ensure a good quality of print and prevent the warping problem. The leveling process is started by homing the heat bed to the zero Z position. If the heat bed is too close to the extrude nozzle, the adjusting screw is lifted by rotating the screw anti-clockwise as shown in Figure 4.12 and vice versa. The adjusting screw is adjusted until the distance between the extruder nozzle and heat bed is slightly higher than the height of a piece of paper. After that, the extruder is moved to the position just above the leveling screw and a piece of A4 paper is inserted between the heat bed and the extruder nozzle. The leveling screw is adjusted until the paper is free to pull by one hand while there is still a little bit of friction. This meant the distance between the extruder nozzle and heat bed is just about the thickness of a piece of paper which is around 0.2 millimeters. This process is then repeated for every leveling screw at each of the corner of the heat bed.

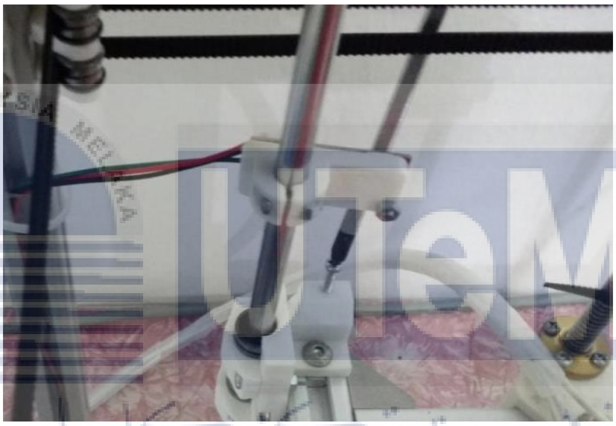


Figure 4.12: Adjustment of adjusting screw



## 4.7 Summary

The developed 3D printer is function properly at the end of the machine development process. Specimens are successfully prepared and analysis is conducted to compare the performance between developed 3D printer and commercial 3D printer. The results obtained from the analysis conducted is discussed in the next chapter.

# CHAPTER 5

# RESULTS AND DISCUSSION

## 5.1 Introduction

Three analyses have been conducted which are the surface roughness analysis, dimensional accuracy analysis and porosity analysis. The results obtained from the analysis are tabulated and discussed in the following sections. The comparison is then made between the developed 3D printer and commercial 3D printer.



## 5.2 Surface roughness analysis

The surface roughness analysis is conducted by measuring the surface roughness of the printed specimen by using the 3D non-contact profilometer as mentioned in the previous chapter. The 3D non-contact profilometer used Winroff software to generate surface roughness report with the value of surface roughness is defined. The surface roughness report generated including the 3D profile of the surface, graph of surface roughness, and table of results as shown in Figure 5.1, Figure 5.2 and Table 5.1 respectively.

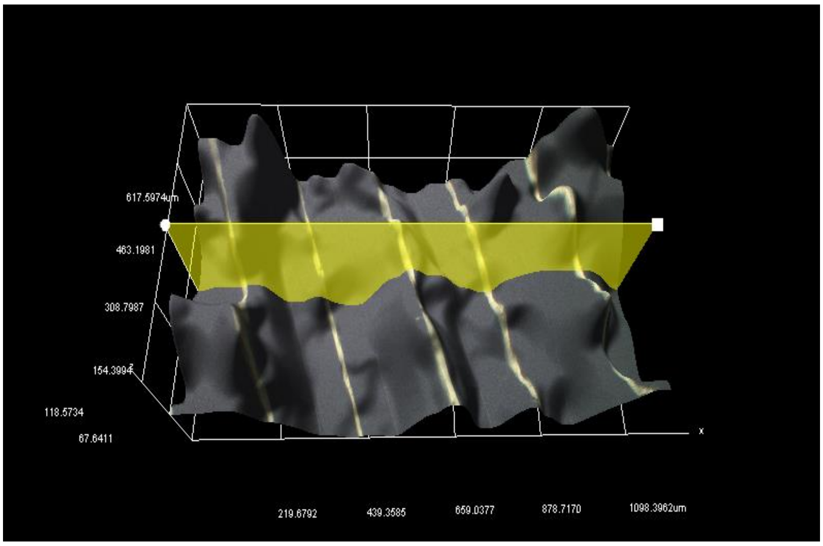



Figure 5.1: 3D profile of surface generated by Winroff software

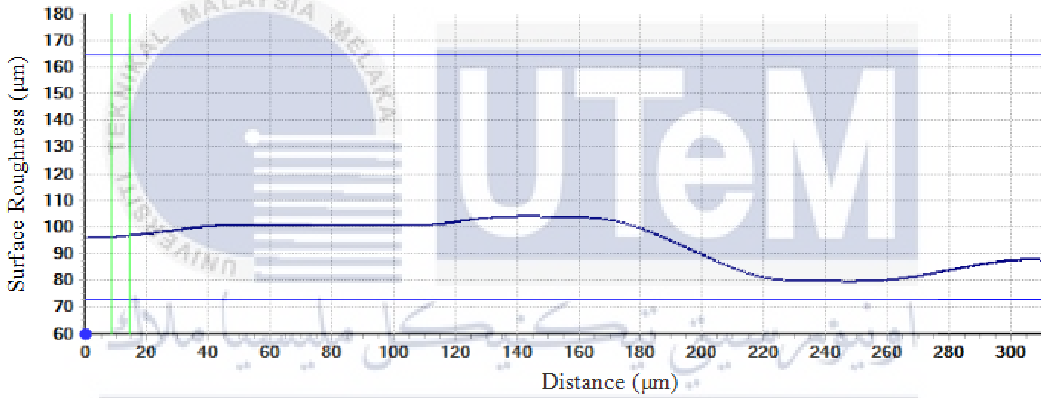





Figure 5.2: Graph of surface roughness generated by Winroff software

Table 5.1: Table of results generated by Winroff software

| Name | Value | Unit |
|---|---|---|
| Height | 91.6804 | um |
| Width | 5.7238 | um |
| Area | 134.411 | um^2 |

| | | |
|---|---|---|
| Diagonal | 91.8589 | um |
| Surface Length | 5.7528 | um |
| Roughness Ra | 10.4635 | um |
| Roughness Rz | 39.179 | um |
| Roughness Rzjis | 32.6119 | um |

All the measurements taken on the surface of the specimens printed by both developed 3D printer and commercial 3D printer are tabulated in Table 5.2. The average values are calculated for each of the printer and comparison is made between them as shown in Figure 5.3.



Table 5.2: Results of surface roughness

| Points | Surface Roughness, Ra | |
|---|---|---|
| | Developed 3D printer | Commercial 3D printer |
| 1 | 5.5851 | 5.7528 |
| 2 | 5.7248 | 13.1037 |
| 3 | 5.7255 | 9.6012 |
| 4 | 10.2241 | 9.1533 |
| 5 | 18.1829 | 12.8824 |

| | | |
|---|---|---|
| 6 | 8.6732 | 11.1574 |
| 7 | 10.9083 | 9.4069 |
| 8 | 11.4042 | 18.0251 |
| 9 | 11.8894 | 18.0577 |
| Average | 9.8131 | 11.9045 |

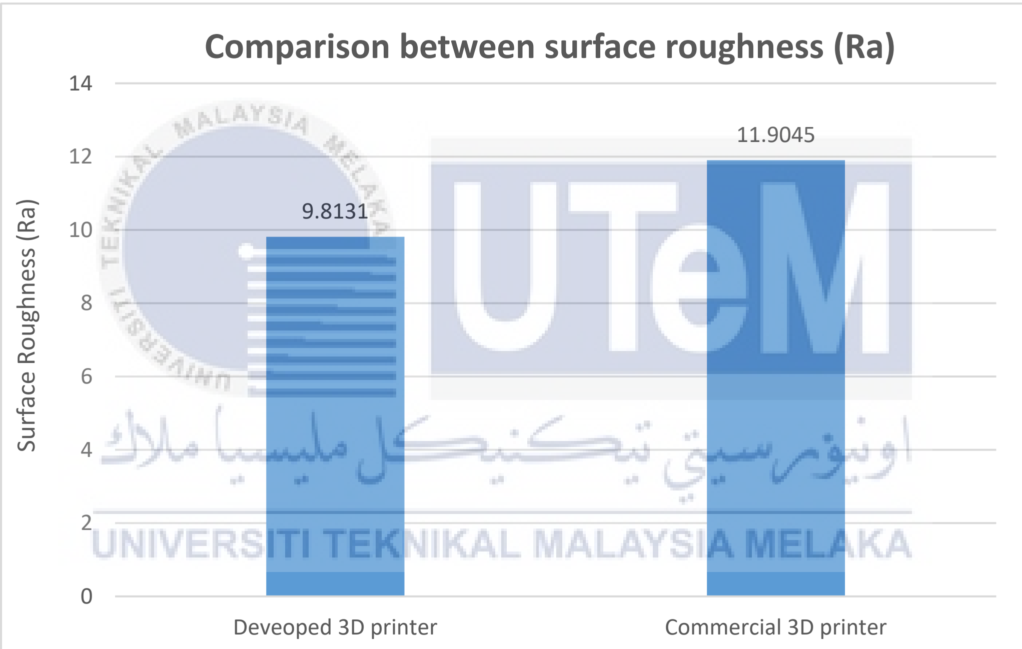



Figure 5.3: Comparison between surface roughness

The results shown the average value of surface roughness for specimens printed by developed 3D printer and commercial 3D printer are 9.8131 Ra and 11.9045 Ra respectively. This shown that the surface roughness of specimens printed by developed 3D printer is 17.57% lower than the surface roughness of specimens printed by commercial 3D printer. Therefore, the developed 3D printer is 17.57% better in performance as compared to commercial 3D printer in term of surface roughness.

## 5.3 Dimensional accuracy analysis

Dimensional accuracy analysis is conducted by measuring the dimension of the 2 mm cube specimens by both developed 3D printer and commercial 3D printer by using digital vernier calliper. All the measurements taken is tabulated and the average value is calculated as shown in the Table 5.3 and Table 5.4 respectively.



Table 5.3: Dimensional accuracy results for developed 3D printer

| Side | Dimension (mm) | | | Average value (mm) |
|---|---|---|---|---|
| | Specimen 1 | Specimen 2 | Specimen 3 | |
| L1 | 20.20 | 20.09 | 20.1 | 20.1300 |
| L2 | 20.13 | 20.17 | 20.15 | 20.1500 |
| L3 | 20.01 | 20.07 | 20.06 | 20.0467 |
| Average length (mm) | | | | 20.1089 |
| W1 | 20.17 | 20.15 | 20.18 | 20.1667 |
| W2 | 20.06 | 20.20 | 20.16 | 20.1400 |
| W3 | 20.07 | 20.13 | 20.13 | 20.1100 |

| | | | | |
|---|---|---|---|---|
| Average width (mm) | | | | 20.1389 |
| H1 | 20.41 | 20.28 | 20.22 | 20.3033 |
| H2 | 20.42 | 20.29 | 20.28 | 20.3300 |
| H3 | 20.30 | 20.18 | 20.35 | 20.2767 |
| Average height (mm) | | | | 20.3033 |

Table 5.4: Dimensional accuracy results for commercial 3D printer

| Side | Dimension (mm) | | | Average value (mm) |
|---|---|---|---|---|
| | Specimen 1 | Specimen 2 | Specimen 3 | |
| L1 | 20.01 | 20.02 | 20.08 | 20.0367 |
| L2 | 20.03 | 19.91 | 20.04 | 19.9933 |
| L3 | 20.02 | 19.86 | 19.95 | 19.9433 |
| Average length (mm) | | | | 19.9911 |
| W1 | 19.84 | 20.04 | 20 | 19.9600 |
| W2 | 19.83 | 19.98 | 19.96 | 19.9233 |
| W3 | 19.84 | 20.03 | 19.96 | 19.9433 |
| Average width (mm) | | | | 19.9422 |
| H1 | 19.81 | 19.79 | 19.73 | 19.7767 |

| | | | | |
|---|---|---|---|---|
| H2 | 19.83 | 19.75 | 19.75 | 19.7767 |
| H3 | 19.73 | 19.81 | 19.81 | 19.7833 |
| Average height (mm) | | | | 19.7789 |

The percentage errors are then determined by using Equation 5.1 and tabulated in Table 5.5 while comparison is made between developed 3D printer and commercial 3D printer as shown in Figure 5.4.

$$Percentage\,Error(\%) = \frac{|Approximate\,Value - Exact\,Value|}{|Exact\,Value|} \times 100\% \qquad (5.1)$$

Table 5.5: Percentage error of dimensional accuracy analysis

| Description | Developed 3D printer | | Commercial 3D printer | |
|---|---|---|---|---|
| | Average value (mm) | Percentage error (%) | Average value (mm) | Percentage error (%) |
| Height | 20.1089 | 0.54 | 19.9911 | 0.04 |
| Width | 20.1389 | 0.69 | 19.9422 | 0.29 |
| Length | 20.3033 | 1.52 | 19.7789 | 1.11 |
| Average value | 20.1837 | 0.92 | 19.9041 | 0.48 |

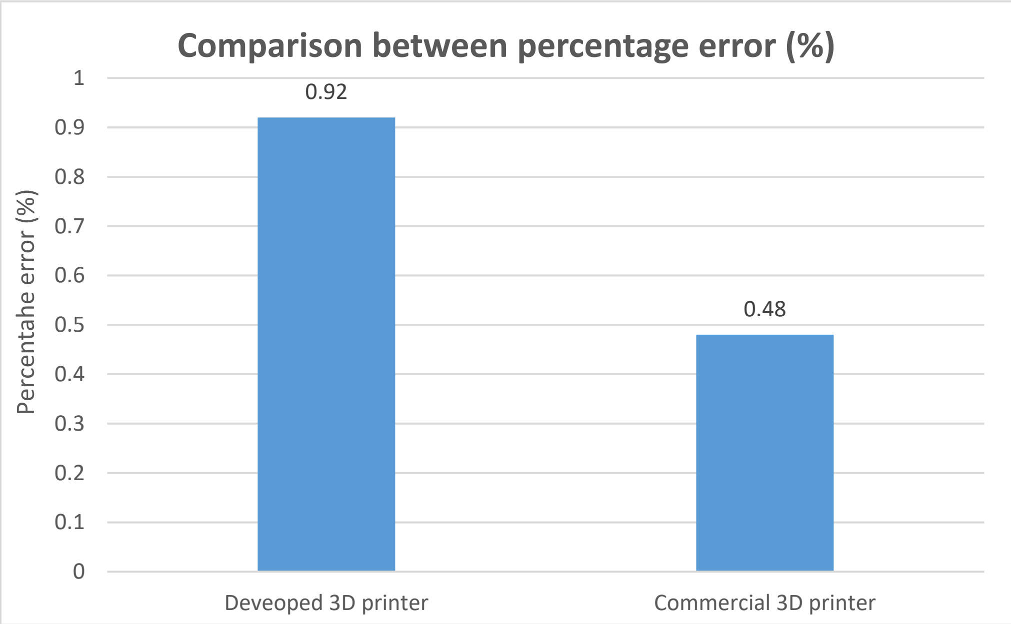



Figure 5.4: Comparison between percentage error

From the results, the percentage error of dimensional accuracy for developed 3D printer and commercial 3D printer are 0.92% and 0.48%. This shown that the developed 3D printer has a lower dimensional accuracy as compared to commercial 3D printer.



## 5.4 Porosity analysis

The porosity is a function of bulk density and particle density of the printed specimen as shown in Equation 5.2. Firstly, the bulk density have to be calculated by using the Equation 5.3. The weight of the specimen is measured by using the electronic balance model ATX 224 and tabulated in Table 5.6. The volume of the specimens is calculated based on the average value of length, width and height obtained from previous section by using Equation 5.4. Furthermore, the particle density of PLA is determined by using the Equation

5.5 and the results of porosity are tabulated in Table 5.7. Then comparison is then made between developed 3D printer and commercial 3D printer as shown in Figure 5.5.

$$Porosity(Pt) = 1 - \frac{Bulk\ density(Pb)}{Particle\ density(Pd)} \tag{5.2}$$

$$Bulk\ density(Pb) = \frac{mass(m)}{volume(V)} \tag{5.3}$$

Table 5.6: Weights of specimens

| Numbers | Weight, g | |
|---|---|---|
| | Developed 3D printer | Commercial 3D printer |
| 1 | 10.1597 | 9.6270 |
| 2 | 10.1932 | 9.5588 |
| 3 | 10.1765 | 9.5256 |
| Average | 10.1765 | 9.5705 |



$$volume(V) = height(h) \times width(w) \times length(l) \tag{5.4}$$

The particle density is determined by calculate the density of the material applied to print the specimens. The material used in this project is 1 kilogram PLA with the diameter of 1.75 millimeters and length of 325 meters.

$$Particle\ density(Pd) = \frac{W}{\pi \times r^2 \times L} \tag{5.5}$$

| | | | |
|---|---|---|---|
| where, | Weight of filament, W | = 1 | kg |
| | | = 1000 | g |
| | Radius of filament, r | = 0.875 | mm |
| | | = 0.0875 | cm |
| | Length of filament, L | = 325 | m |
| | | = 32500 | cm |

Hence, $$Particle\,density, Pd = \frac{1000}{\pi \times 0.0875^2 \times 32500} \quad g/cm^3$$

$$= 1.2792 \quad g/cm^3$$



Table 5.7: Results of porosity

| Specification | Developed 3D printer | Commercial 3D printer |
|---|---|---|
| Average weight, g | 10.1765 | 9.5705 |
| Volume, $cm^3$ | 8.2223 | 7.8852 |
| Bulk density, $g/cm^3$ | 1.2377 | 1.2137 |
| Porosity | 0.0325 | 0.0512 |
| Porosity (%) | 3.25 | 5.12 |

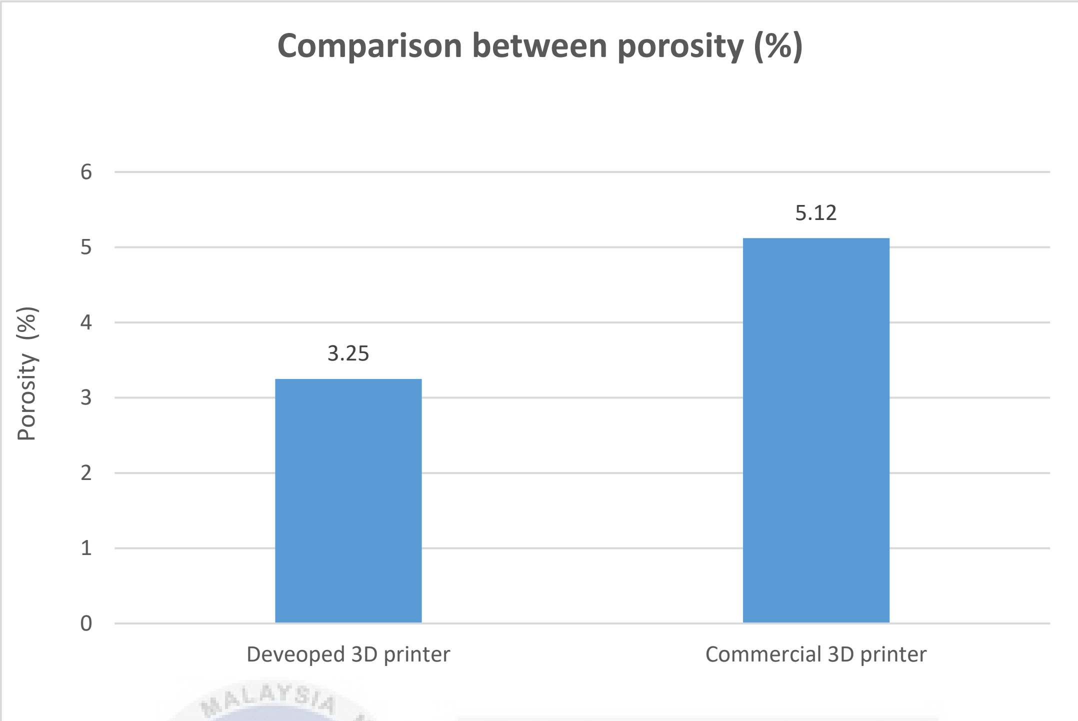



Figure 5.5: Comparison between porosity

The result shown the porosity of specimens printed by developed 3D printer and commercial 3D printer are 3.25% and 5.12% respectively. This shown that the developed 3D printer has a higher performance as compared to commercial 3D printer in term of porosity. Therefore, the printed specimens of developed have a higher density and closer to the expectation.

## 5.5 Summary

The results obtained from the analysis conducted is summarized and tabulated in Table 5.8.

Table 5.8: Summarized results from the analysis conducted

| Description | Developed 3D printer | Commercial 3D printer |
|---|---|---|
| Surface Roughness, Ra | 9.8131 | 11.9045 |
| Dimensional percentage error, % | 0.92 | 0.48 |
| Porosity, % | 3.25 | 5.12 |

The results from analysis conducted shown that the developed 3D printer outperformed commercial 3D printer in term of surface roughness and porosity. However, the dimensional percentage error of developed 3D printer is higher than the commercial 3D printer.

# CHAPTER 6

# CONCLUSION AND RECOMMENDATION

This project has shown the potential of developed open source 3D printer in achieving performance better than commercial 3D printers. The developed 3D printer had outperformed the commercial 3D printer in term of surface roughness and porosity. However, the dimensional accuracy of the developed 3D printer is inferior as compared to the commercial 3D printer.

The objectives of the project have been achieved whereby a low-cost 3D printing machine is constructed and developed at a very low cost as compared to commercial 3D printer. Besides, surface roughness analysis, dimensional accuracy analysis and porosity analysis have been conducted to study the performance of the 3D printer. Furthermore, the comparison is made between the developed 3D printer and commercial 3D printer.

Improvement in the dimensional accuracy is recommended by adjusting the step per unit value of the X and Y motors. In addition, more efforts are suggested to put in design and development of 3D printer with higher performance. Improvements on the existing design of 3D printer are also highly recommended by adding new features and components.

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## APPENDIX

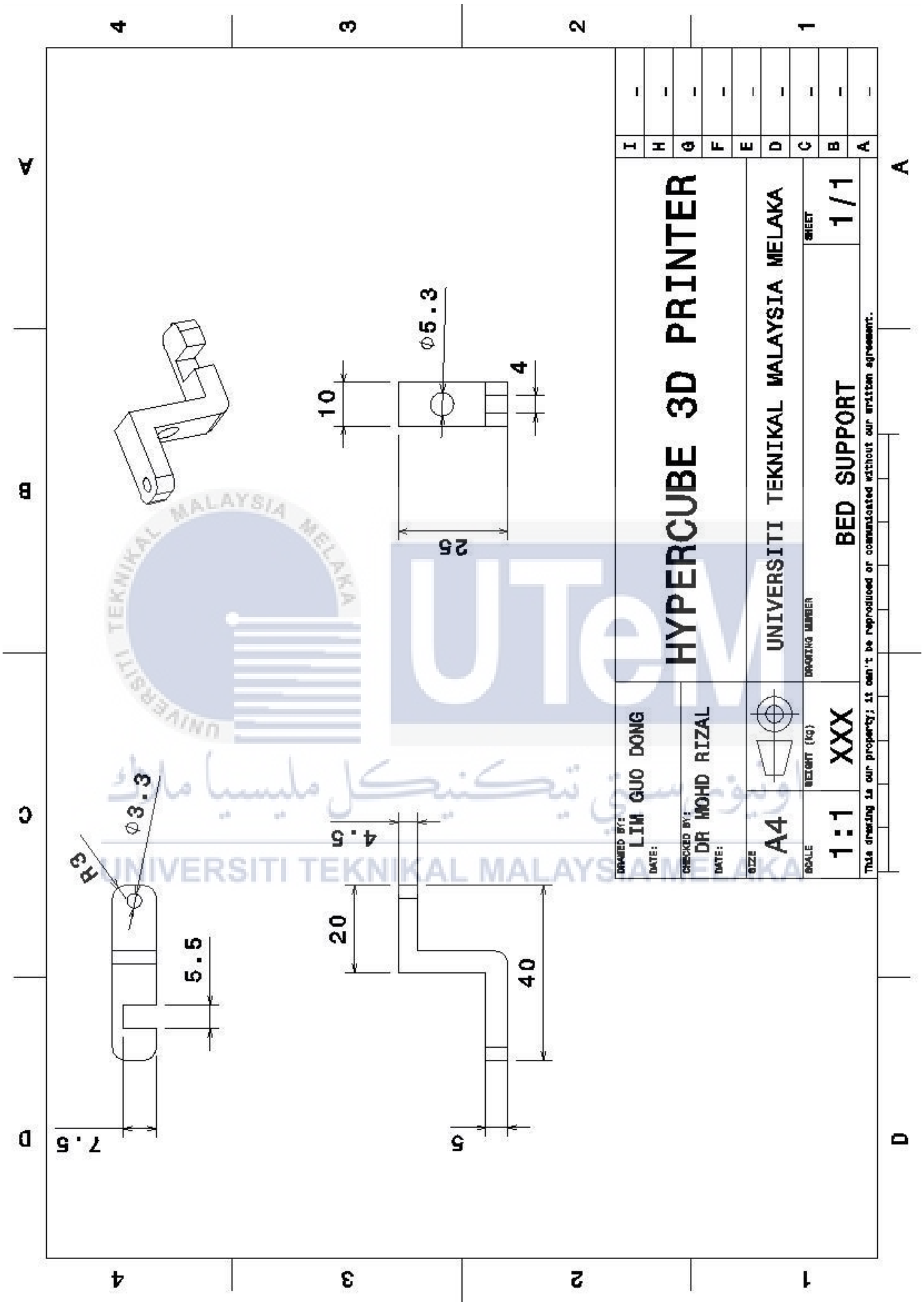


Figure A1: Dimension drawing of bed support

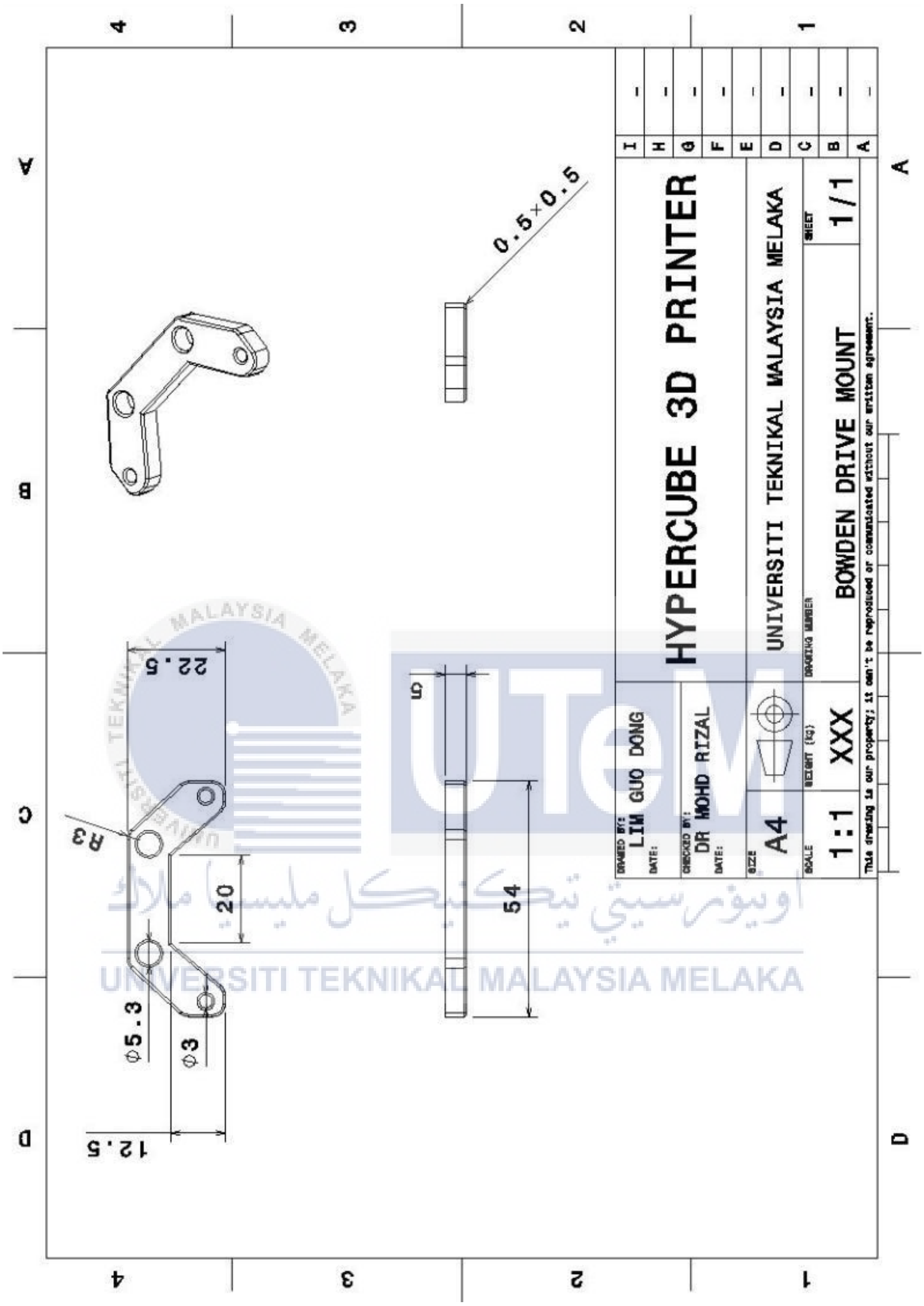


Figure A2: Dimension drawing of bowden drive mount

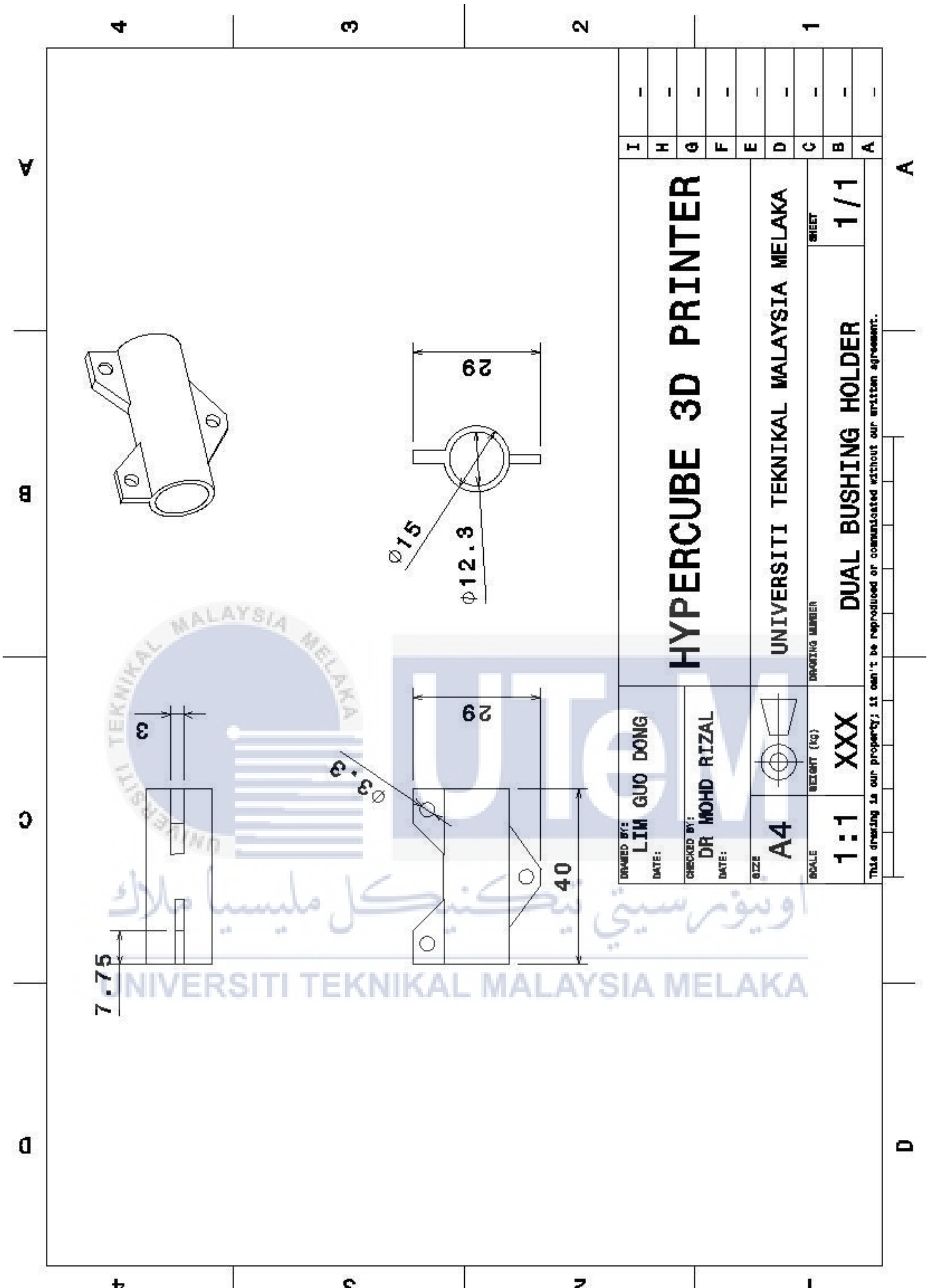


Figure A3: Dimension drawing of dual bushing holder

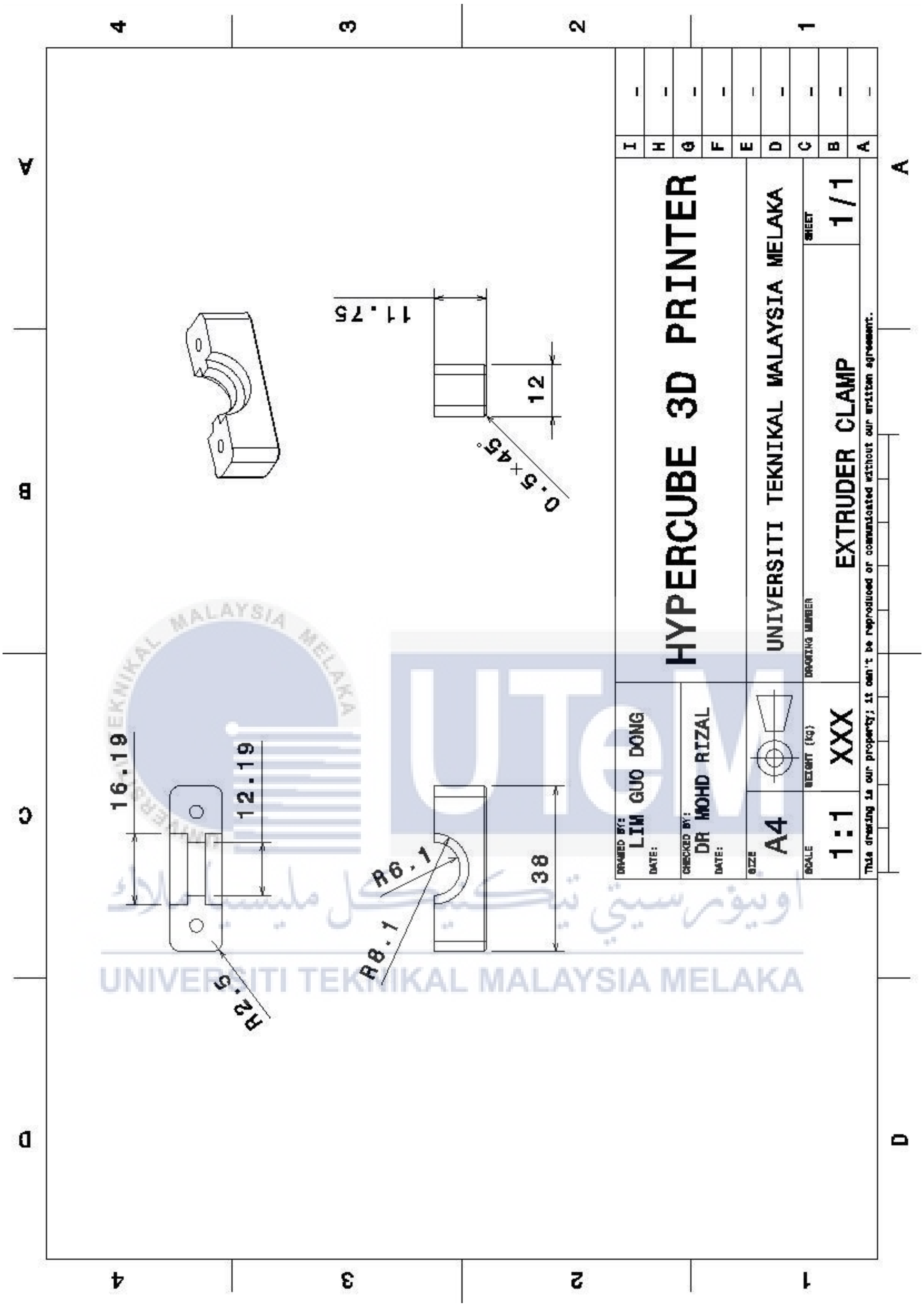


Figure A4: Dimension drawing of extruder clamp

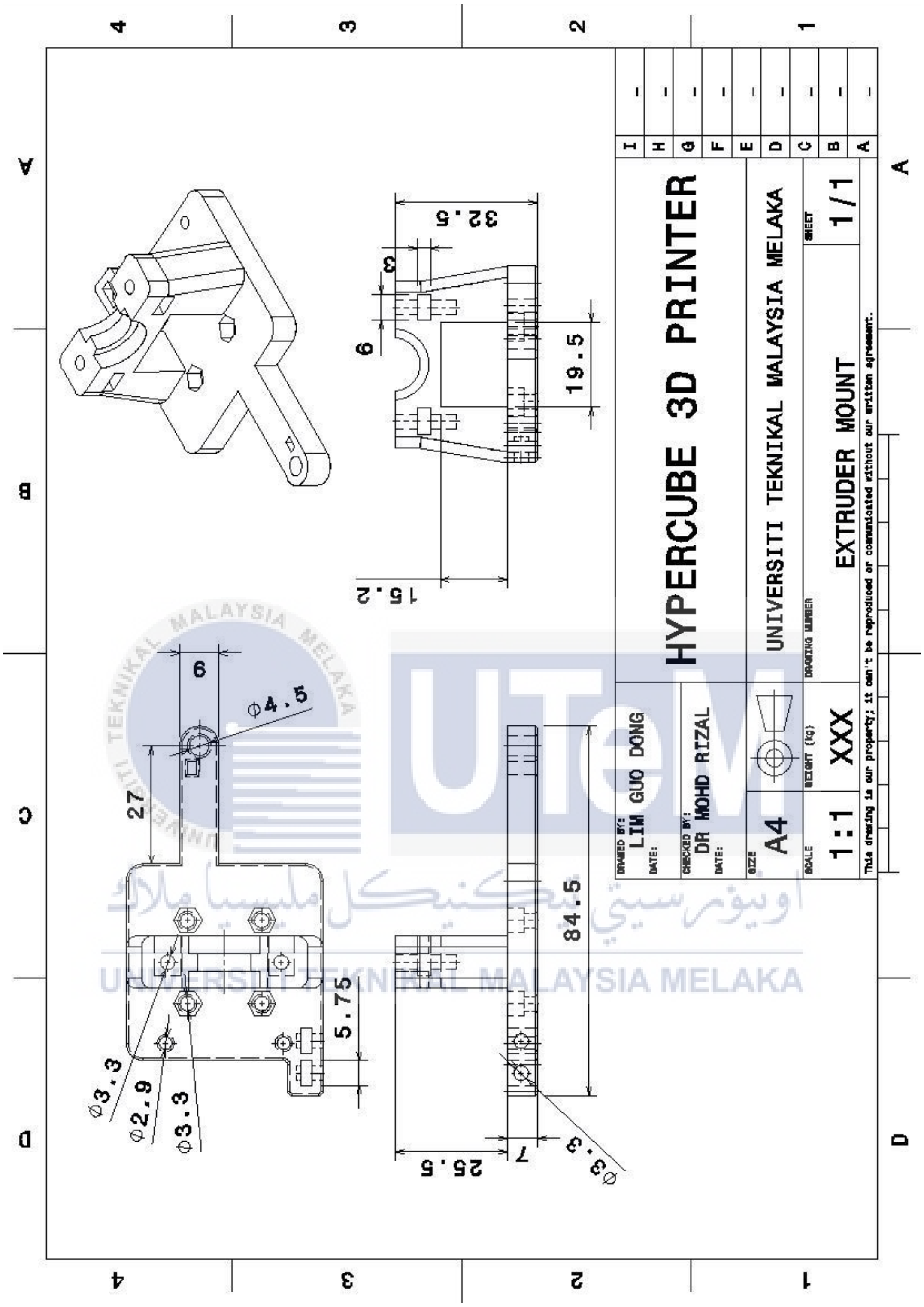


Figure A5: Dimension drawing of extruder mount

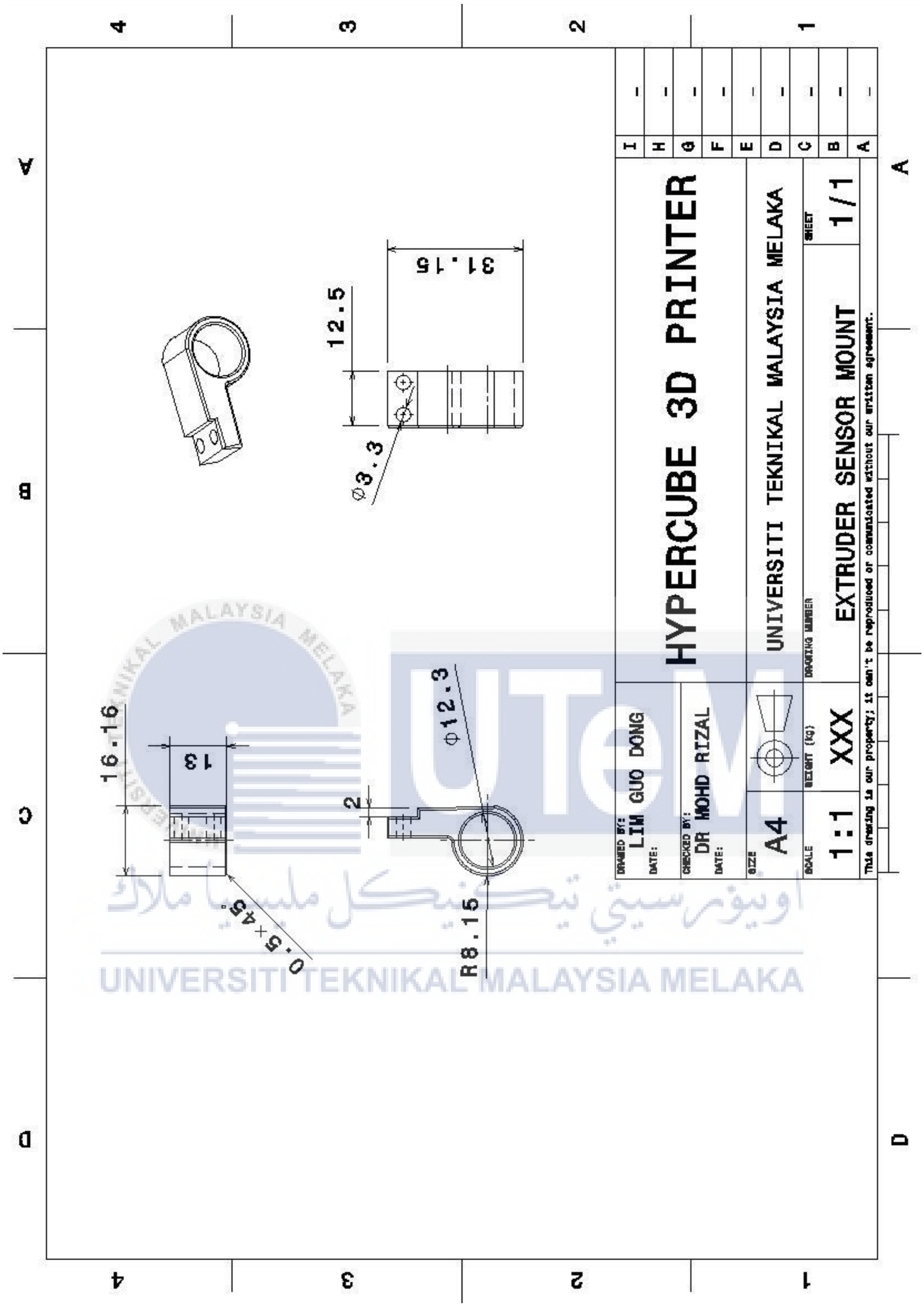


Figure A6: Dimension drawing of extruder sensor mount

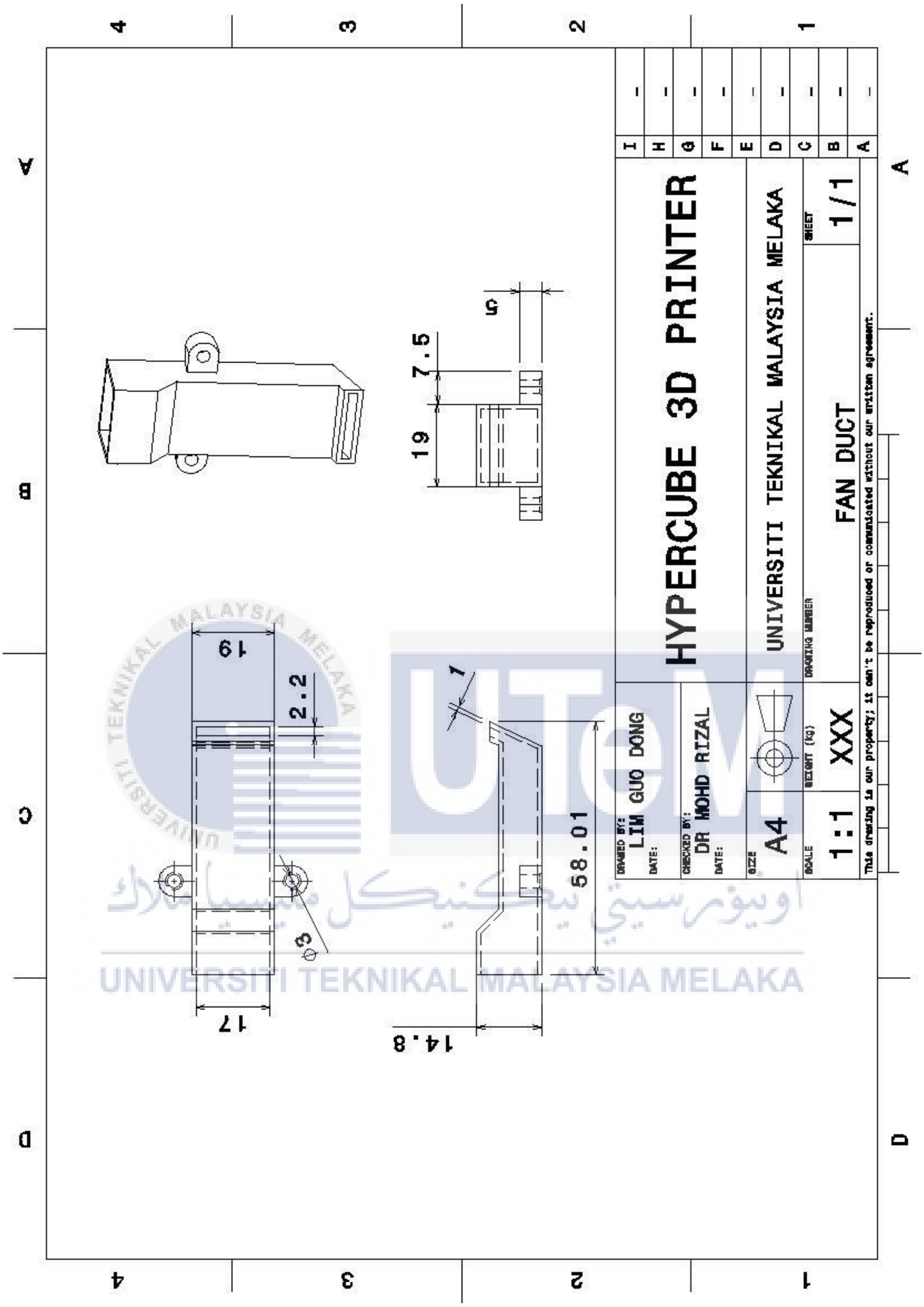


Figure A7: Dimension drawing of fan duct

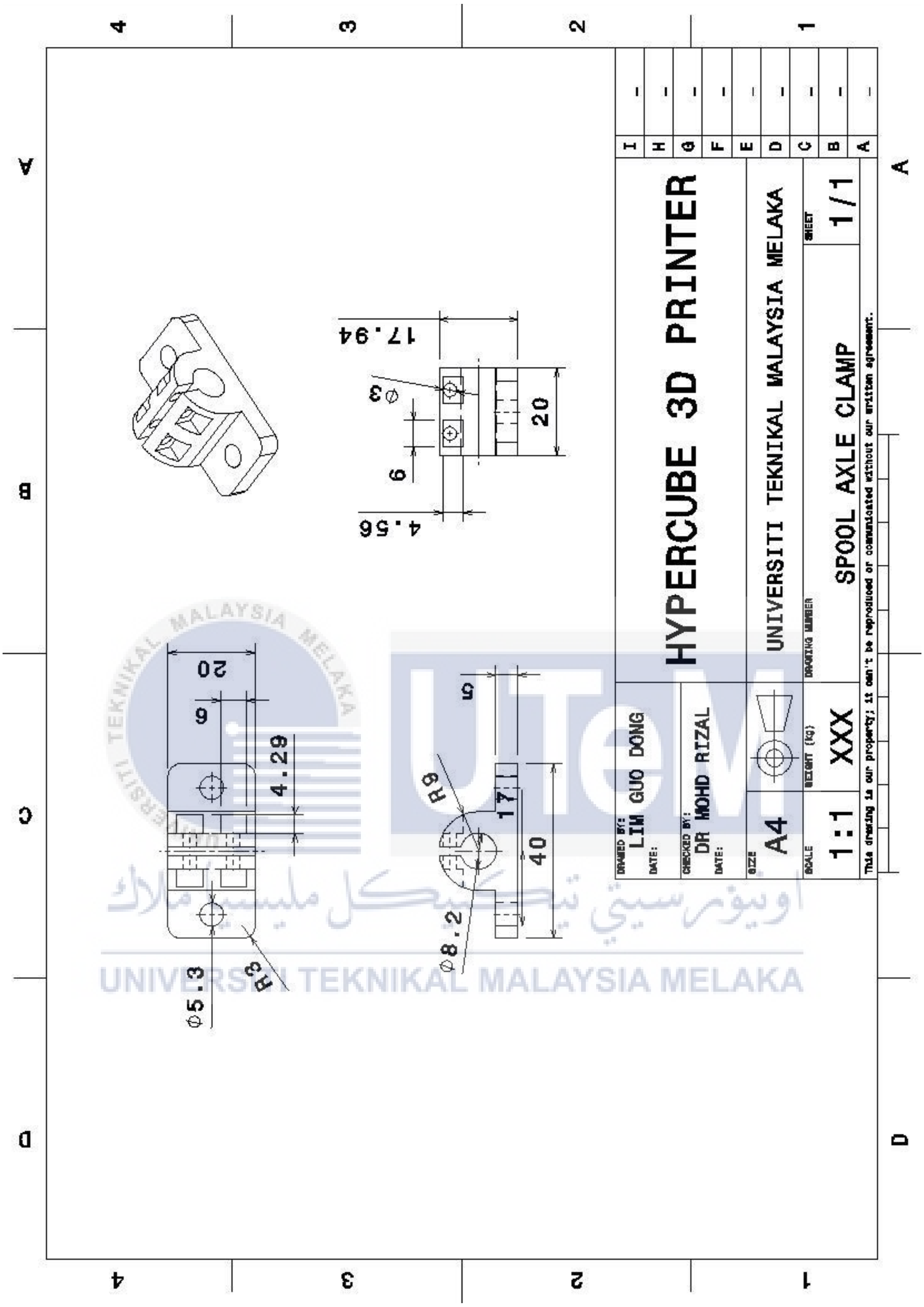


Figure A8: Dimension drawing of spool axle clamp

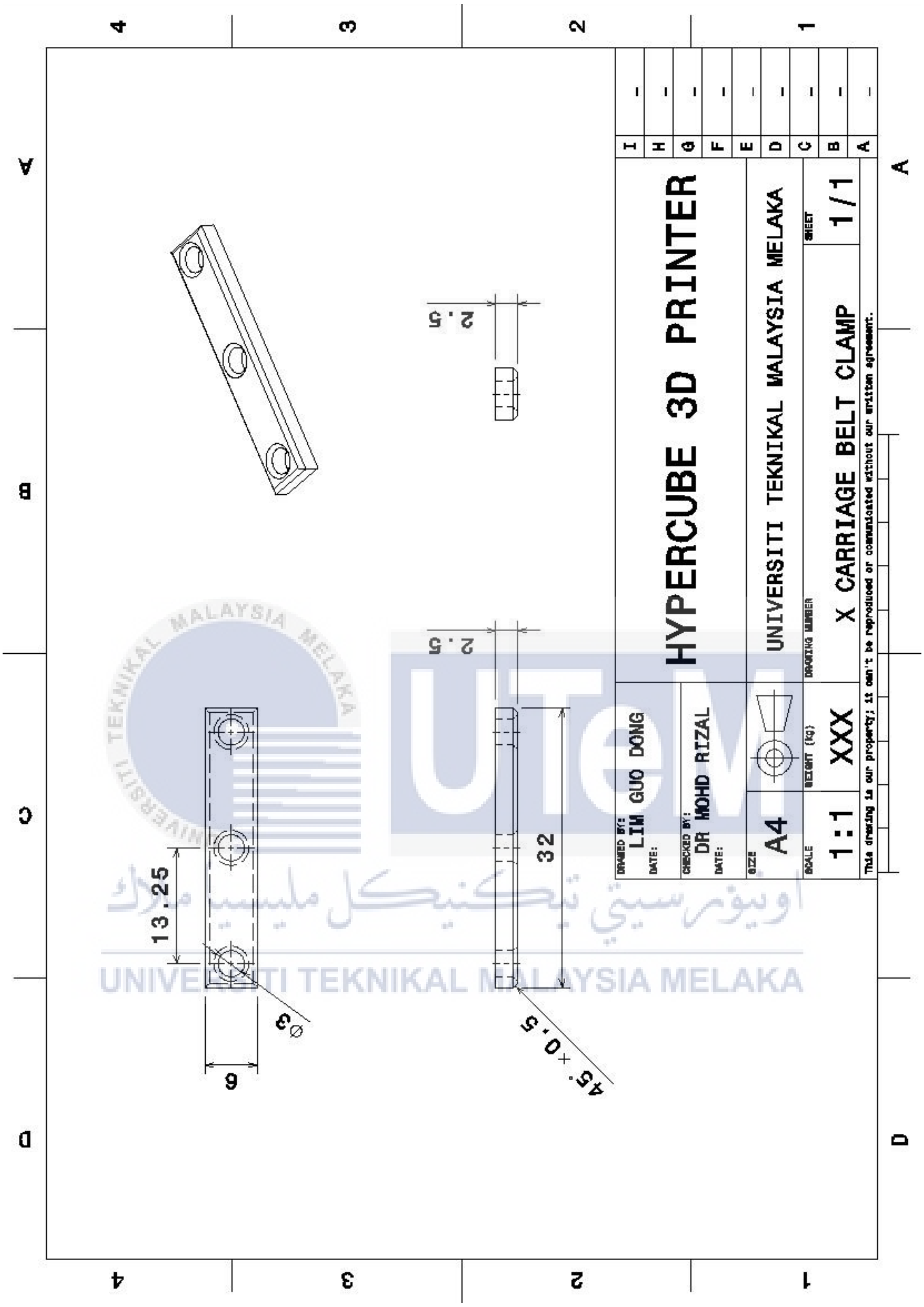


Figure A9: Dimension drawing of X carriage belt clamp

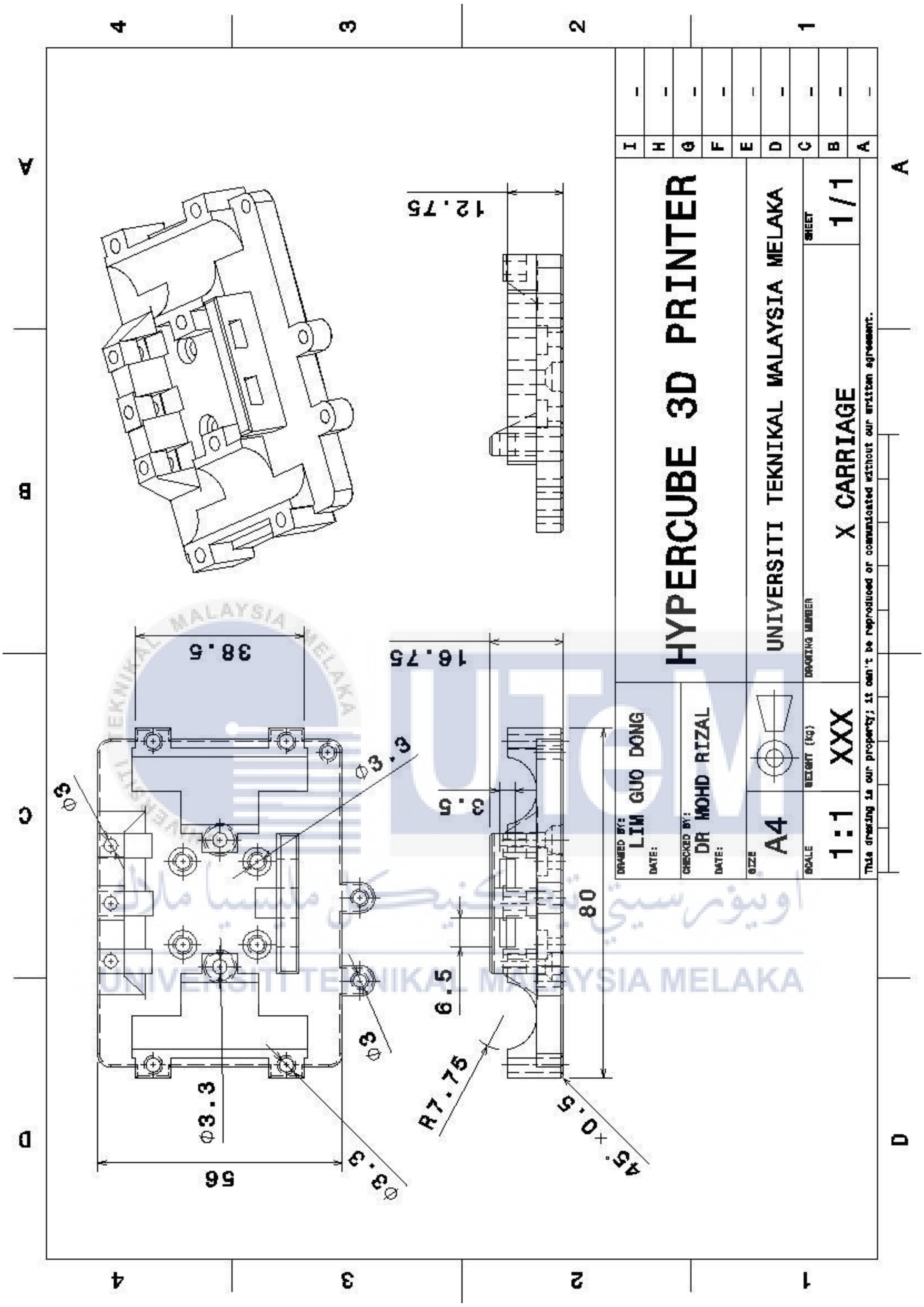


Figure A10: Dimension drawing of X carriage

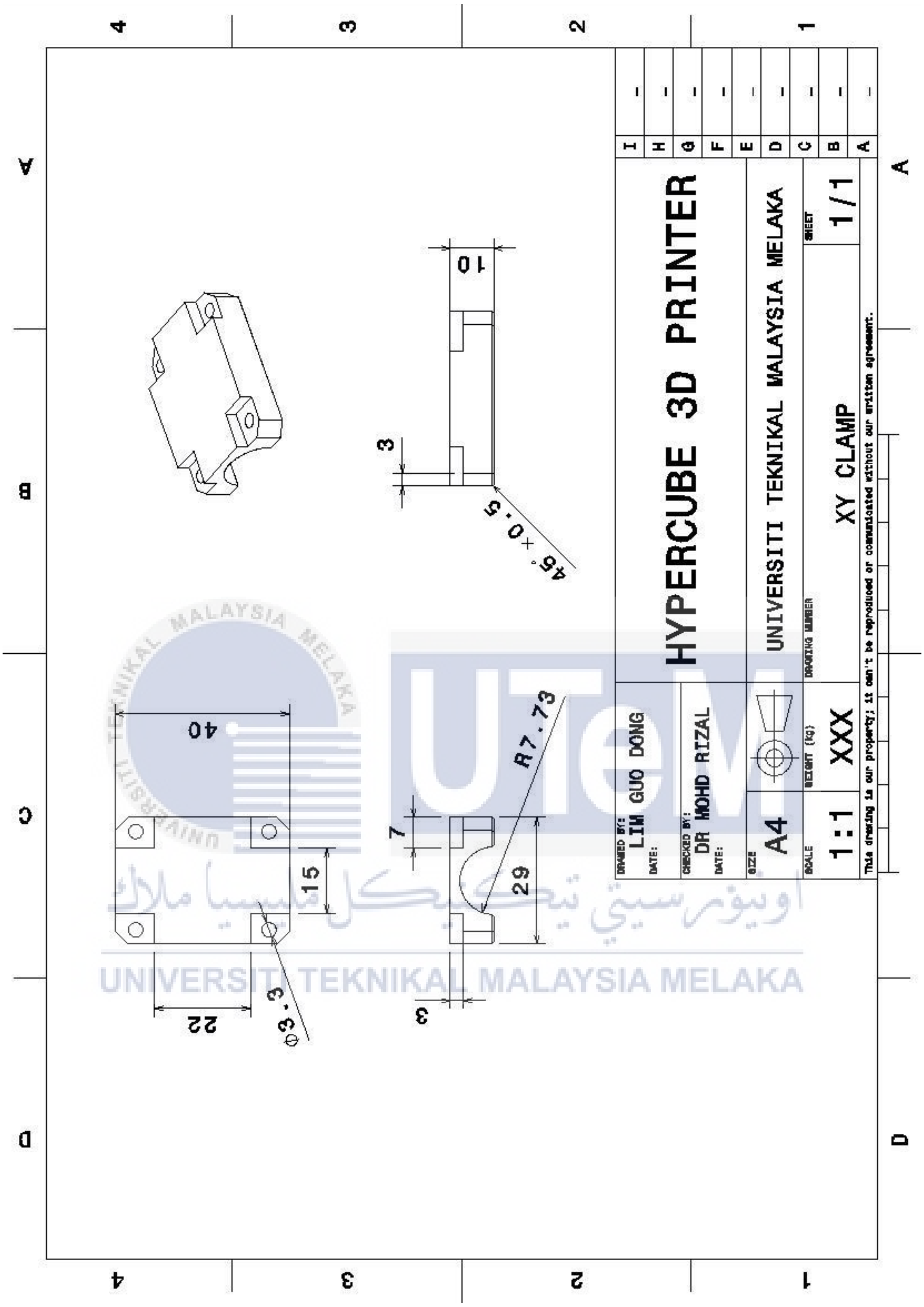


Figure A11: Dimension drawing of XY clamp

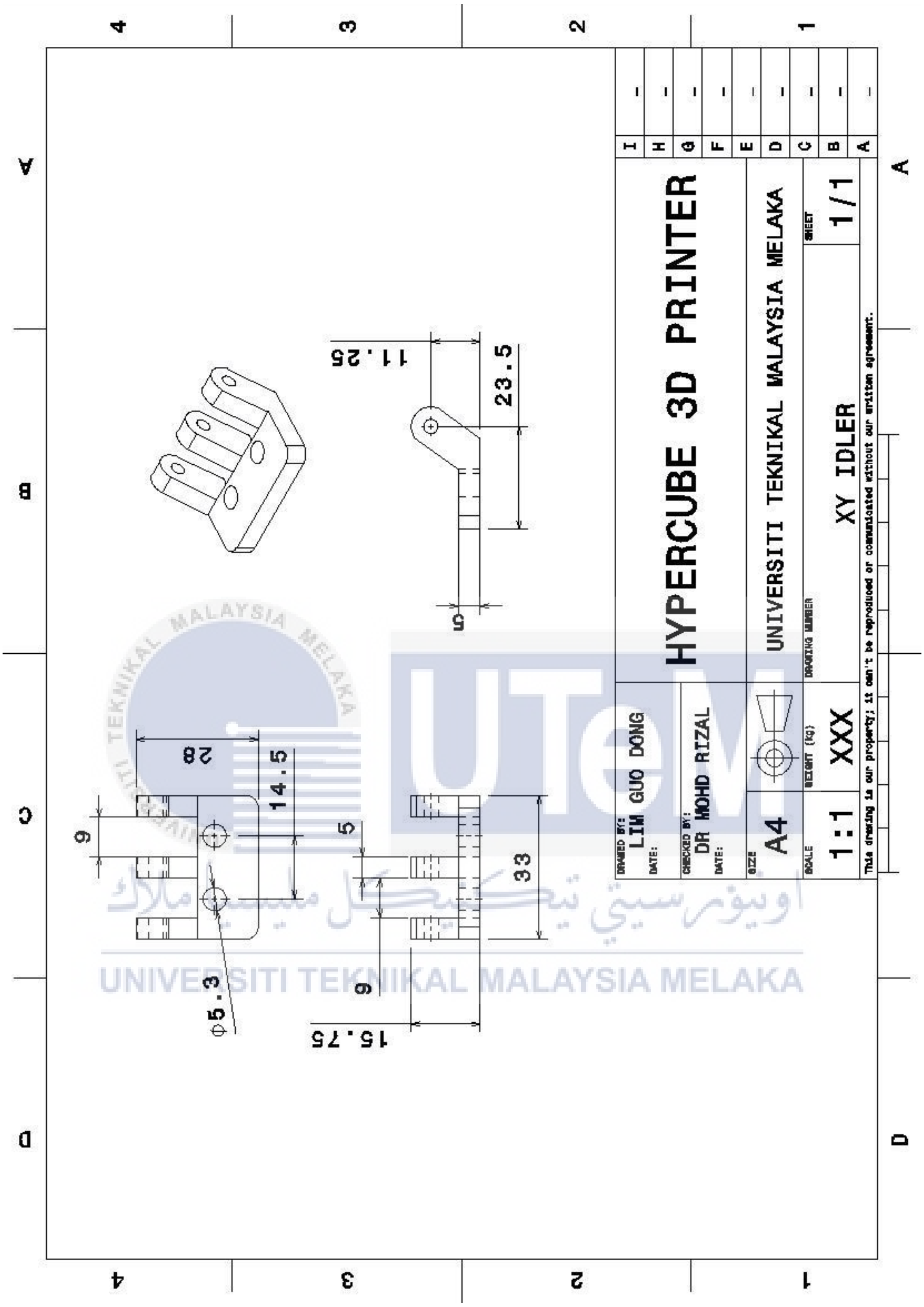


Figure A12: Dimension drawing of XY idler

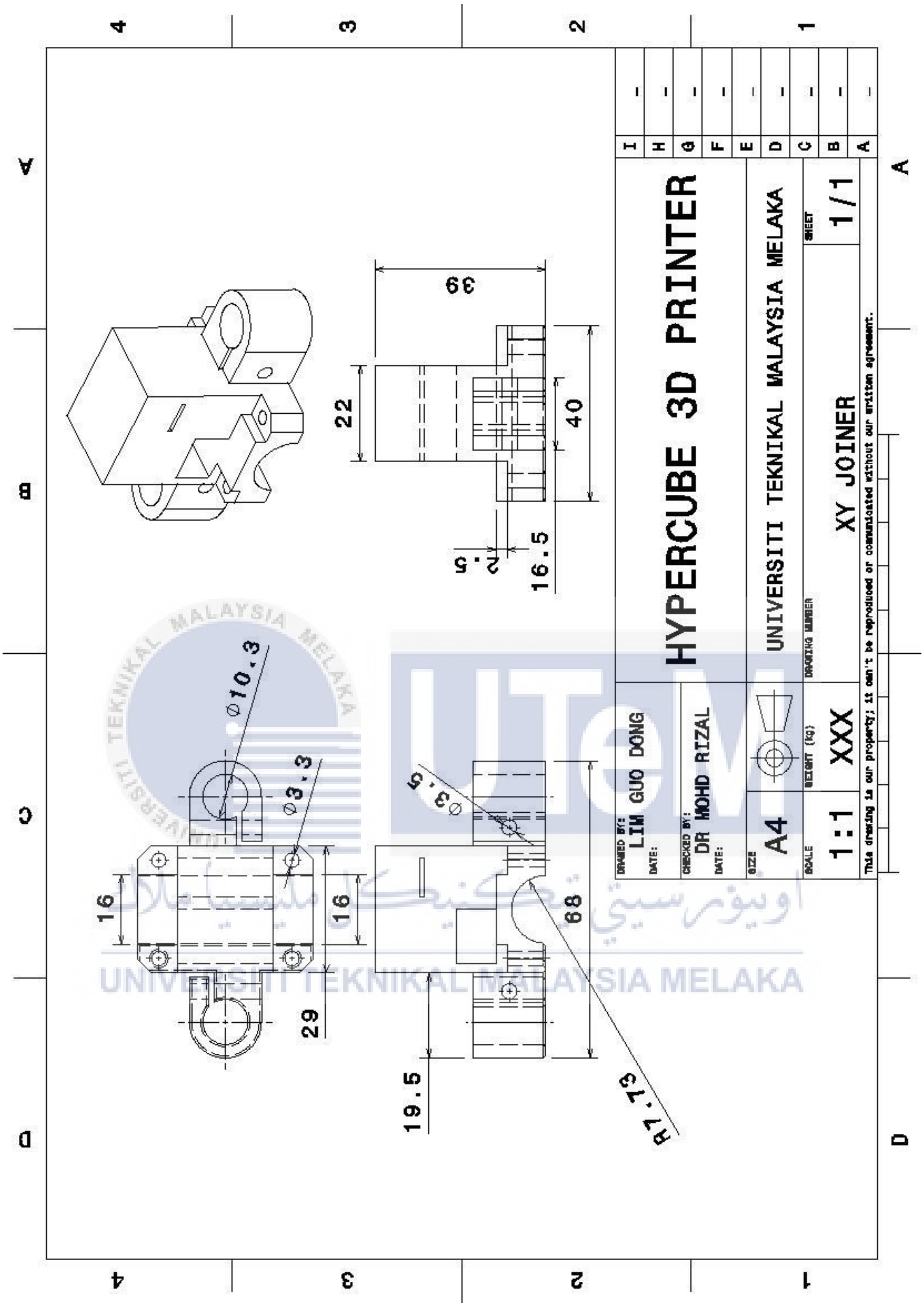


Figure A13: Dimension drawing of XY joiner

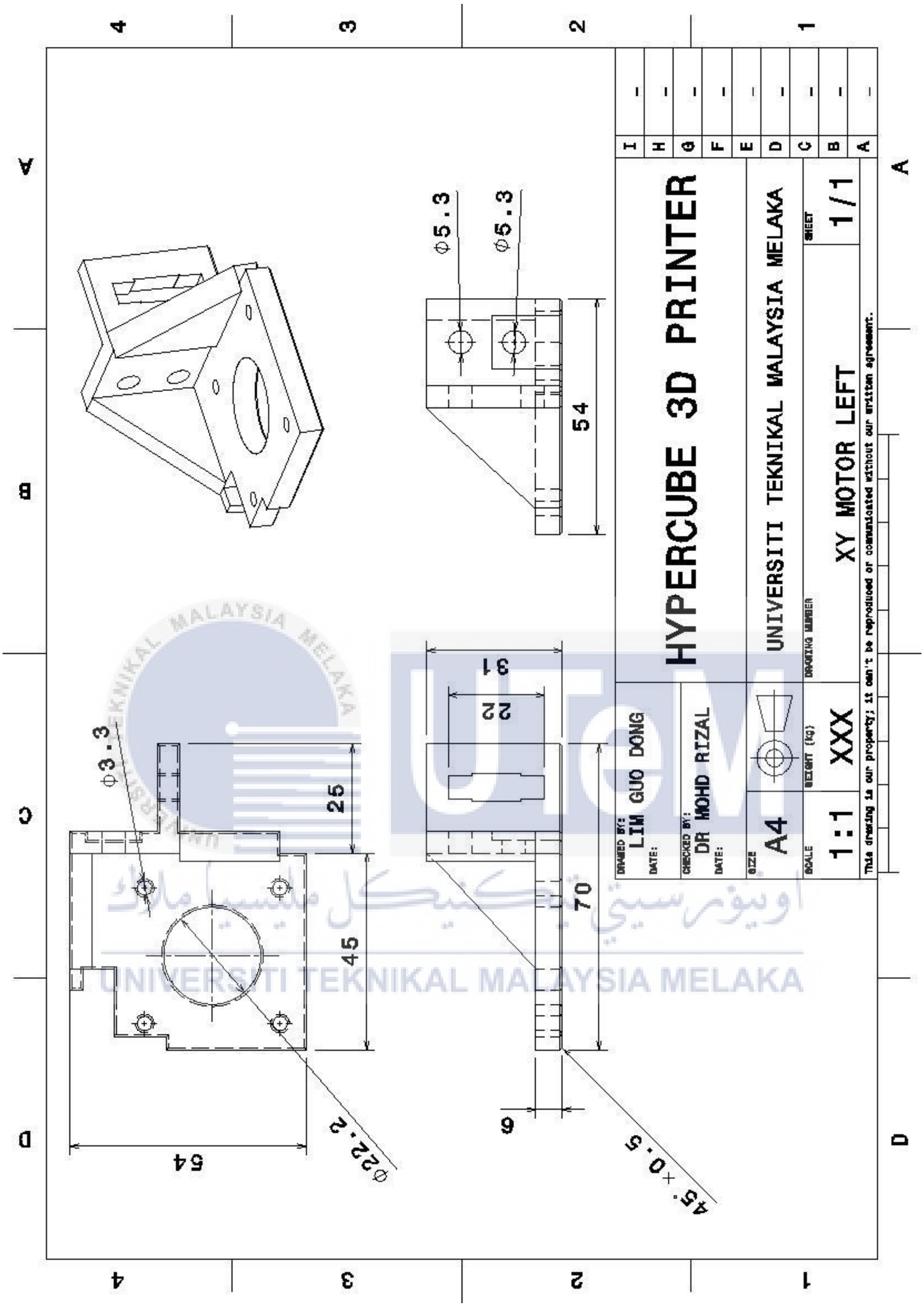


Figure A14: Dimension drawing of XY motor left

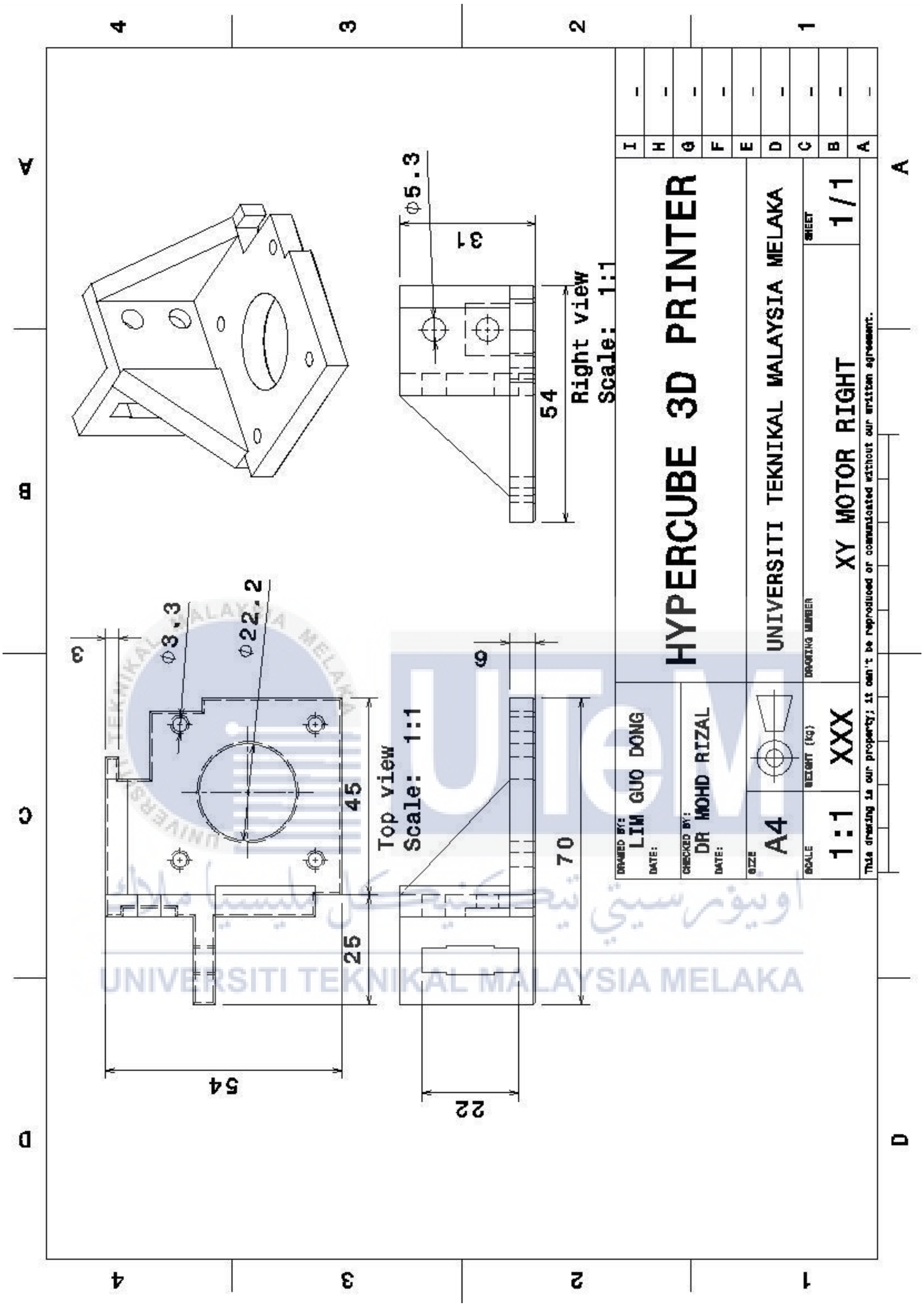


Figure A15: Dimension drawing of XY motor right

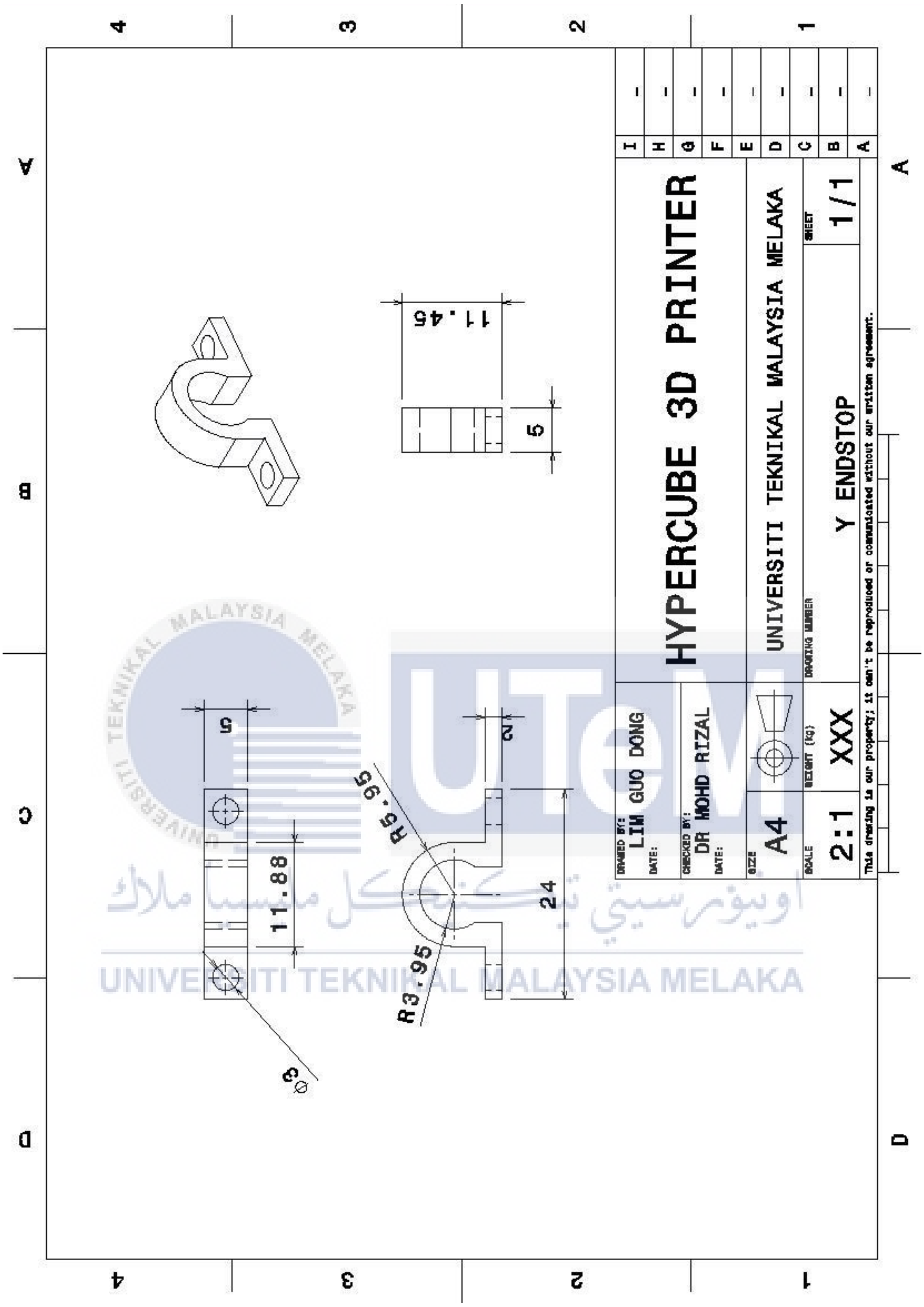


Figure A16: Dimension drawing of Y endstop

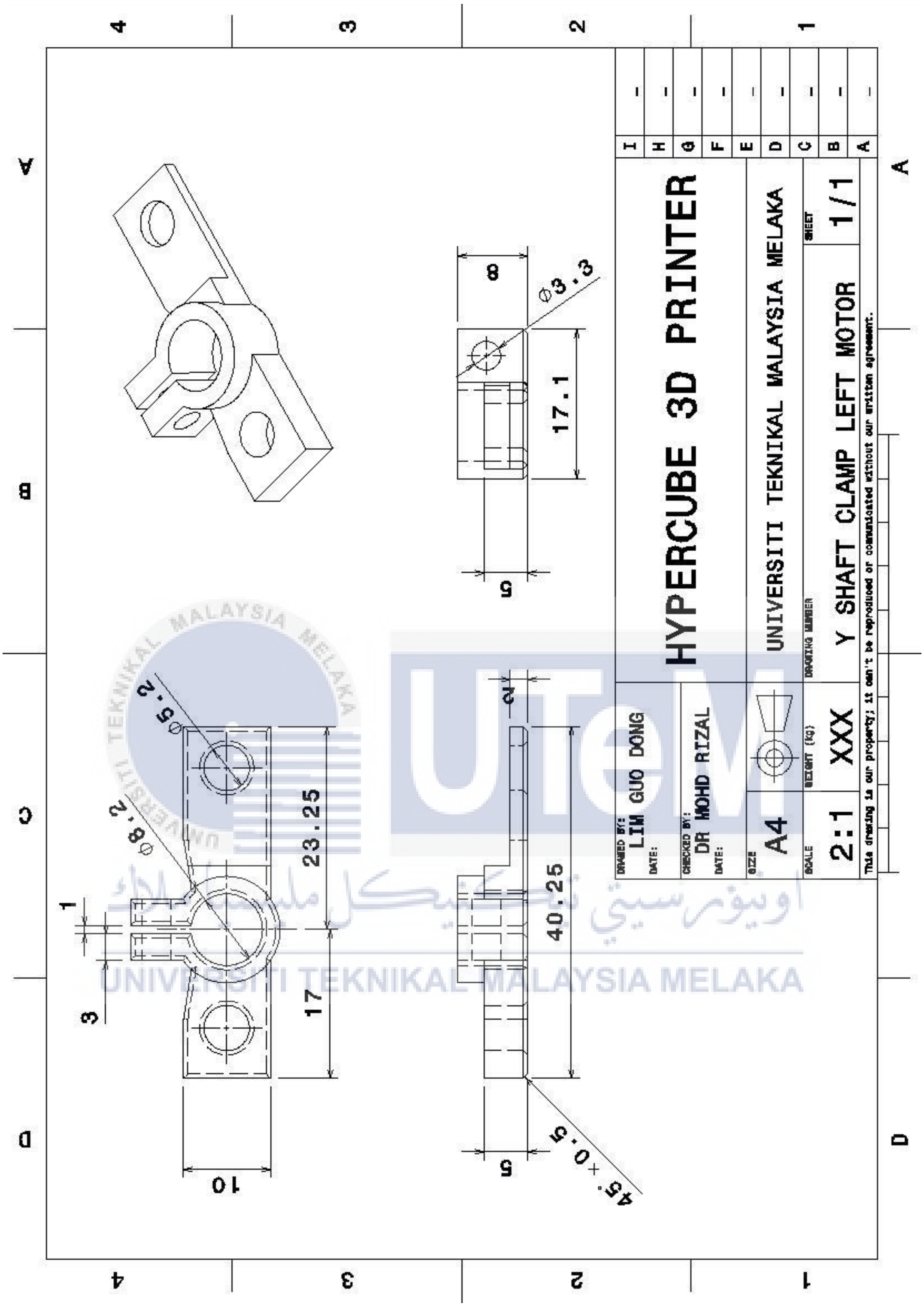


Figure A17: Dimension drawing of Y shaft clamp left motor

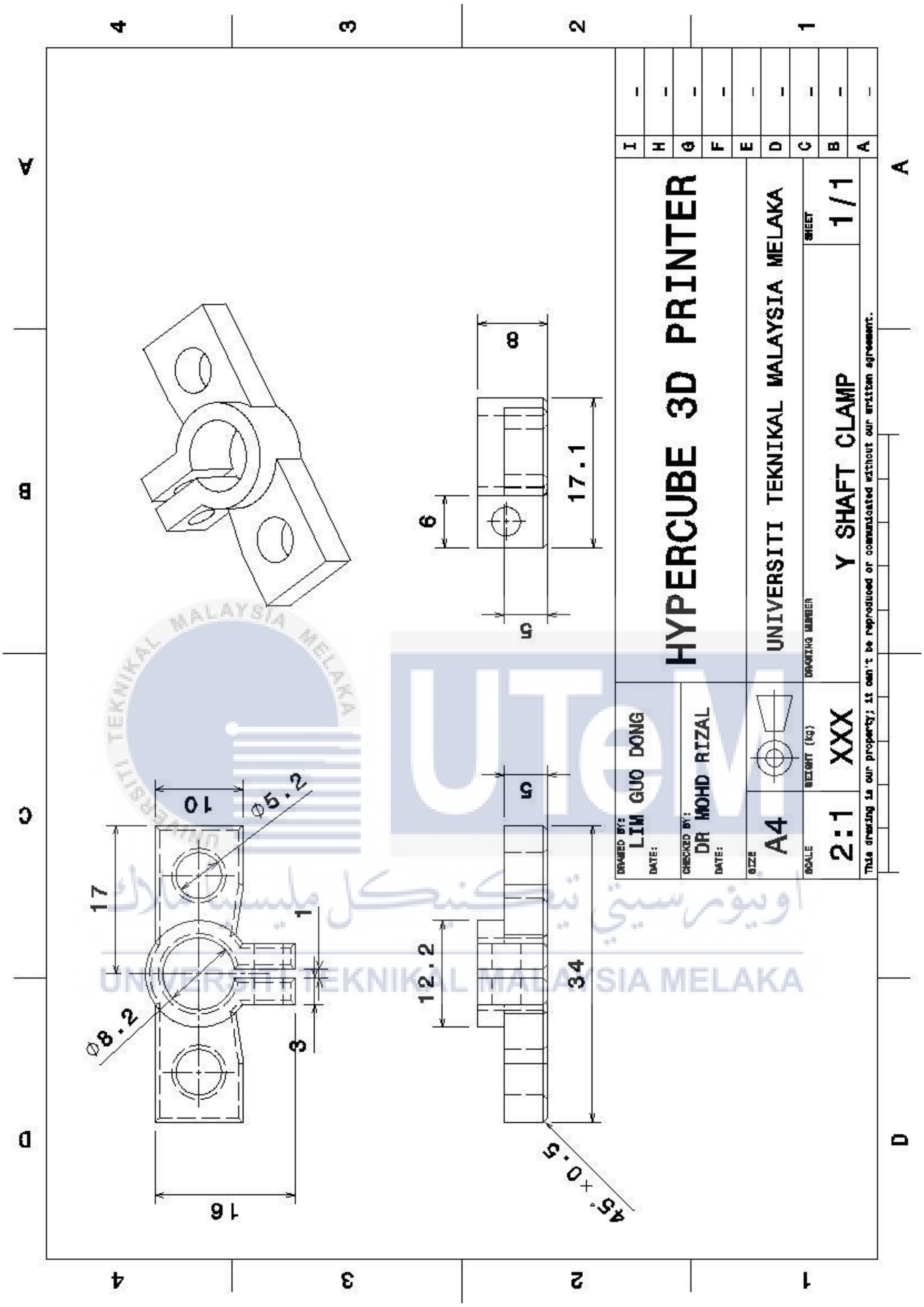


Figure A18: Dimension drawing of Y shaft clamp

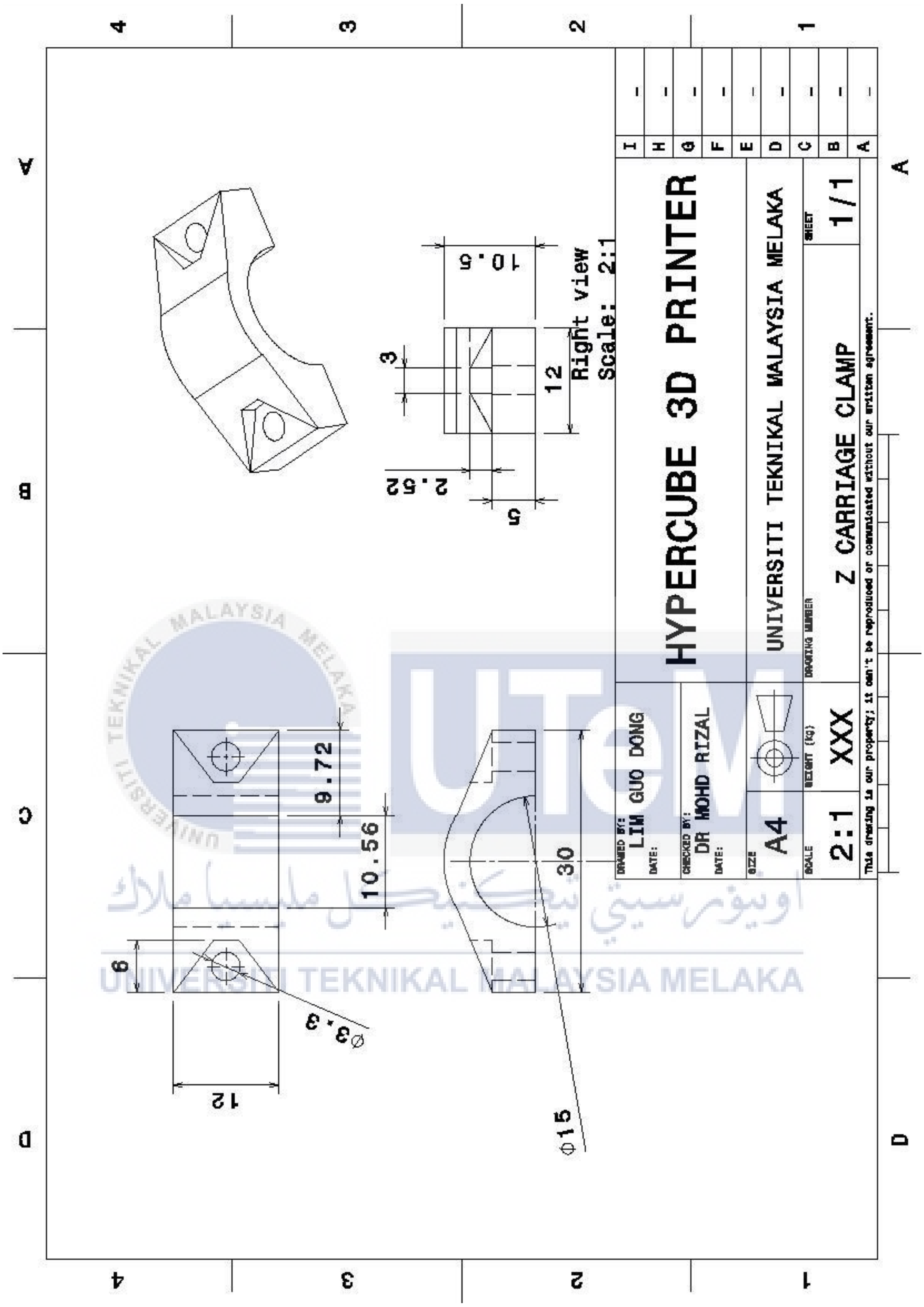


Figure A19: Dimension drawing of Z carriage clamp

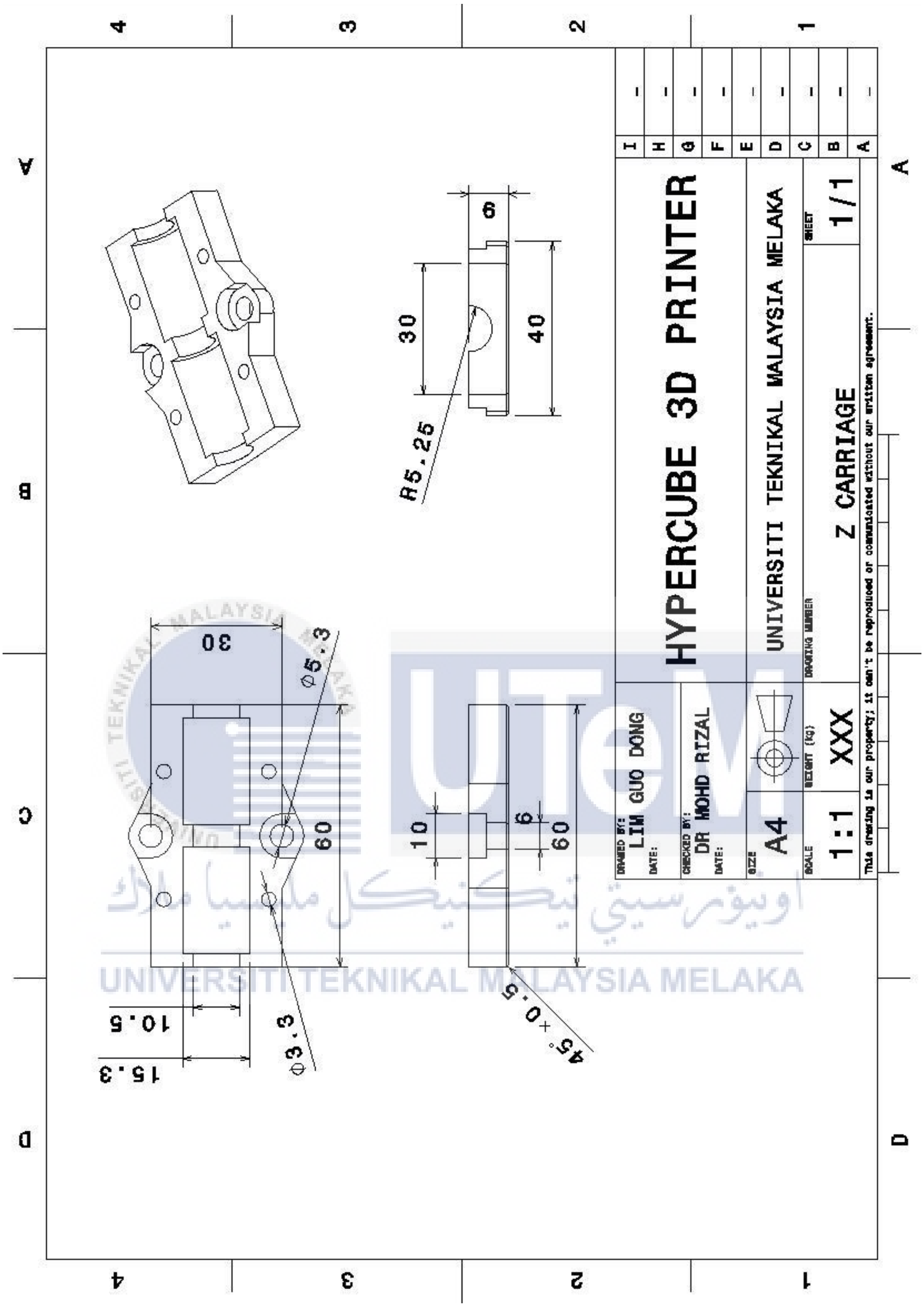


Figure A20: Dimension drawing of Z carriage

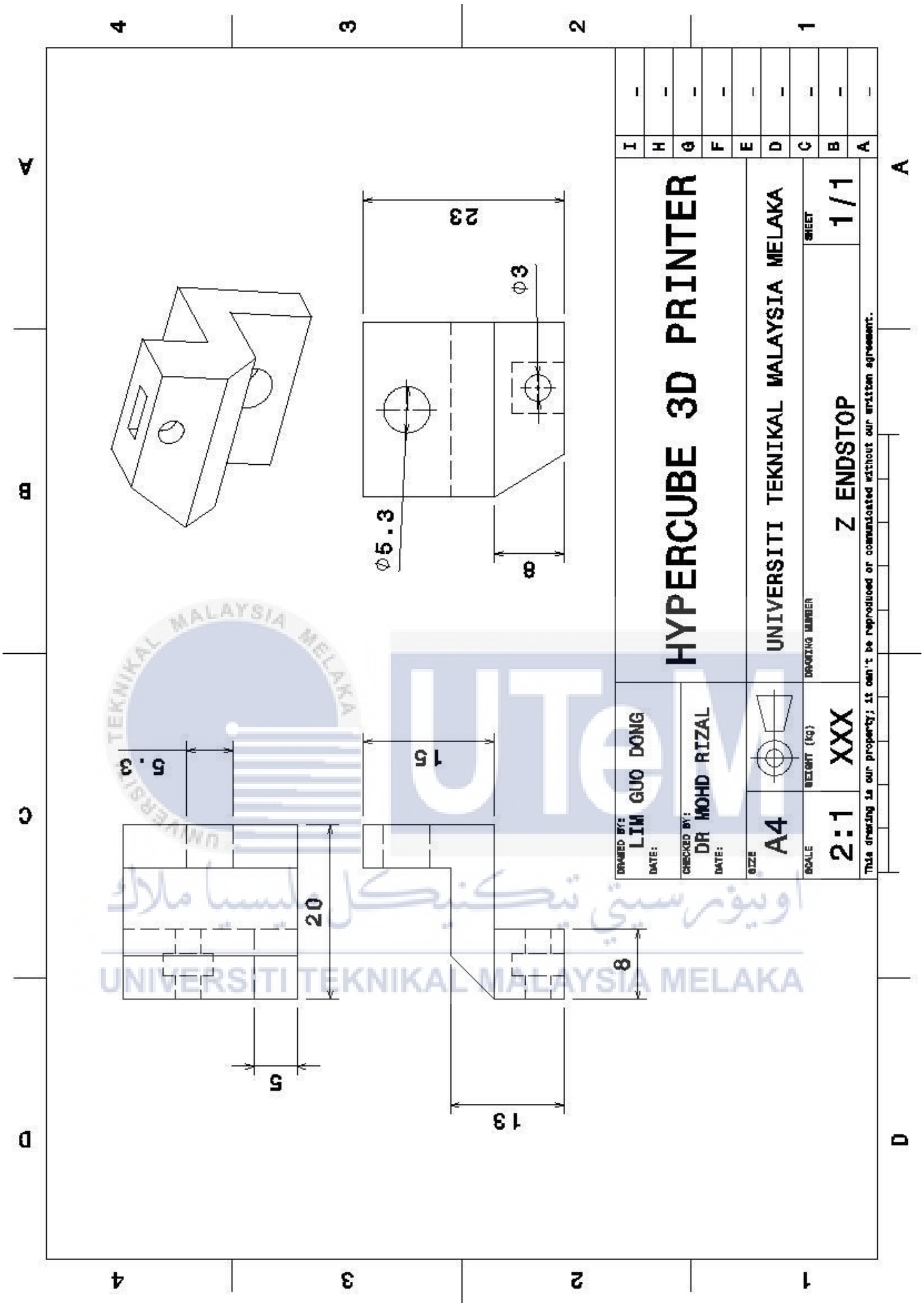


Figure A21: Dimension drawing of Z enstop

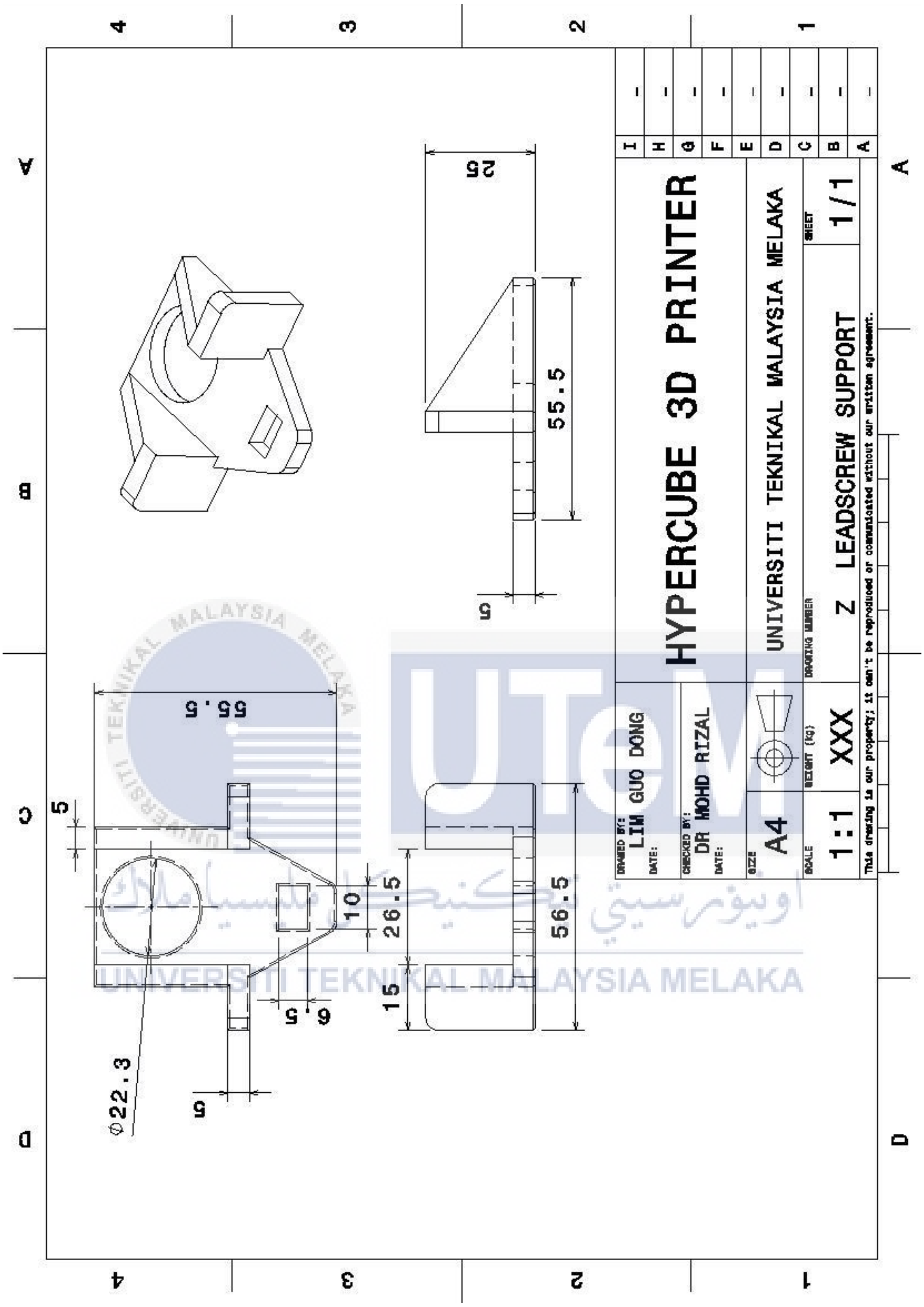


Figure A22: Dimension drawing of Z lead screw support

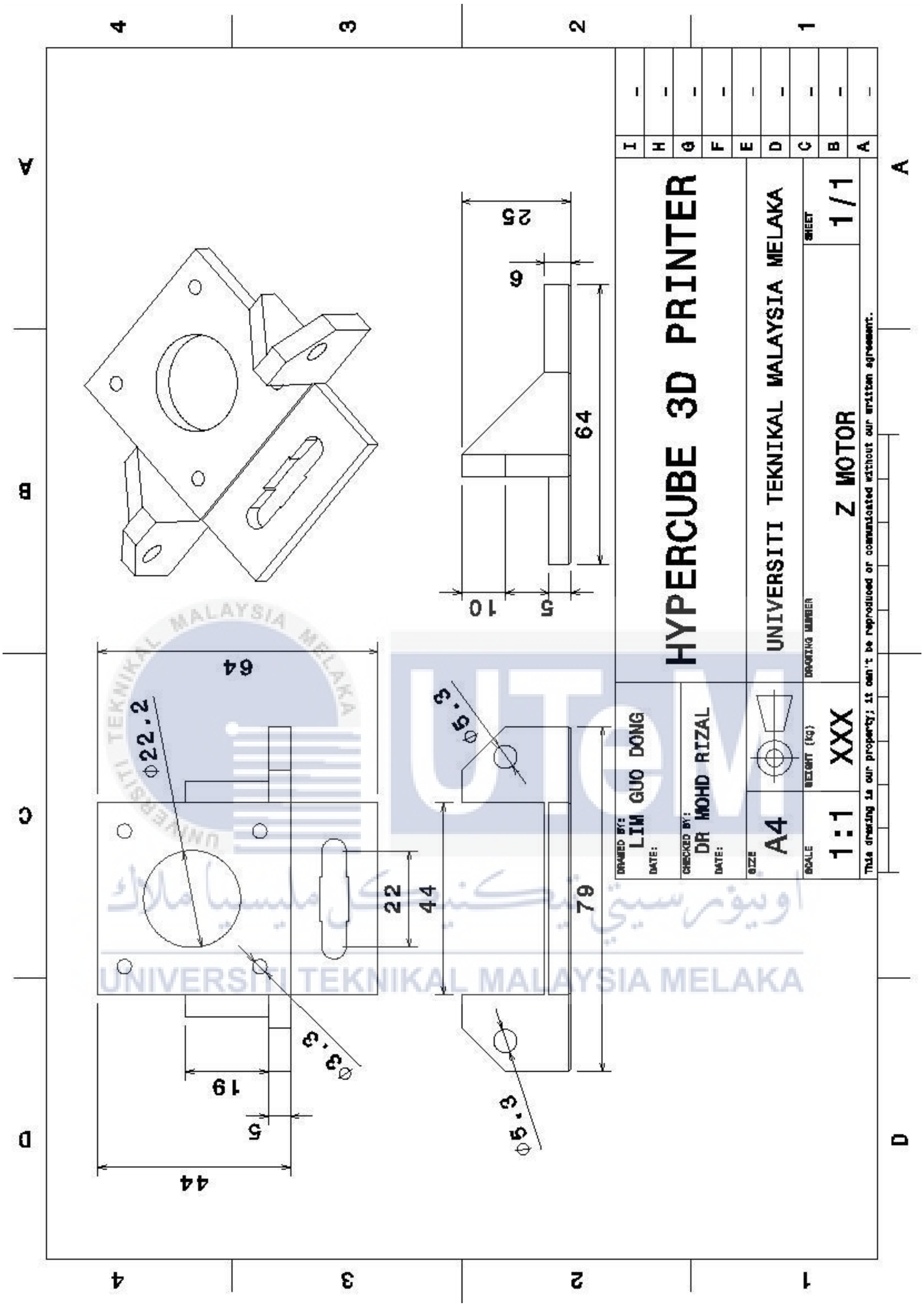


Figure A23: Dimension drawing of Z motor

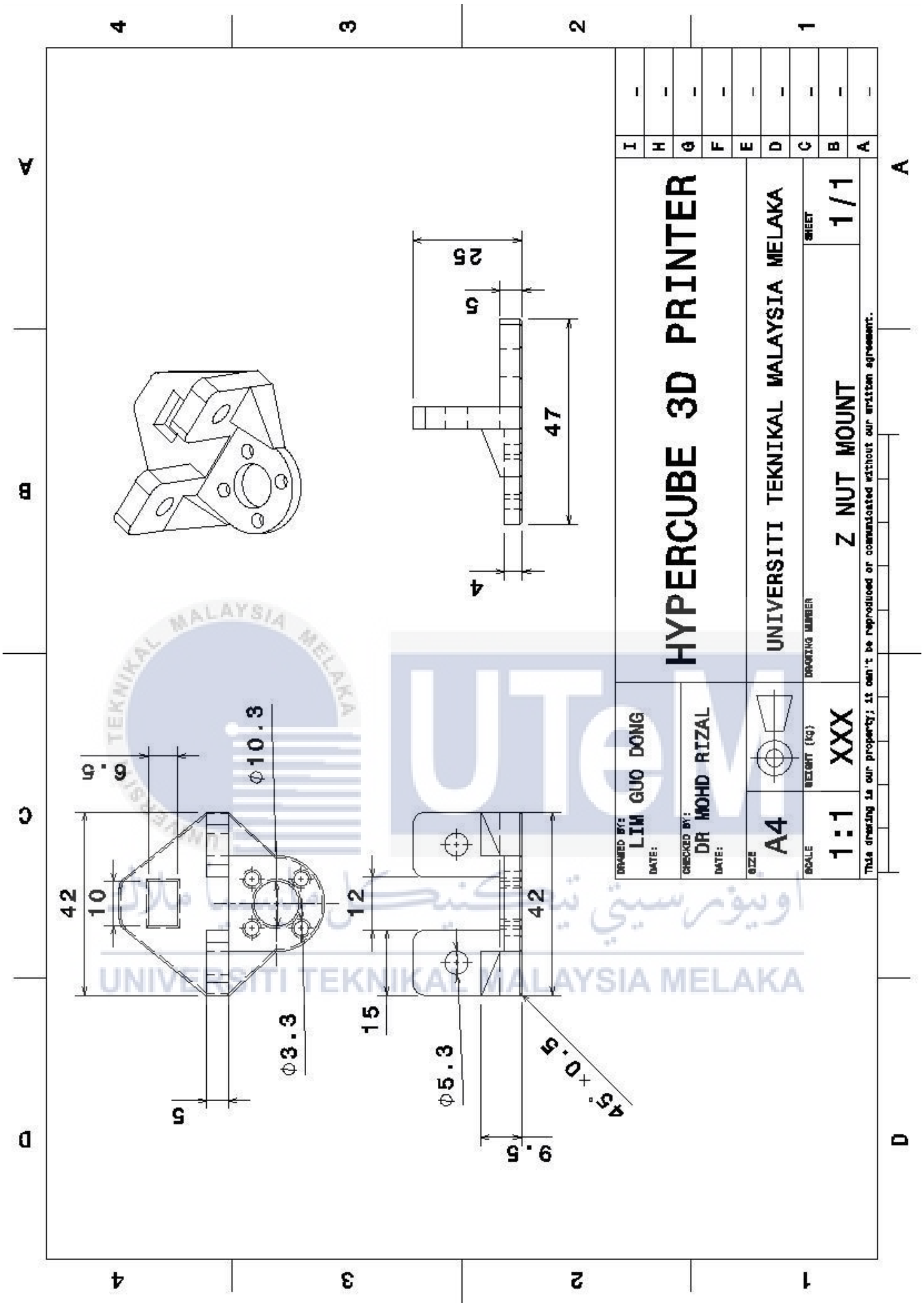


Figure A24: Dimension drawing of Z nut mount

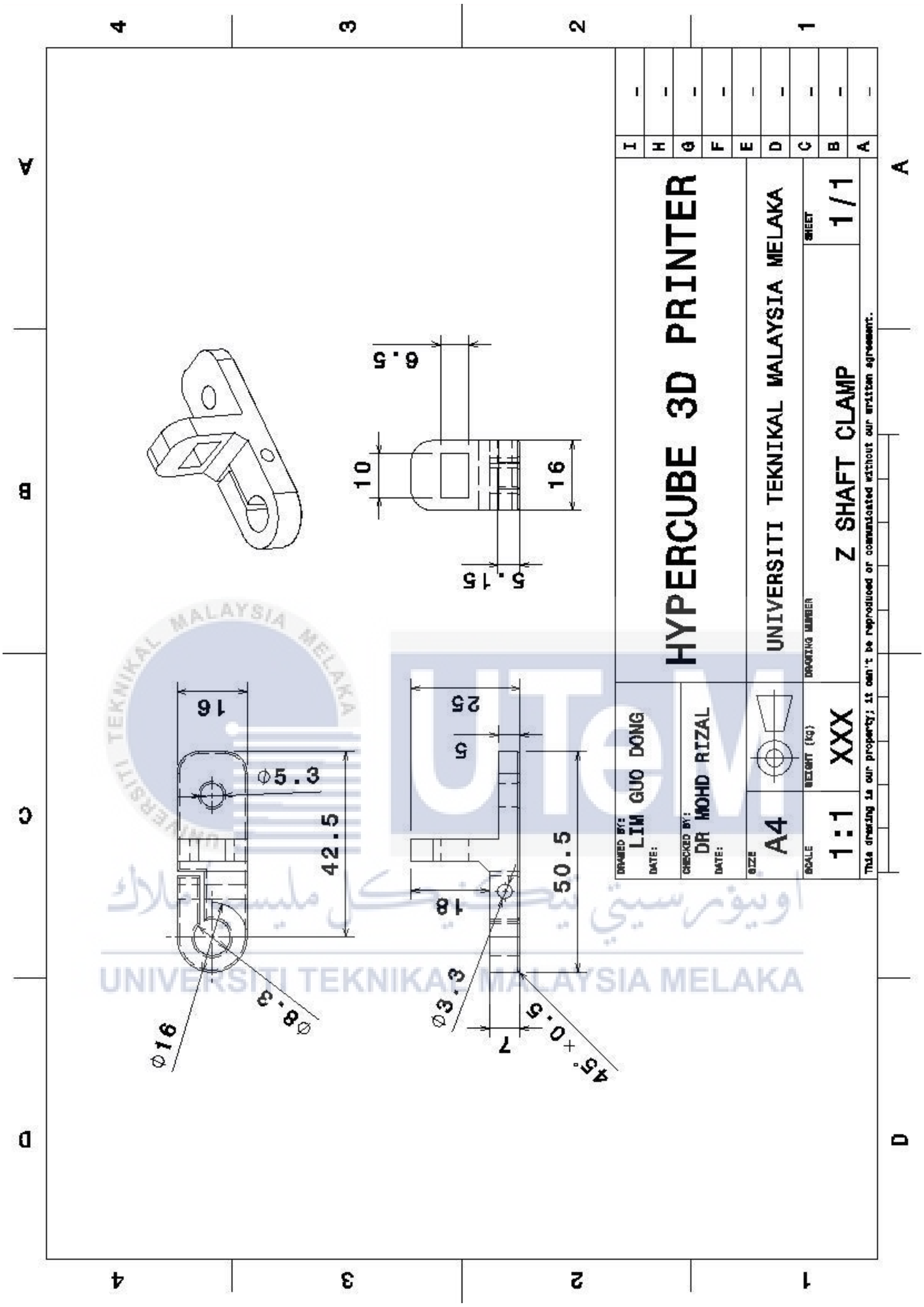


Figure A25: Dimension drawing of Z shaft clamp