UNIVERSITI TEKNIKAL MALAYSIA MELAKA

# 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**

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**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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| Signature | : | ........................................... |
| 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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**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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| | |
|---|---|
| 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.

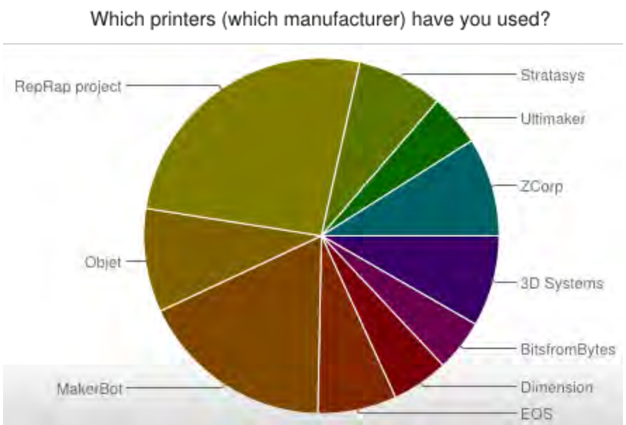


Figure 2.1: Survey on the 3D printing community (RepRap.org, 2017)

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.

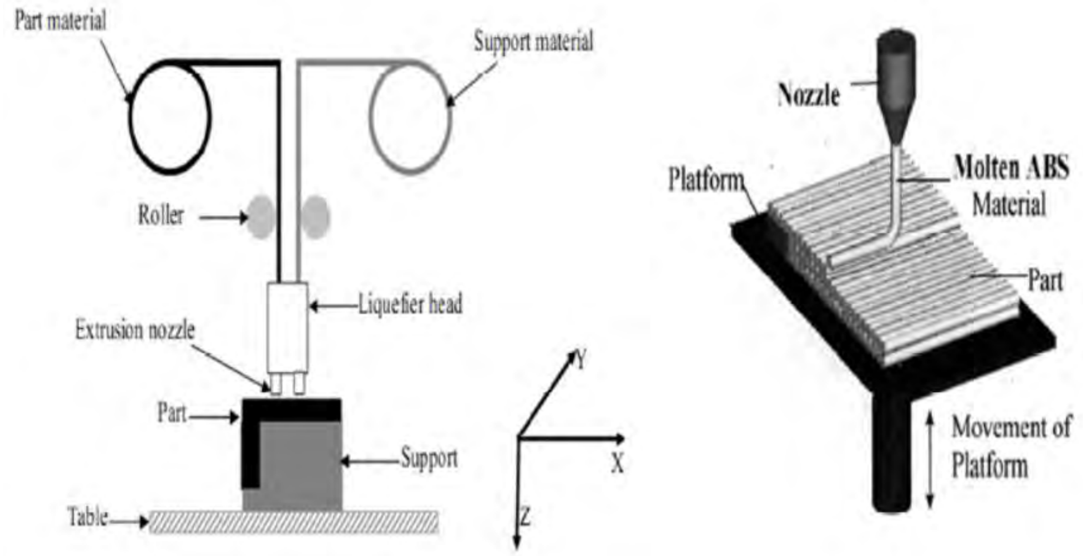


Figure 2.2: Schematic diagram of FDM process (Schmitt et.al., 2016)

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).