DIMENSIONAL ACCURACY ANALYSIS FOR DESKTOP 3D PRINTERS FOR FUSED DEPOSITION MODELING (FDM)

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Abstract: Three-dimensional (3D) printing via Fused Deposition Modeling (FDM) technique has gained acceptance in many fabrication arenas due to its outstanding advantages andcurrently there are more than 20 types of desktop 3D printers available in market nowadays. Quality of every printer is the key that drive competitive advantage among the same type of printer and product quality is basically referring to the extent to which printer meet the expectations of customer.This research is an analysis on dimensional accuracyspecific shape and geometries ofproduct printedbyfive (5) types of desktop 3D printers that are commonly used in fabrication industry.The dimension of all 5 product printed by each printer was measured and compared with one another and the result was analyzed thoroughly and finally the best dimensional accuracy of product printed is chosen among the sample studied.The finding results shows that some printers are showing good accuracy in specific shapes and geometries while on other shapes and geometries the high percentage error.

Keywords: 3D Printing, Fused Deposition Modeling, PLA, Dimensional Accuracy, Percentage Error.

I. INTRODUCTION

The emergence of new advanced manufacturing technologies creates opportunities for changing how manufacturing activities are organized, alongside with important of advances in innovation processes [1]. Additive manufacturing (AM) is one of new advanced manufacturing technologies.
Additive Manufacturing (AM) is commonly known as Rapid Prototyping (RP), is an advanced manufacturing technology commercialized in the middle of 1980s. At present, RP technology is widely used in engineering for conceptual models and functional models [2]. Three-dimensional (3D) printing of AM represents a relative novel technology in manufacturing which is associated with potentially strong stimuli for sustainable development.
Among the recent technological developments, 3D printing has been deemed as one of the most promising. This has the potential to remake the economics of manufacturing from a large-scale industry back to an artisan model of small design shops with access to 3D printers [3]. The most commonly used technology in this process is Fused Deposition Modeling (FDM). Fused deposition modeling (FDM) technology was developed and implemented at first time by Scott Crump, Stratasys founder, in 1980s [4].
Additive Manufacturing has been used initially for prototyping. In fact, it was the first and successful area of application which made it categorized in Rapid Prototyping concept. Prototypes which were used for visual understanding or presentation models were later used for testing operations also, and current application of this technology is heading more and more towards part production, besides prototyping [5].
Due to the pressure of international competition and market globalization in the 21st century, there continues to be strong driving forces in industry to compete effectively by reducing manufacturing times and costs while assuring high quality products and services. With aim of overcoming the limitations, an innovative reference sample part is proposed for comparison purpose of dimensional accuracy analysis.
Depending on part, shape and serial volume, using 3D printing as a manufacturing method, it is possible for creating a need to improve geometric quality [6]. As concerns of dimensional accuracy, the presence of simple classic geometries is imperative [7]. Thus, some simple classic geometries are representing in a plate form to make measurement process easier.

II. DETAILS EXPERIMENTAL

Generative production techniques have the advantage of manufacturing parts via an additive process without needing a forming tool. One of these additive manufacturing technologies is “Fused Deposition Modeling” (FDM). It is one of the most used additive manufacturing processes to produce prototypes and end-use parts [4]. The FDM technology needs software which processes an STL file (stereo lithography file format) which is known as slicer software. A slicer is 3D printing software that converts digital 3D models into printing instructions for 3D printer to create an object. The slicer cuts a CAD model into horizontal layers based on the settings chosen, and calculates how much material that the printer will need to be extrude and also how long it will take to do it. All of this information is then bundled up into a G-Code file which is sent to the printer. Slicer settings do impact the quality of the product printed. Thus, it is important to have the right software and settings to get the best quality print possible [8].

2.1. Machines and Instrument

Desktop 3D printers are increasingly gaining popularity [10] as it is more convenient for household used. Even though desktop 3D printers have been to some extent limited when it comes to a print area, it is widely used by either researcher, hobbyistor common user. Desktop 3D printer is more simple and easier to be use in daily life as it is easy to be learn on how to be operated especially for new user. Desktop 3D printer is smaller in size compare to industrial 3D printer, thus it is more suit for household use as it would not need large area to be keep [11]. In compatible with the home and office conditions, materials required by these desktop 3D printers are generally thermoplastics, which can be processed at relatively moderate temperature and pressure [12].
The printers used in this research are as shown in Figure 1.

Figure 1: Types of 3D Printers Used

There were several research being done on surface roughness and surface texture that have been made [13, 14]. However, research on dimensional accuracy are rarely to be made in detail [15] especially using manual instrument. Thus, this research is made to overcome the lack of research so that it can be used as reference for further research on product dimensional accuracy.

For dimensional accuracy analysis purpose, the measurement of each shape print on testing plate are required to allowed the comparison to take place and also the percentage error for the product print with the product design to be calculate. All the analysis then could be representing in graph form to provide easier interpretation.

Figure 2: Digital Vernier Caliper

Important instrument involve in this research is a digital vernier caliper as shown in Figure 1. Digital vernier caliper is used to measure the dimensional accuracy of product print. The measurement of each shape printed on testing plate product is taken using this instrument before the percentage error is calculated. The sensitivity of this digital vernier caliper is 0.01mm. The measurement is taken several time before the average of the readings is calculated. The actual measurement is compared to average value to increase the accuracy of the result gained.

2.2. Material and Slicer Software

Generative production techniques have the advantage of manufacturing parts via an additive process without needing a forming tool and one of these additive manufacturing technologies is "Fused Deposition Modeling" (FDM). The FDM technology needs software which processes an STL file (stereo lithography file format) which is known as slicer software. A slicer is 3D printing software that converts digital 3D models into printing instructions for 3D printer to create an object. The slicer cuts a CAD model into horizontal layers based on the settings chosen, and calculates how much material that the printer will need to be extrude and also how long it will take to do it. All of this information is then bundled up into a G-Code file which is sent to the printer. Slicer settings do impact the quality of the product print. Thus, it is important to have the right software and settings to get the best quality print possible [8].

There are tons of settings which user can fiddle around with such as extruders, layer control, various infill methods, temperature and cooling settings, even raw G-code and scripts can be edited. These settings can be saved in "Processes", which can come in handy if experimenting with different settings, 3D printer nozzles or different filaments. Help is available by hovering over the buttons [9].
In this study, the slicer software used was Simplify 3D software. Simplify 3D suited for everyone who desires to get a quality prints of product. Though there is a basic mode, user that have some experience with a 3D printer will gain advantages**.**

Materials that usually used in 3D printing is thermoplastic as it is cheap in cost and also can easily require in market but for this study however Poly Lactic Acid (PLA) have been chosen as the research material. PLA is a compostable, biodegradable thermoplastic made from renewable sources. It has unique properties like good appearance, high mechanical strength, and also low toxicity. PLA has good barrier properties that broadened its applications. Numerous researchers have studied the different properties of PLA alone and also in combination with other polymers either as blend or copolymer. The temperature properties of PLA are as shown in **Table 1.**

Table 1: Temperature Properties of PLA

Thermoplastic filament	Nozzle Temperature	Print Bed Temperature

	(◦C)	(◦C)
Poly Lactic Acid (PLA)	190 – 220	70 - 90

2.3. Sample Preparation and Procedures

Accuracy is a key factor in deciding which rapid prototyping system to chose. Experience has shown that the accuracy attainable in a particular part is often a function of its geometry [6]. As can be expected, relatively small prismatic parts can be fabricated to a higher degree of accuracy than relatively large flimsy parts.

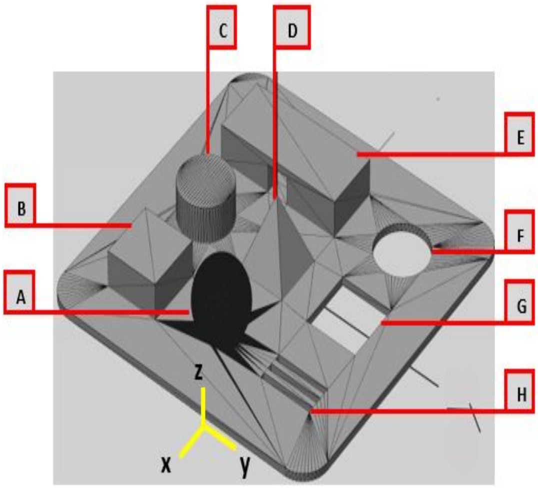

Figure 3: Dimensional Accuracy Sample Plate

Table 2: Shape Name and Nominal Value for Sample Plate

Label	Shape	Nominal (mm)		
		x-axis	y-axis	z-axis
A	Sphere	10.00	10.00	10.00
B	Cube	10.00	10.00	10.00
C	Cylinder	10.00	10.00	5.70
D	Pyramid	9.00	9.00	9.70
E	Cuboid	10.00	24.00	10.00
F	Circular hole	9.80	9.80	-
G	Square hole	9.80	9.80	-
H	Rectangular hole	0.90	9.80	-

Measurement of dimension for each shapes was taken using digital vernier caliper and the measurement was taken for 4 samples and the value recorded. From the data, average value for each axis was calculated and the average value and then used to calculate the percentage error for each axis and compared with the nominal measurement. The percentage error was calculated to present the quality analysis of printed product from each 3D printers in quantitative way thus information that essential in order to precisely establish the exact geometric and dimensional accuracy that 3D printer offer can be obtained.

III. RESULTS AND DISCUSSION

3.1. Percentage Error Result

The analysis was dividedinto two category depends on its geometry. Cube, cuboid, cylinder, pyramid and sphere is in 3D shape geometry while circular, rectangular and square is in hole shape geometry. The result of percentage error for each shape was analyzed in graph form as shown in Figure 2 (a) and Figure 2 (b).

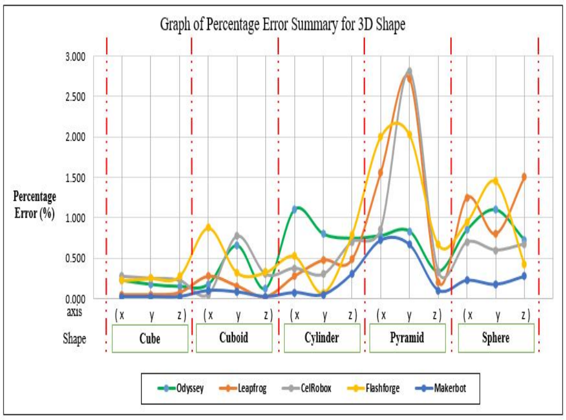

Figure 4: Graph of Percentage Error for 3D Shape

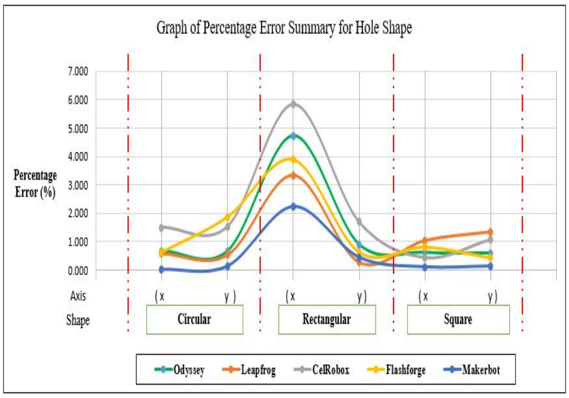

Figure 5: Graph of Percentage Error for Hole Shape

Based on result from Figure2 (a) and Figure 2 (b), Makerbot 3D Printer product show the most accurate measurement for most shapes compare to another printer product following close by Leapfrog 3D Printer product. Odyssey 3D Printer product show highest percentage error for 3D Shape while Cel Robox 3D Printer product show highest percentage error for Hole Shape.

3.2. Discussions

High value of percentage error shows that the product has small accuracy thus small value of percentage error show that the product has high accuracy compare to the product design. Based on the result, Makerbot is the most accurate printed product compare to another four (4) product printed by different 3D printers.

Dimensional accuracy of a product can decrease if the printer does not maintain properly and occasionally. 3D Printers should be maintaining properly by user as all the system in the printer is connected with one another. Even if only one part of the printer cannot act correctly, it will damage the production and finally the output quality. The percentage error of product can also increase naturally as the life span of the printer increase, which decrease the dimensional accuracy of the product printed. For better performance, the printer that have used for too long should be maintenance more often so that the user could control the product quality from time to time.

CONCLUSIONS

The development of a variety of improved in materials for rapid prototyping systems is one of the most significant issues to impact the applications of prototype parts and tooling. The improvements have led to increased accuracy and surface finish, which in turn can be applied to tooling applications in the form of molds and fixtures, or for conversion to product product using 3D printing. Because some rapid prototyping systems can use a variety of materials, the opportunity to build parts that meet the end product material requirements is getting closer to being a reality.

This research is mainly aims to assist user of 3D printer on the fabrication cost of product by desktop 3D printers and compare to the quality gained based on its dimensional accuracy. Indirectly, this research also comparing the value of desktop 3D printers with each other. Thus, new user could use this research as a guard in order to choose which type of desktop 3D printer that suit their fabrication setting demand. However cost consideration in purchasing the printers are varies and users must make decision which printer suits them based on their application.

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