Design and Fabrication of Fused Deposition Modelling 3D Printer for Early-Age Students Using Quality Function Deployment Method

Yuni Vadila[1], Meldia Fitri[2], Jana Hafiza[1], Herris Yamashika[1], Irfan Hilmy[3], Erry Y. Y. Adesta[4], and Rudi Kurniawan Arief[1](✉)

[1] Muhammadiyah University of West Sumatera, Padang, Indonesia
{herrisyamashika,rudikarief}@umsb.ac.id
[2] Putra Indonesia University, Padang, Indonesia
meldiafitri@upiyptk.ac.id
[3] Higher Colleges of Technology, Fujairah, UAE
ihilmy@hct.ac.ae
[4] Indo Global Mandiri University, Palembang, Indonesia
eadesta@uigm.ad.id

Abstract. 3D printing technology is one of the key technologies to support the rise of the 4th Industrial Revolution. The use of FDM 3D printers is growing fast since the Open-sourced RepRap FDM 3D printer was introduced. Unlike European countries that already introduce this technology to children (early-age students), in Indonesia and most South East Asian countries, the introduction of this technology only reaches the University level. Low penetration of this technology is caused by the price of 3D printers that are safe to be used by younger students but still relatively expensive. Therefore, this research was carried out to develop an FDM 3D printer machine that is easier and safer to use at a reasonable price. The design of the FDM 3D printer machine is intended to be used safely by children at the junior high school level. The introduction of this at an early age hoped it could broaden children's knowledge, increase their creativity and attract them to be interested in the world of engineering.

Keywords: FDM 3D printer · rapid prototyping · education · early age · technology introduction

1 Introduction

Nowadays Fused Deposition Modelling (FDM) has become a widely used Rapid Prototyping (RP) technology that uses for research, education, the home industry and hobbyist [1]. The machine was invented by Scot Trump in 1989 [2] and further developed by Professor Adrian Bowyer to become the pioneer of open-sourced Replicating Rapid Prototyper (RepRap) 3D printing machine. The open-sourced system makes it possible for anyone to build and modify a 3D printer, therefore this technology starts to spread widely all over the world [3].

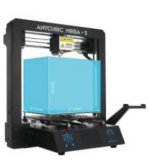
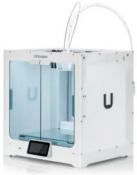
T. P. Syawitri et al. (Eds.): MEST 2022, AER 222, pp. 323–332, 2023.
https://doi.org/10.2991/978-94-6463-134-0_32

The FDM 3D printer works by distributing melted plastic materials to form a product layer by layer [4]. Most of the FDM 3D printer machines adopt the cartesian system for their movement method. In this method, the heated bed and the nozzle head is moving along the X, Y, and Z axes [5]. Other movement methods; Delta, SCARA dan Rotary are less favourable for their complex coding system [6]. The size of 3D printers varies from large scale to desktop sizes that are lighter and easier to move around and can be placed on a work desk only [7]. This machine is reliable and inexpensive to produce small quantities of goods and manufacture replacement parts [8].

The FDM 3D printing technology has been introduced by several European countries in early age education. In Indonesia, this technology has just begun to introduce at the University level. This technology can facilitate students in project work and prototype development [9]. The late introduction of this technology compares to western countries is due to the high price of 3D printers that are safe and appropriate to be introduced to children. Several cheap 3D printers available in the market are still too complicated and difficult to be operated [10]. Therefore, a 3D printer designed with a fairly low price, safe, and easy for children to operate is still required. The concept of a "cheap and easy" FDM 3D printer will be developed in this research so that can be used for the education sector in Indonesia. Introducing this technology could stimulate children to open their horizons and stimulate their creativity because this technology can also be utilized as means of teaching, especially those related to science and technology [11]. As means of teaching The FDM 3D printer can be used to create a mini model to represent the real concept and can make learning activities more interactive and interesting.

Even though widely used by engineering students in University, the FDM 3D printer technology can be adopted into the concept of early childhood education [12]. Using the FDM 3D printer, students will be able to witness the realization of the concept or design they made [13]. The FDM 3D printer introduction to children may increase their interest in science lessons, improve math skills and increase the attachment of teachers to technology and their students [14, 15]. Eseinberg (2013) in his research, states several challenges in introducing this technology to children [16], such as; expanding the range of printing media, developing a "pick-and-place" mechanism in the 3D printing process, creating portable printing devices, developing finishing tools, to define design software techniques, modify and incorporate 3D elements in the design and printing process. Previous research by Kostakis (2015) also identified several challenges in the introduction of 3D printing technology in high schools in Greece including; significant differences in technological literacy and attitudes toward accepting new technologies, freedom for students in making a product can cause difficulties for teachers, and the relatively high price of the 3D printer. However, the observations show that introducing 3D printing technology in schools has had a positive impact and was able to encourage students to be more creative [17].

Table 1. Competitor's specifications from 3 reputable brands

Brand	Anycubic mega-S	Ultimaker	Prusa I3
Price (IDR)	9.660.000	90.000.000	16.880.000
Size (mm)	210 x 210 x 205	390 x 390 x 500 (mm^3)	250 x210 x 200
Nozzle Quantity	1	2	1
Weight (kg)	15	20	13
Pics			

2 Material and Method

This new 3D printer was designed using the Quality Function Deployment (QFD) approach. QFD is a method to gather customer needs and helps companies for developing a customer-based product [18]. The House of Quality (HOQ) of the QFD is used to depict the customer needs and illustrate which design team should be focused on. The customer requirement section is derived from the previous research findings conducted by several researchers about the introduction and implementation of 3D printing technology in early-age education. Ultimaker, Prusa i3 and Anycubic-S are the world's major brands of 3D printer makers that were taken for the competitor assessment section (Table 1). The design was developed from various types of FDM 3D printer designs that already exist and adjusted to children's needs. The new concept of the FDM 3D printer was created using 3D modelling software before being manufactured.

3 Result and Discussion

To capture the customer needs for the HOQ, articles with the topic of 3D printing technology introduction for children have been closely reviewed, resulting customer requirement list as in Table 2.

The weighting value was taken from the number of researchers who stated the needs in column C (Fig. 1).

The HOQ was then processed completely further to gather data to be analysed (Fig. 2).

Table 2. Customer requirements based on the research articles

No	Requirements (A)	Researchers (B)	Amount (C)
1	Low cost	Berry et al., 2010; Ford & Minshall, 2018; Kostakis et al., 2015	3
2	Easy to operate	Berry et al., 2010; Ford & Minshall, 2018	2
3	Better viewing (Free to observe)	Berry et al., 2010; Brine & Roy, 2017	2
4	Complete Feature	Berry et al., 2010	1
5	Lightweight	Eisenberg, 2013	1
6	Portable (easy to carry around)	Eisenberg, 2013	1
7	Open-sourced system	Kostakis et al., 2015	1
8	Less printing failures	Ford & Minshall, 2018	1
9	Fast	Kostakis et al., 2015	1
10	Accurate	Kostakis et al., 2015	1
11	Simple	Eisenberg, 2013	1

Row #	Weight Chart	Relative Weight	Customer Importa	Customer Requirements (Explicit and Implicit) / Functional Requirements
1	|||||||||	20%	3	Low cost
2	||||||	13%	2	Easy to operate
3	||||||	13%	2	Better viewing (Free to observe)
4	|||	7%	1	Complete Feature
5	|||	7%	1	Light weight
6	|||	7%	1	Portable (easy to carry around)
7	|||	7%	1	Open-sourced system
8	|||	7%	1	Less printing failures
9	|||	7%	1	Fast
10	|||	7%	1	Accurate
11	|||	7%	1	Simple

Fig. 1. Voice of customers' weighting value based on the research papers

The HOQ matrix shows the highest value obtained by the frame with 24% of the total weighting value (Fig. 2), others can be seen below:

Row #	Weight Chart	Relative Weight	Customer Importance	Customer Requirements (Explicit and Implicit) / Functional Requirements	Column #	1	2	3	4	5	6	Competitor		
					Direction of Improvement	▼	▲	◇	▼	◇	◇			
						Frame (rangka)	Motor penggerak	Nozzle (Haet)	Bed (platform)	Sistem Kontrol	Komponen elektrik	Anycubic mega-S	Ultimaker	Original Prusa I3
1	|||||||	20%	3	Harga yang murah		●	○	○	●	▽	▽	3	1	2
2	|||||	13%	2	Cara pengoperasian yang mudah		○	▽	▽	○	●	○	4	1	3
3	|||||	13%	2	Proses kerja mesin bisa diamati dengan jelas		●	▽	○	○	▽	▽	5	2	4
4	|||	7%	1	Feature yang lengkap		●	▽	○	○	●	○	3	5	4
5	|||	7%	1	Ringan		●	●	▽	○	▽	○	1	3	2
6	|||	7%	1	Portable dan mudah dipindah lokasikan		●	○	▽	○	▽	○	3	2	3
7	|||	7%	1	Sistem open-sourced		▽	▽	▽	▽	●	▽	5	1	3
8	|||	7%	1	Jarang terjadi eror		▽	▽	○	○	●	●	3	5	4
9	|||	7%	1	Cepat		▽	●	▽	▽	●	○	3	5	4
10	|||	7%	1	Akurat		○	●	○	▽	●	●	3	5	3
11	|||	7%	1	Sederhana		○	○	○	○	○	○	5	2	3
					Technical Importance Rating		580	326,7	220	380	486,7	300			
					Relative Weight		25%	14%	10%	17%	21%	13%			

Fig. 2. Complete House of Quality

Table 3. Weighting result for functions requirement

No	Requirements (A)	Amount (C)
1	Frame	25%
2	Motor	14%
3	Nozzle	10%
6	Heated bed	17%
5	Control system	21%
4	Electrical components	13%

The result shown in Table 3 gives direction to the designers on where to focus during product development. The design was focused to develop the printer's frame to have a light and simple structure. Control system will use any available open-sourced control

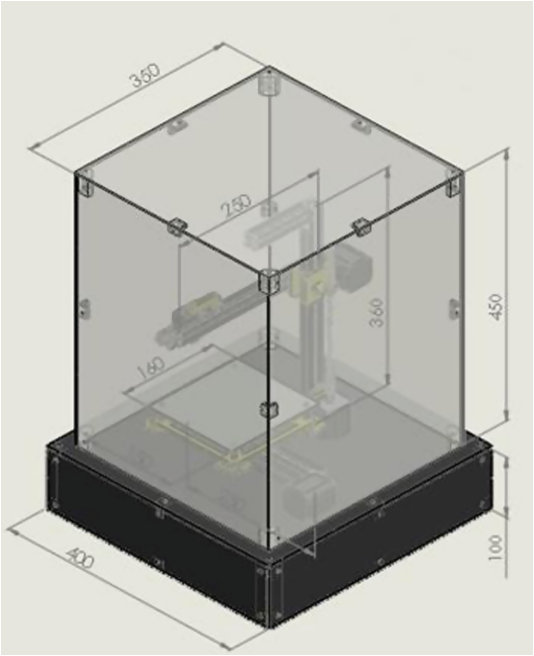


Fig. 3. Conceptual design of the new FDM 3D printer

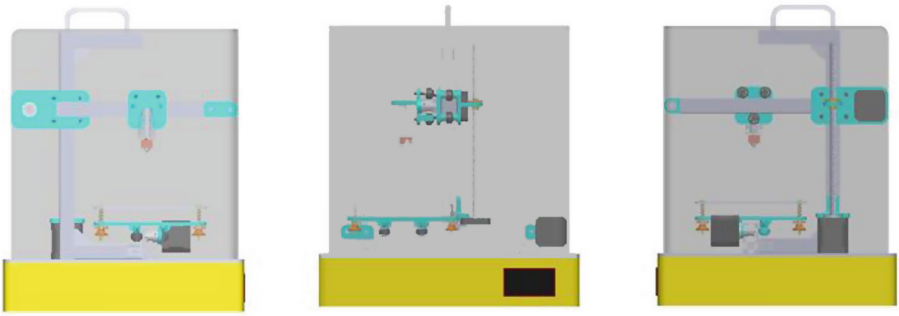


Fig. 4. Clear box and semi-gantry style adopted for better viewing.

system to keep it cheap, therefore no need for further improvement. This FDM 3D printing machine was designed using 3D modelling software to reduce time and error during prototype manufacturing. To fulfil the customer requirements this design uses an overhang arm type, aluminium profile and 3D printed components (Fig. 3). To ensure safety and better observation, a transparent closure box is added (Fig. 4).

The prototype was evaluated based on the customer requirements as below:

1. Low cost: This machine has been successfully built with a cost of around IDR 3.000.000 far below the average market price, this should be suitable for education institutions to purchase. Several components manufactured using 3D printing to reduce cost.
2. Easy to operate: This criterion is still the same as other products, therefore still needs further improvements.
3. Better viewing (Free to observe): Overhang gantry and clear enclosure box ensure a better observation view from at least 3 different sides and this makes it possible for the students to gather around during the observation (Fig. 5).
4. Complete Feature: To save more cost the feature will be lower than competitors but important features are still available.
5. Lightweight: This machine has less than 5kg of total weight, therefore it will be able to carry by the students.
6. Portable (easy to carry around): The lightweight and boxed shape features, make this machine easy to carry around safely.
7. Open-sourced system: Nowadays this is the standard system used by almost all FDM 3D printers that make this machine easy to develop by the owner.
8. Less printing failures: This criterion is still the same as other products, therefore further improvements require.
9. Fast: This criterion is still the same as other products, current speed is enough for better observation and means of education.

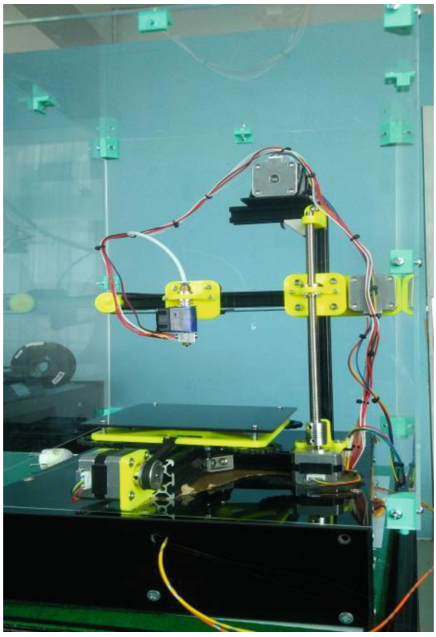


Fig. 5. Clear enclosure box for better viewing and safety

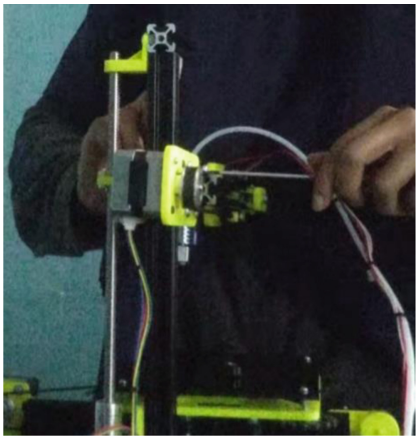


Fig. 6. Components are connected using bolts for an easy assembly process

10. Accurate: 4 starts threaded rod used to obtain more movement accuracy.
11. Simple: Simple boxed design also supports production cost reduction. Despite its simplicity, vibrant and contrasting colours are used to attract students.

To reduce cost, several components are also manufactured using the 3D printing process. Most of the components are connected using bolts and nuts for ease of assembly and maintenance (Fig. 6).

4 Conclusion

Based on the review of several research articles and the deployment of QFD method, a new 3D printer model was successfully designed and manufactured according to customer needs. Low cost is the most demanding requirement of the costumers, and the development of printer frame is the highest value from the HOQ result are used are the focus of product design. Both of those focused points are successfully translated to a machine prototype yielding a light, safe, observable with reasonable price. This new FDM 3D printer ensures a better and safety 3D printing experience for students. Several points are still unable to reach and could be used for further improvements, especially for software development topics.

Acknowledgement. This paper conveys the final result of the research previously presented paper on the International Conference on Engineering and Applied Technology.

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