A Development of a 3D Bio-Printer

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Abstract

3D Bio-printer is said to have potential in the applications of medical studies and tissue engineering. A 3D Bio-printer could be used to print the artificial organs for organs transplant and cell tissue culture for generating new cell tissue. It could help in future medical and biological research. This paper presents a full process on the development of the 3D Bio-printer. The 3D Bio-printer is designed based on Core XY Fused Deposition Modelling (FDM). It is customized in size and the extruder is specially developed for a syringe pump. It could print 3D Bio-model accordingly as designed in a computer aid design (CAD) software.

Keywords: 3D Bio-printer, Fused Deposition Modelling (FDM), Core XY mechanism, Syringe-based extruder.

1. Introduction

The earliest 3D printing technique was first introduced by Charles "Chuck" Hull in 1986 in which the 3D printer solidifies the ink using light radiation and print the 3D model [1]. There are types of 3D printers available in the market such as Stereolithography (SLA), Digital Light Processing (DLP), Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS), Selective Laser Melting (SLM) and etc. [2]. FDM-typed 3D printer is the most famous among all the 3D printers in which the printer build a 3D model layer by layer from bottom to upward [3]. The ink of the 3D-printer is a molten layer of plastic that fused up together [3].

The 3D printer evolved rapidly in many fields nowadays and of the famous field is in medical. Lately, 3D Bio-printer became vital in medical fields in printing artificial organs, tissue, skins and bones [4-10]. Millions of patients are dying every year in the process of long term waiting

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for an organ transplant [11]. In medical treatment, there are difficulties in obtaining the healthy organs like the lack of organ donors, suitability of the organs on blood type, the condition of patients and the ages of the patients [11]. 3D Bio-printer plays an important role to cover the shortage of healthy and suitable organ for those who may need them.

M. Ozturk *et.al* [12] described that there are three techniques of 3D Bio-printing commercially used today such as Inkjet-Based Printing, Extrusion Based Printing and Laser Based-Write. These facts are also supported by the journal published by M. Calado *et.al* [13]. C. Ventola *et.al* [14] stated that 3D bio-printing is very famous especially in medical fields for research and study in many fields of researches such as tissue engineering, regenerative medicine and organ transplant since the 2000s. The first 3D bio-printer (citation needed here) is introduced by Wake Forest Institute in the year 1999 in which a fully functioned artificial urinary bladder was successfully printed. In the year 2002, once again in the medical field, 3D bio-printing produced artificial kidney that 100 percent replicated to the original one using 'bio-ink' technique [15]. There are many other applications involving 3D Bio-printing such as Orthodontic which is one of the medical fields that widely used of 3D Bio-printing in producing Invisalign Braces for repairing the teeth alignment [16]. The other application of 3D Bio-printing is on the anatomical model and surgical preparation which give a big help in assisting surgery doctor [14]. Last but not least, 3D Bio-printing is applied in Pathology field, the 3D Bio-printing is used to print polypeptide model of the disease structure for diseases study purpose, type of disease and biological structure of disease [14]. This paper intends to propose the development of 3D Bio-printer based on the Fused Deposition Modelling (FDM) using customized syringe based nozzle to print 3D Bio-model products.

2. Methodology

2.1 System Overview

The flow of the 3D Bio-printer system starts with creating a 3D model as the input of the system and was saved into a stereolithography (STL) file type. Then, a slicer program translates this model into individual layers. The slicer program named CURA [https://ultimaker.com/en] was used to convert the model into G-codes which are transferred into a Secure Digital (SD) card. G-code is a programming language for CNC that instructs machines where and how to move. All these processes were done on the computer. The SD card that contains G-code is inserted into the 3D Bio-printer controller. The 3D Bio-printer will execute and move according to the

G-codes to print the desire 3D Bio-model. Figure 1 shows the overview of the 3D Bio-printer system.

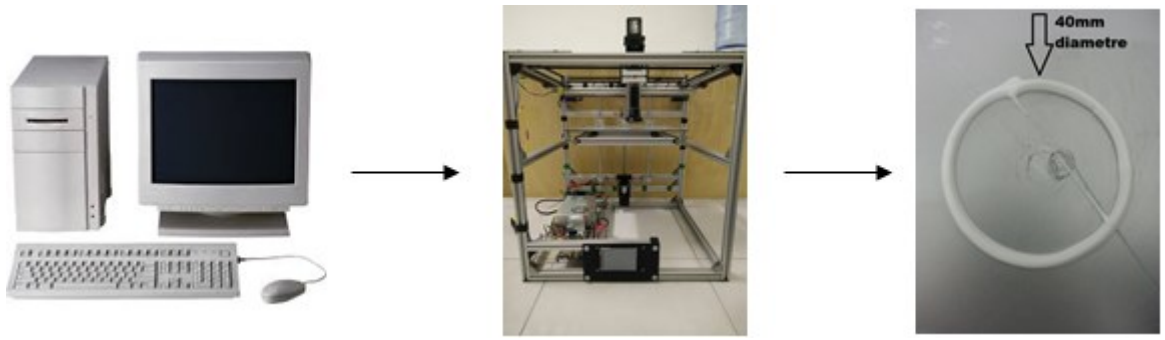


Figure 1. Overview of the 3D Bio-printer system

2.2 Mechanical Design

The design of the 3D Bio-printer starts with the software design where the SolidWorks [https://www.solidworks.com/] was used to design the sketch for the customized 3D Bio-printer. SolidWorks is come in handy to sketch every component parts that are needed for building the 3D Bio-printer parts. The design of 3D Bio-printer includes the core XY mechanism in controlling the movement of X and Y axis, Fused Deposition Model (FDM) printing technique and syringe-based extruder. Figure 2 shows the isometric view of the 3D Bio-printer.

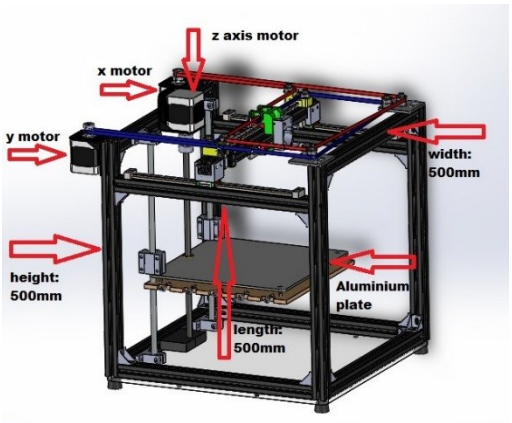


Figure 2. Isometric view of 3D Bio-printer

Core XY mechanism is one of the mechanism for 3D bio-printer techniques that are widely used by the researchers. The Core XY mechanism was applied in this project for customized 3D Bio-printer. Figure 3 shows the sketch of the Core XY mechanism where the belting

connected the stepper motor of the X-axis plane and Y-axis plane for movement. A Core XY is a parallel manipulator system [https://reprap.org/wiki/CoreXY] that positions XY coordinates of the nozzle in a Cartesian plane.

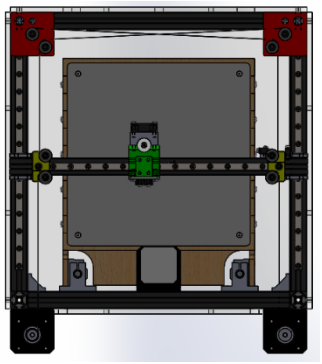


Figure 3. Core XY mechanism

Z axis of the Cartesian plane controls the volume of the 3D model that can be printed. The Z-axis plane mechanism is upward and downward movement only that control by one stepper motor that attached to a ball screw and supported by two sliders as shown in Figure 4.

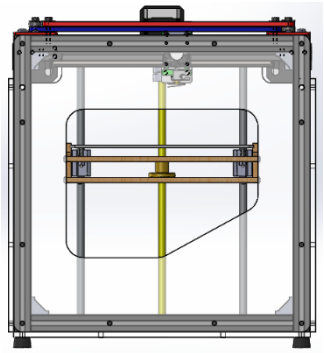


Figure 4. Z axis

The customized design of the extruder in CAD as shown in Figure 5, is used to extrude the gel-type ink. A NEMA-17 stepper motor is used to step a single axis mechanism via a ball screw. The barrel of the syringe is fixed stationary on the structure body and the syringe plunger is being pushed by the mechanism, squeezing gel-type ink in controlled volume.

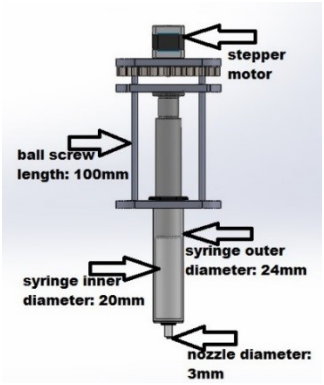


Figure 5. Syringe-based extruder

2.3 Electrical Design

For electrical design, a 3D Controller named as CHITU [http://www.cbd-3d.com/] was used as the controller for the 3D Bio-printer that reads and translates G-Codes into corresponding NC movements of the Core XY, Z-axis and Extruder for the printing process. Fig. 6 shows the schematic diagram for the connection between mechanical components, electrical parts and the CHITU controller. The schematic diagram shows the connection of the main components for the 3D Bio-printer in which the connection starts from the power source where the controller is powered up by 12V-24V DC Voltage. The connection of each Stepper Motor was connected to the CHITU Controller according to the label which are X motor, Y motor, Z motor and Extruder motor. Limit Switches are also connected to the controller with the labels of X-min to control X axis, Y min to control Y axis and Z min to control Z axis. They define the maximum and minimum strokes in each axis. Their minimums also define as the home position, [X, Y, Z] = [0, 0, 0]. The SD card slot is used to read an SD memory card for the purposes of firmware flashing and G-Codes for normal printing. A 2.8" TFT colour touch screen provides an interface to monitor and command the printer.

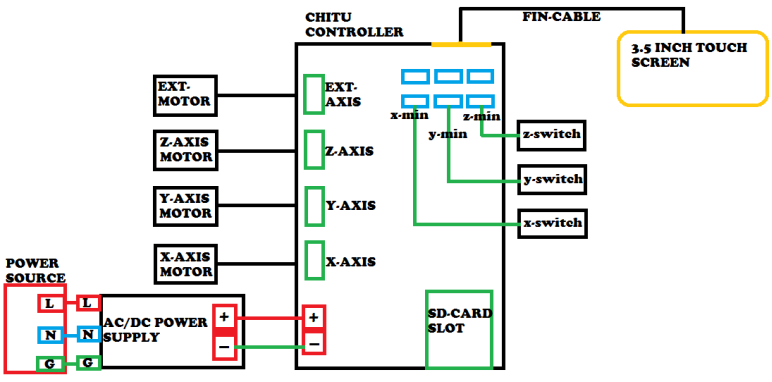


Figure 6. CHITU controller schematic diagram

2.4 Calculation on Axis Movement

The calculation for every single axis is done to determine the suitable value step needed for the NEMA 17 stepper motor to move while printing. Four calculations are done for each axis including X, Y, Z axis and extruder movement. For extruder calculation, the real value of the pitch need to be neglected due to the size of the nozzle is larger than the usual size of the extruder nozzle size used in the 3D printer. The 320 mm value was chosen for the suitable calculation in step needed for NEMA 17 stepper motor to move the customized syringed extruder. All calculations share the same equation as stated in Equation 1. The step size is calculated and tabulated in Table 1.

$$Step\ Size = \frac{Pitch\ Diameter \times (Angle/Step)}{16 \times Angle} \quad (1)$$

Table 1. Calculations on step size of X-axis, Y-axis, Z-axis and extruder

Axis	Pitch Diameter (mm)	Angle (º)	Angle/Step (º)	Step Size (mm/step)
X	40.64*	360	1.8	0.0127000
Y	40.64*	360	1.8	0.0127000
Z	5**	360	1.8	0.0015625
Extruder	5**	360	1.8	0.0015625

* *Core XY – 20 tooth GT2 timing pulley. Diameter = 2.032mm x 20 tooth = 40.64mm*

** *Ball screw pitch = 5mm*

2.5 Calibration

Calibration is the most important part of the research as it troubleshoots the problems occur while executing the 3D Bio-printer to reduce the error of the output. There are three types of calibration executed for X, Y and Z axis movements such as manual calibration, exercised calibration and extruder calibration.

Manual calibration is the process that steps each axis manually and performs a manual inspection using a ruler. Stepping length was entered and each axis stepped separately. Exercise program calibration is the calibration that involved with G-code. Several G-codes were coded to exercise three axis in performing point-to-point, linear paths, ramps and circles. The purpose of exercised G-code programs is to ensure the system works harmonically together.

Extruder calibration is the calibration made for customized extruder only. The purpose of calibration is to check the movement of pushing the plunge into the barrel of a syringe. Manual adjustment of the speed and step size settings could be done to determine the extruded output.

2.6 Hardware Assembly

Figure 7 shows a completed customized 3D Bio-printer hardware with the specification. All the main components are attached to the Aluminium Strut 20x20mm main frame of the 3D Bio-printer. Core XY and Z-axis also are placed precisely inside the mainframe and all electrical parts such as NEMA 17 Stepper motors and CHITU controller are connected and checked.

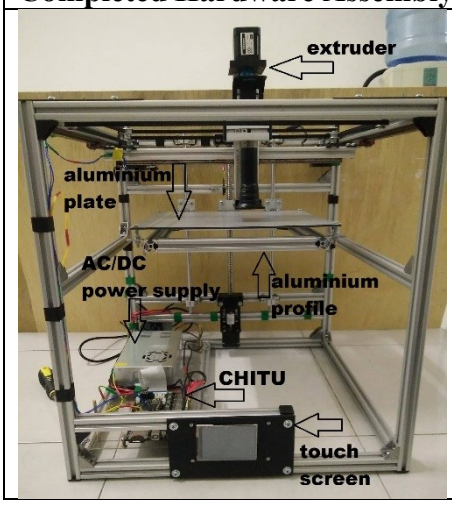
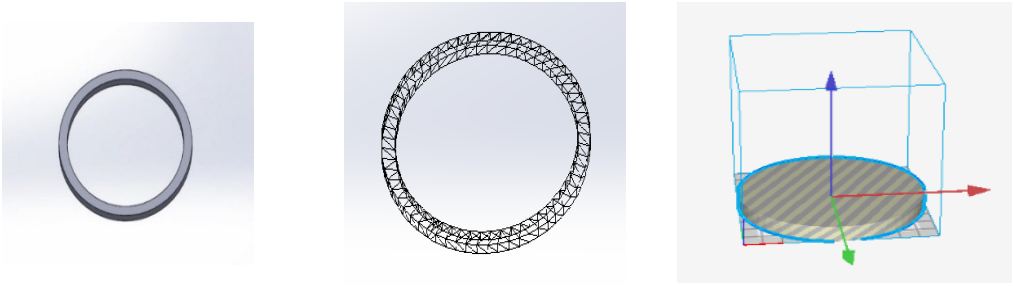
Completed Hardware Assembly	Specifications
	• Type: Fused Depositioning Modelling (Bio-Printing) • Dimension: 500 x 500 x 500 mm^3 • Weight: 12 kg • Controller: CHITU Controller • Extruder: Syringe based • X and T axis mechanism: Core XY type

Figure 7. Completed hardware assembly and specifications

3. Results and Discussion

CAD design on the 3D Bio-model needed to be done before any 3D Bio-printing is executed. Figure 8 shows the full process on the CAD design of the ring-shaped 3D Bio-model. Firstly, the CAD drawing of the sample is designed by using SolidWorks with desired diameter value and shape as illustrated in Figure 8(a). Next, the CAD drawing file will be saved in STL file format to be read by the Slicer software CURA as illustrated in Figure 8(b). Lastly, the STL file is opened using CURA to slice the drawing into multiple layers as illustrated in Figure 8(c). After all the processes have been done, the 3D Bio-model is ready to be printed. Every single layer of the CAD design contains streams of G-codes which will be executed by the 3d printer.



(a) (b) (c)

Figure 8. (a) Sample design in SolidWorks, (b) Sample design in STL format, (c) Sample design in CURA

In this experiment, 10 samples of the ring-shaped 3D Bio-model with 40mm diameter as shown in Figure 9 have been printed by the 3D Bio-printer using toothpaste as the medium of ink. All the samples are measured and calculated for data analysis.

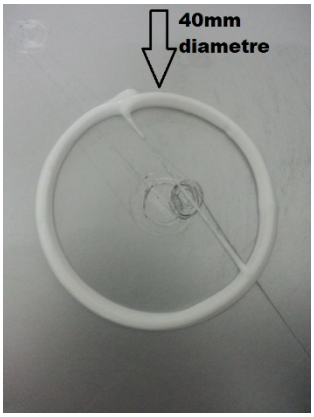


Figure 9. 3D Bio-Model Product using toothpaste

Table 2 shows the measured and error values for every single sample. The average measured value is 40.72mm which is a difference of 0.72mm to the target value. Meanwhile, the average error value is 0.72mm because the printed product is collapsed due to the viscosity of toothpaste ink. The standard deviation for measured and error values is 0.2455. One of the factors for this error could be the relative flow rate by nozzle size. The nozzle size has a diameter of 3mm which might not be suitable for the usual flow rate setting. The vibration occurred in the printer itself when printing may contribute to the error in printing. The vibration might cause the toothpaste to collapse and spread horizontally.

Table 2. Samples results (target value = 40mm)

No. of Samples	Measured Values (mm)	Error Values (Measured-Target) (mm)
1	41.0	1.0
2	40.5	0.5
3	40.7	0.7
4	40.8	0.8
5	40.4	0.4
6	40.6	0.6
7	40.7	0.7
8	40.5	0.5
9	40.8	0.8
10	41.2	1.2
Average	**40.72**	**0.72**
Standard Deviation	**0.2455**	**0.2455**

4. Conclusion

In conclusion, the development of the customized 3D Bio-printer was a success in terms of software or hardware design. The customized 3D Bio-printer was able to function properly and print out the 3D Bio-model successfully according to CAD design with an acceptable error. This 3D Bio-printer can be further improved by implementing a more precise and accurate calculation on the alignment of the Core XY, by adding up the number of Limit switch used for more accurate positioning in Core XY and Z plane. The 3D Bio-printer can be further upgraded by using WiFi as a communication system to transfer file from a computer terminal to a 3D Bio-printer wirelessly.

Acknowledgement

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