DESIGN ON FDM BASED 3D PRINTING SYSTEM FOR INDUSTRIAL APPLICATIONS

Kyaw Kyaw[1], May Zin Nyein[2], Hnin Yu Khaing[3]

Abstract

This research work focus on the modelling and construction of fused deposition method (FDM) based 3D printing system, specifically focusing on optimizing the structural design and hot end thermal analysis for FDM 3D printers. The study explores strategies aimed at maximizing the accuracy and resolution of the 3D printed objects. By acknowledging the specific constraints and potentials in FDM 3D printing, researcher can better tailor their designs for FDM printing, thus enhancing outcomes. This research work emphasizes the importance of considering the capabilities and restrictions of the manufacturing method when it comes to the design process. In this research study, all the electronic and mechanical parts are successfully built and fully functional, the Cartesian coordinate positioning-based 3D printing machine printed 3d models with desired accuracy level. In terms of current regulation in Ramps controller, it was observed that the current regulator achieved the required output current to control motors such as stepper motors and heating elements, which was to simply control the current flowing on phase winding, even when facing input voltage ripple. In its real implementation, however, it was observed current spikes that might lead to motor overall life cycle reduction.

Keywords: FDM, 3D Printing, Accuracy, Resolution, thermal Analysis

Introduction

Nowadays, 3D printing has become very popular. 3D printing technology is currently applied to many fields like engineering, sciences, medicine and entertainment. 3D printing is becoming increasingly capable and affordable. 3D printing is widely used to prototype the components but also to produce the working products. 3D printing technique also has the ability in realizing flexible designs. The implementation of three-dimensional objects can take place through both subtractive manufacturing process and additive manufacturing process. Generally, the subtractive manufacturing processes are known as traditional. In that process, the 3D objects are obtained by cutting or milling the material from a larger shape. The most utilized technologies of this type are numerically controlled machine drills or laser cutter. On the other hand, the additive manufacturing method allows to create an object through the superposition of several layers of the same material or different materials. Actually, additive manufacturing or 3D printing techniques are categorized according to the procedure the layers are deposited. 3D Printing or additive manufacturing is a process of making a three-dimensional solid object of virtually any shape from a digitally designed model. Successive deposited layers of fused material are laid down to construct a desired object. Metal 3D printing process also greatly reduces material waste since subtracting manufacturing generates metal chips while additive manufacturing uses only what is necessary and lays material down layer by layer [Gianfrano F., *et al*]. 3D printing is a manufacturing method that is recently used to build three dimensional objects by using digital CAD (computer aided design) files. 3D model was created by using (CAD) software like SolidWorks, 3D scanner and Ansys software. The most popular and affordable type of additive manufacturing is known as Fused Deposition Modeling (FDM). These method utilize the extrusion of heated thermoplastic filament to build parts one layer at a time. FDM printers are capable of building parts from (CAD) files, however they must first be converted into a file format that the printer can understand, such as a STL file. The STL files allow the printer to operate how the part must be built layer by layer, ensuring the printer is capable of extruding both the part material and any support material for thin materials parts.

[1] Department of Physics, University of Mandalay
[2] Department of Physics, Ba Maw University
[3] Department of Physics, Mandalay University of Distance Education

Fused Deposition Modelling (FDM) was selected as the printing method for this research work according to its fabrication cost and reliability. In the FDM, the filament was firstly heated until it reached a semi-liquid state and then extruded through a nozzle on a platform or previously printed and deposited layer. This method relies on the thermoplasticity of the material to fuse together during the heating process. The durability of the materials, the stability of mechanical properties, and the suitability of the material for the detailed functional prototype are the main advantages of this printing method [Karel D., *et al*]. The two types of 3D printing devices exist within the field of FDM printing, these are the Cartesian coordinate system and polar coordinate system. All utilized filament extrusion to fabricate objects, however they differed in the depositing ways how they extrude filament, which can lead to numerous differences in print time, print quality, and machine usage.

System Components and Operation

The central processing control unit is implemented with Arduino Mega2560 development board. The linear movement for Cartesian coordinate system was drove with the help of high precision TB6600 stepper motor drivers. The Repetier host software was installed in the PC and the corresponding GCODE of 3D model was send via RS232 serial communication protocol through USB port. The block diagram of the constructed 3D printer is illustrated in Figure 1.

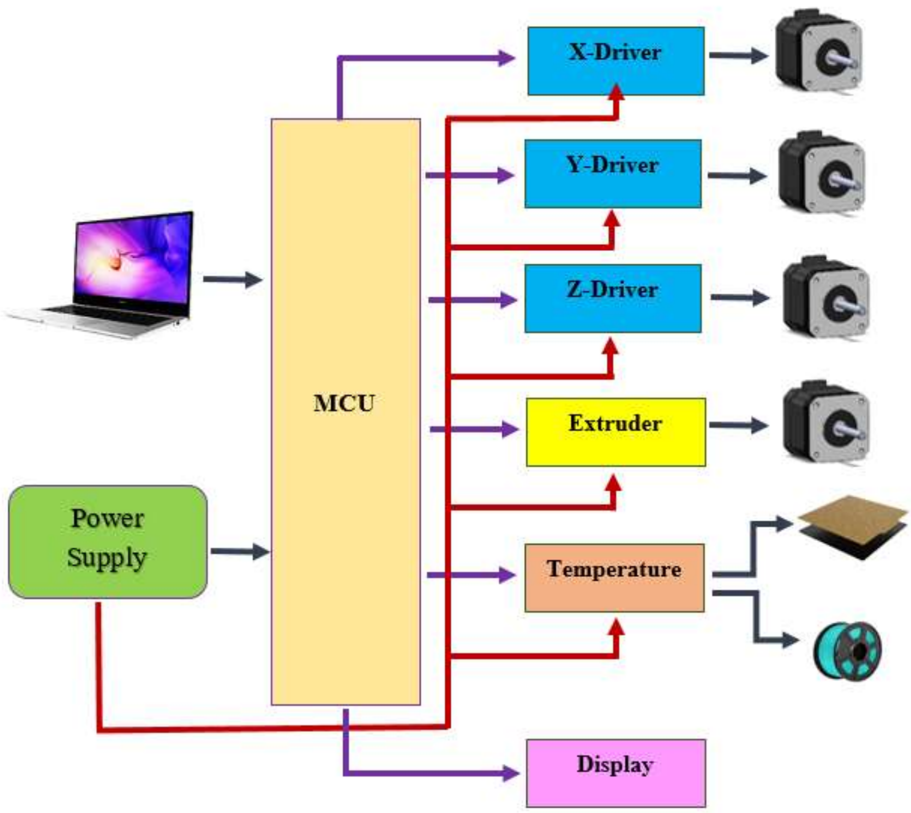

Figure 1. Block diagram of the constructed system.

Hardware Mechanism for 3D Printing System

A 3D printing machine was designed with three Cartesian axes, with 150 mm of length in X axis and 90 mm of length in Y axis and 20 mm of length in Z axis. In this constructed system, three stepper motors with holding torque of 10 kg.m, 8 W of power per phase, 1.8º step angle and positioning precision higher than 95% were conducted as axial motion actuators. The MK8 Extruder was combined as end effector (hot end) with nominal power of 40 W at 12 V, and nominal feed rate of 100 mms^{-1}. The 1045 steel threaded rods were used to convert rotational to translational mechanic converter for moving end effector. Its pitch had 3 mm per step and threading precision was higher than 95%. The machine's general characteristics are listed in Table 1 and 3D model of printer components are illustrate in Figure 2.

Table 1. The specification of the constructed 3D printing machine

Travel on axis X and Y	150 mm, 90 mm
Travel on axis Z	20 mm
Maximum torque on axis	10 kg.m
Motor wiring	Bipolar
Bipolar motor parameters	L = 0.020 H, R = 4 Ω
Resolution	200 steps per revolution at full step control mode
Driving mode	Half step
Threaded Rod	Trapezoidal, 14 mm diameter, 3mm step
Nut	Polyacetal and Bronze
End effector	MK8 extruder with stepper motor and 0.4 mm nozzle
Mandrel	3.2 mm diameter

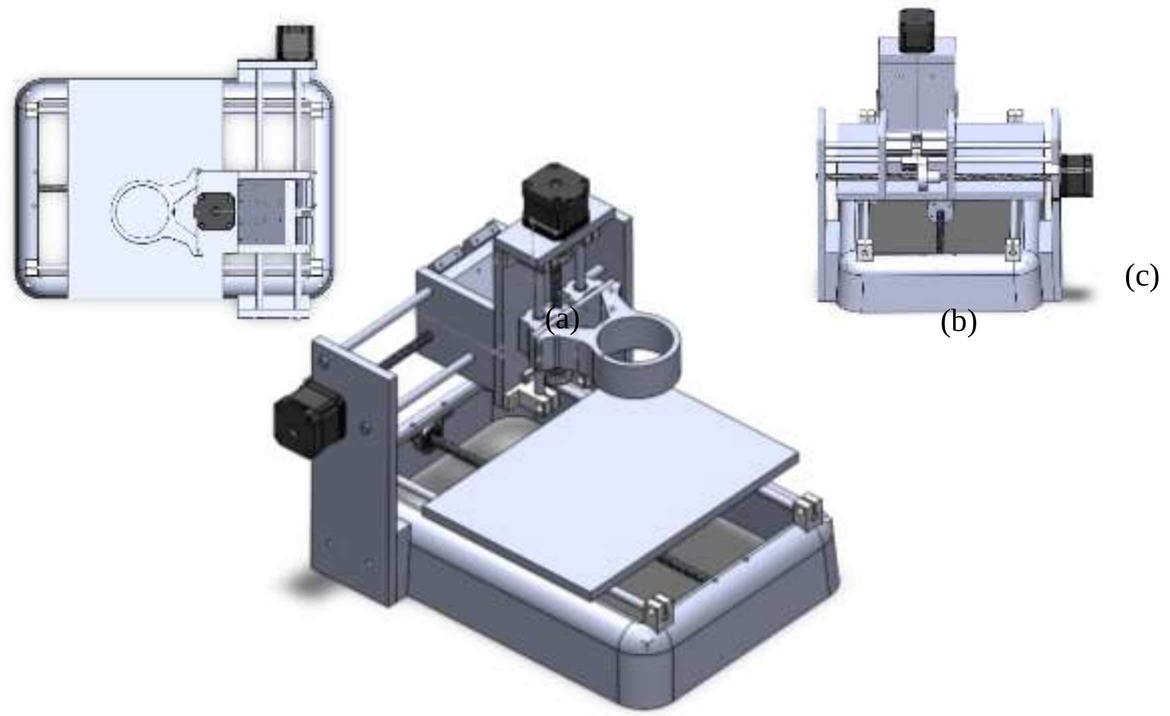

Figure 2. 3D assemble of the 3D printing system, (a) Top view of 3D printer, (b) Back view of 3D printer and (c) Perspective view of 3D printer

Software Interfacing

The software interfacing was based on Arduino firmware and PC printing host software. Repetier Host software was easy to understand for auto and manual control of 3D printing system. It could not only to display electrical and mechanical variables but also to send GCODE commands and receive commands. It could be implemented as bidirectional interface between 3D printer and the host computer. The communication system followed in a way that the host computer always transmitted the acknowledge signal of the present task being executed by the machine. Therefore, a protocol would have to be developed, allowing the data exchange between the machine and the computer. The program could operate in two operation modes: the manual and the automatic. In the manual mode, the movement coordinates were converted into GCODE and it was sent to the machine to move in predefined discrete steps on each axis. Fused deposition operation was also follow with acquired GCODE related layer height, feed rate and temperature PID control. In the automatic mode, the user would have to load a file containing sliced layer code, such as G and M codes. The program then loads the selected files, decoded commands and sent them to the 3D printing machine. GUI interface of the host software is illustrated in Figure 3.

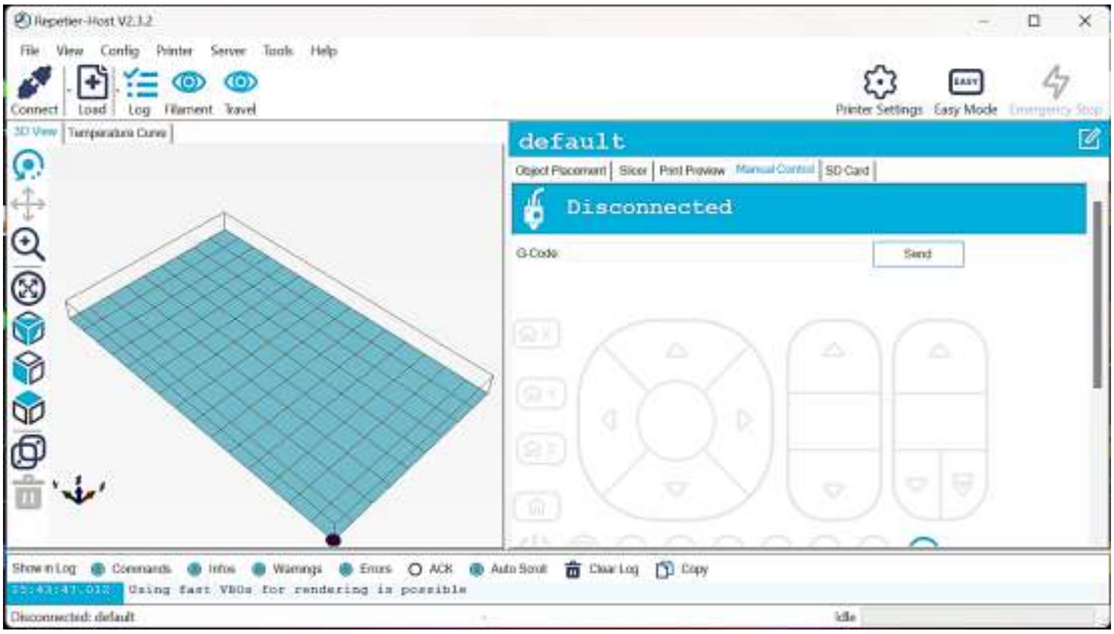

Figure 3. Desktop of the 3D printer control software.

Results and Discussion

After the designing of all the mechanical parameters of the machine, the initial 3D model was developed using the SolidWorks 2020 software. The model was of great relevance for the physical implementation of the machine, allowing the individual design of each component, reducing the possibility of vibration errors. The partial assembly of the machine were also shown in previous figures. Some of the parts of the machine were not meant to be permanent, such as the nut holders, which were presently parts were made with plastic. The printer control software was designed in such a way that it had both user-friendly and informative system. In order to achieve this capability, the software was programmed in Arduino IDE and Repetier host, which provided powerful tools to easily design the program. The software includes the necessary controls for the operation as well as all useful variables for the process in a simple and intuitive way.

Thermal Analysis of the 3D Printing Extruder using SolidWorks

The extrusion head (hot end) had the task of heating the plastic material such as ABS, PLA and PVC, and deposited by means of a nozzle on the heated bed platform. Heat could be transferred in three different ways: conduction, convection and radiation. Finite elements analysis was used to calculate the thermal effects in the extruder using SolidWorks 2022 software. Finite Element Analysis (FEA) consists of a computer model of the object that is stressed, analyzed to obtain its behavior for specific loading condition. It is used in new product design, and for existing product refinement. Using this method, it is possible to verify if the constructed design would be able to perform to the 3D printing. In case of structural failure, FEA may be used to help to determine the needed design modifications to meet the desired condition. The assembly of the extruder head was modeled in 3D and meshed in finite elements, to perform in the software program the finite elements simulation. The analysis was performed to quantify the heat transmitted from extruder head to the aluminum frame. The operating temperature of the extruder was 243°C for ABS materials. The environmental temperature was set at 25°C. The heat transmission was steady and was transmitted to the aluminum frame by conduction and radiation (convection is neglected because the ABS material was thermos-isolated inside the extruder). After determining and setting all the boundary conditions, the virtual simulation and analysis was performed. For parts mesh creation, the minimum value for triangular distance parameters was set to 0.2 mm. The FEA analysis performed with SolidWorks is shown in Figure 4. The photographs of the constructed 3D printing machine and the printing process are illustrated in Figure 5 and Figure 6.

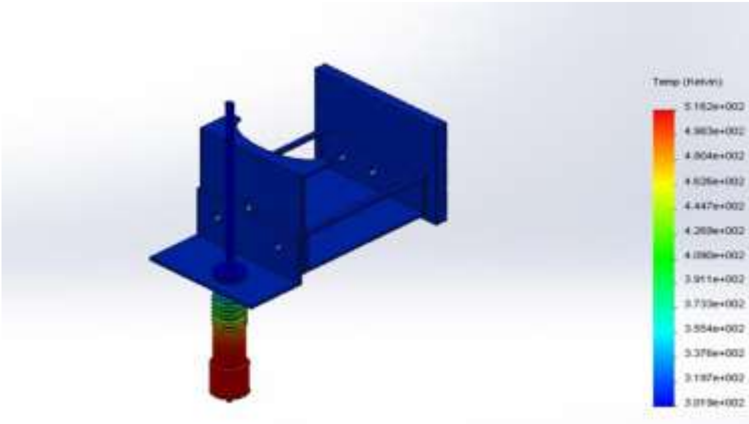

Figure 4. The FEA analysis of 3D printer extruder.

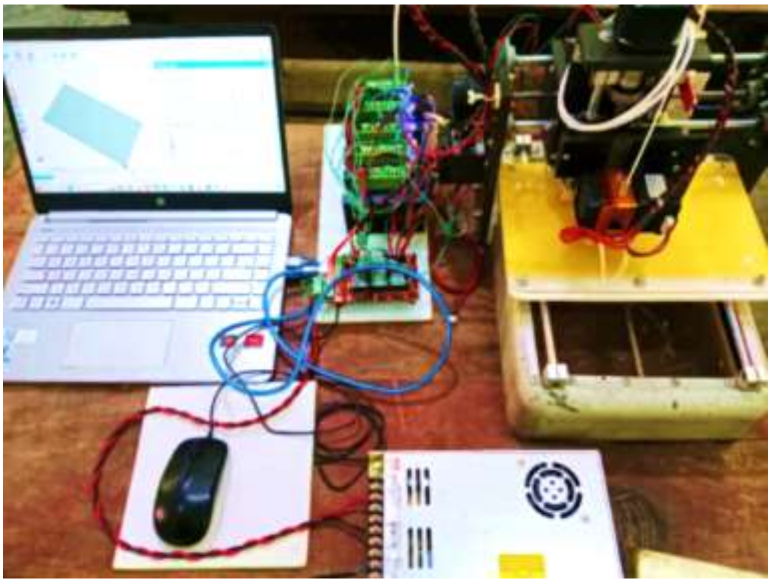

Figure 5. The photograph of the constructed 3D printing system.

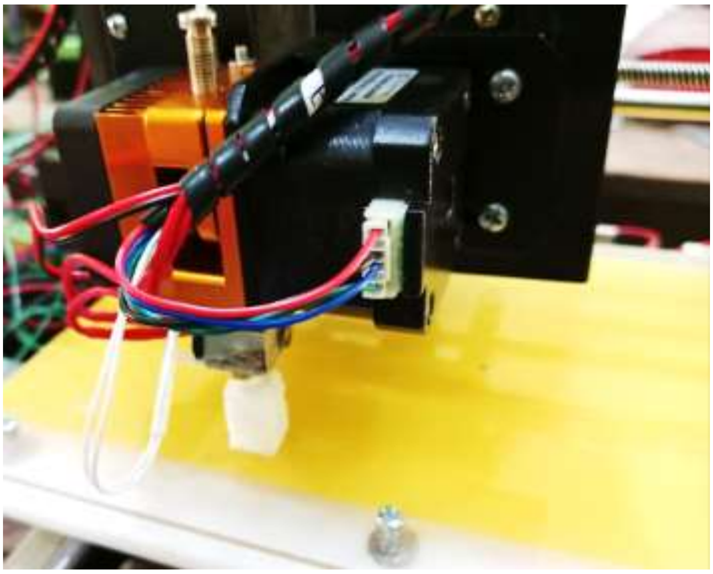

Figure 6. The printing process of the 3D printing system.

Conclusion

The Cartesian coordinate positioning-based 3D printing machine was successfully built with electronic and mechanical parts. In terms of current regulation in Ramps controller, it was observed that the current regulator achieved the required output current to control system components such as stepper motors and heating elements, which was to simply control the current flowing on phase winding, even when facing input voltage with ripple. In its real implementation, it was observed current spikes that might lead to motor overall life cycle reduction. The analysis led to the conclusion that the current spikes were caused by very high switching-off latency and diode latency, lack of coordination on switching the H bridge transistors and measurement interference caused by the currents surge that in its turn are caused by the switching of the load. As solution to these problems, it was suggested that the replacement of the BJT based H bridge by a power MOSFET based H bridge and use of switching diodes even faster than those MBR350 used, and revision of the driver board, considering more carefully the design of the board in what it refers to the current carrying lines.

The extruder head was designed and analyzed to ensure a better heat concentration only in the area of heating block containing the nozzle and heater. It was also needed to avoid as much as possible dissipation of heat to the aluminum frame or to the environment. Furthermore, cooling fan would be used to lowering the temperature of the deposited ABS material passage which improved the flowing of the material, because it is heated only in the area of extrusion, where it is needed.

The FEA thermal analysis confirmed the design requirements, the temperature measured on the nozzle was observed 240 °C and it was equal to the value needed to melt the ABS materials. The temperature value of the extruder thermal insulator part was equal to 40.7 °C. In the FEA analysis, the temperature value of the extruder thermal insulator part was 37 °C. The difference of 3.7 °C is related to the environmental temperature of 25 °C set during the simulation, different from the value measured during the thermographic analysis that was 28.7 °C. This difference of three degrees decreases the difference to 0.7 degrees between the FEA analysis and thermographic analysis. This is a small difference and it can be neglected, because it does not affect and disturb the system for printing with ABS materials.

Acknowledgements

This research work was totally implemented in Electronics lab, Department of Physics, University of Mandalay.

References

Alaa J. A., (2015), "The process and Technologies of 3D Printing", International Journal of Advances in computer science and technology, vol.4 (10), pp.161-163.

Budi H., Robby W., (2021), "Development and Accuracy Test of a Fused Deposition Modeling (FDM) 3D Printing Using H-bot mechanism", Springer, vol.3 (1), pp. 46-53.

Gianfrano F., (2019), "Print on air: FDM 3D Printing without Supports", IEEE access, vol. 19, pp. 350-352.

Joseph F., (2019), "Cartesian, Delta, and Polar 3D Printers: What are they and what's the difference?", Web resource: https://www.JosephF.org,(Accessed date - 15.7.2024).

Karel D., (2017), "3D Model Preparing for Rapid Prototyping by FDM method", 8th Edition, McGraw Hill Press, USA.

Kevin H., "What is a CoreXY 3D printer?", Web resource: https://www.3dtechvalley.com/what-is-a-corexy-3d-printer/, (Accessed date - 3.7.2021).