COMPACT SIZE PORTABLE 3D PRINTER AND CLOSED LOOP MOTION CONTROL FOR LAYER SHIFTING COMPENSATION

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ABSTRACT: 3D printing technology has become accessible to community changing from extensive industrial machine to cheap DIY 3D printer. The common printing technology, Fused Deposit Modeling (FDM) enables construction of many open design of FDM printer thanks to RepRap project. However, most of the designs are solid rigid body which are immobile. This inspires the construction of portable 3D printer in a fold-up suitcase structure that eases transportation and storage. The project used 2020 aluminum extrusion as the primary framing material, together with sub-assemblies consist of mechanical parts, electronic components, and 3D printed parts. The folding mechanism was designed and tested using CAD program Solidworks and the components were assembled together to form the finished unit. This project also proposed a closed loop system in stepper motion of Cartesian FDM printer on X-Y axes gantry with the position feedback of print head and print bed from linear encoder at each axis. It is believed to be able to compensate for layer shifting problem during printing operation. An external motor controller made up of Arduino microcontroller is implemented on both X and Y axis aims to detect error and rectify the motion of print head during printing process.

KEYWORDS: *Additive Manufacturing; 3D Printing; Fused Deposit Modeling (FDM); Layer Shifting*

1.0 INTRODUCTION

3D printing is the process in adding together or solidifying material to create a three-dimensional object. There are many different technologies, like stereolithography (SLA), selective laser sintering (SLS) or fused deposit modeling (FDM). Therefore, unlike subtractive manufacturing, 3D printing builds a three-dimensional object from a computer-aided design (CAD) model, generally by successively adding material layer by layer.

3D printing technology has started to become accessible to all after the emerge of RepRap project by Jones et a. (2011), aiming to self-develop a low-cost FDM 3D printer without the need for extensive industrial infrastructure. This excites the hobbyists and researchers in developing many RepRap printer designs, mostly Cartesian and Delta style printers, where majority is immovable. Therefore, this inspires the idea of developing a portable 3D printer which is able to fold up into a suitcase structure so that it is easy for carry and storage, and easy to operate at different location.

Bergen Makerspace Transportable 3D Printer by John Diamond was a Cartesian style 3D printer based on the Open Source RepRap Prusa i3 designed by Josef Prusa. It used 2020 aluminum extrusion as the primary framing material and was designed to be folded up and fit into a carrying box for transportation. However, his design required a carrying box to keep his printer, thus a new design of portable printer without a carrying box could be implemented and developed in this project. Nevertheless, the open loop system of stepper motion may lead to inaccuracy and layer shifting problem that results in defection. This is because there is no feedback of the position of print head and printing bed while printing without self-correction.

Weiss (2015) proposed a closed-loop system which directly interfacing with the motor control through the 3D printer firmware and ARM-based processor for the control system of motion in X-Y stages. His project was built on concept of Intelligent Motor Control (IMC) printer control framework which used a separate ARM-based processor to control each axis, which enabled more complex real-time computations in closed-loop control. He developed a controller using PJRC Teensy 3.0 as the ARM processor and AS5311 magnetic linear encoder as the feedback of the system. However, instead of using expensive magnetic linear encoder and Teensy microcontroller, a cheaper AVAGO inkjet printer linear encoder is proposed and using Arduino UNO as motor controller for this project to achieve low cost purpose. He et al (2017) analysed the actual data from the FDM 3D printer to design the acceleration and deceleration profile of the stepper motor employed in the 3D printer. Lin, Zhang, & Yang (2018) simulate a closed-loop control system for printing system in the pursuit to reduce the processing time of digital light processing.

In this project, knowing the current trend in the maker space and culture, a solution to the problem targeting on reducing the layer shifting problem during the 3D printing is proposed. The solution involves the application of the closed-loop motion control on X and Y stages on the 3D printer. Linear quadrature encoders were employed to provide feedback of the motion of print head and the printing bed. A coded control algorithm will guarantee accurate printing motion thus, minimizing the likelihood of 3D printing error and subsequently, unnecessary wastage of resources. The actual make-up of the system was designed to be portable. On the maintenance perspective, the service life time of the custom 3D printers can be prolonged due to the reduction of wear-and-tear as a result of controlled smoother motion.

2.0 METHODOLOGY

2.1 Construction of Portable 3D printer

The construction assembled several sub-assemblies to form the final unit. The printed parts were designed using CAD program Solidworks, and the whole structure was illustrated and assembled in Solidworks to check and measure the connection and dimension of joints and holes. The project consisted of vertical and horizontal frames with a folding mechanism that abled to close up into a suitcase s shown in Figure 1.

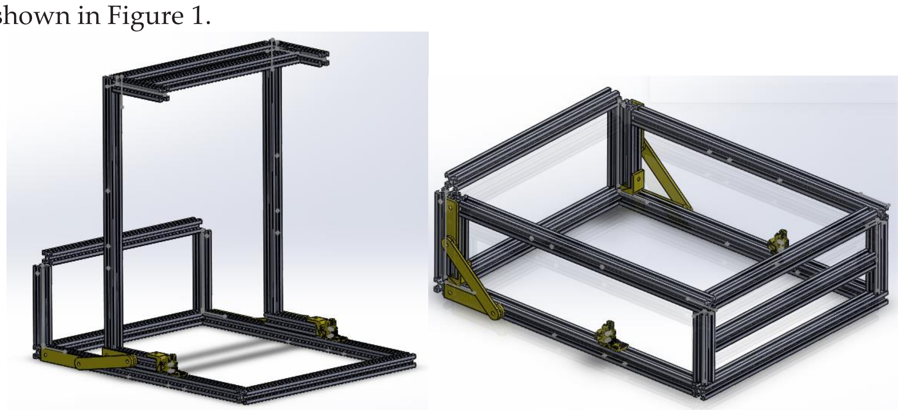

Fig. 1 Solidworks Design in Assembly for "OPEN-CASE" design at the left and "CLOSE-CASE" design at the right

All the STL files for the 3D printed parts were sent to be printed in PLA and then assembled with the specific components for gantry of X, Y and Z axes. The case latches were designed shown in Figure 2 in order to latch up the folded up printer. The power supply was assembled together with the printer shown in Figure 3. The final assembled design was shown in Figure 4.

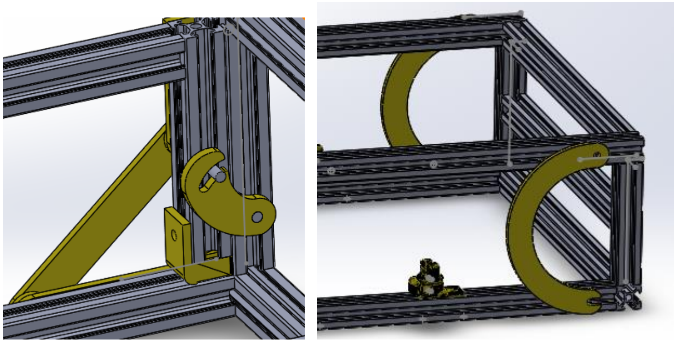

Fig. 2 Latches designed for folded up printer

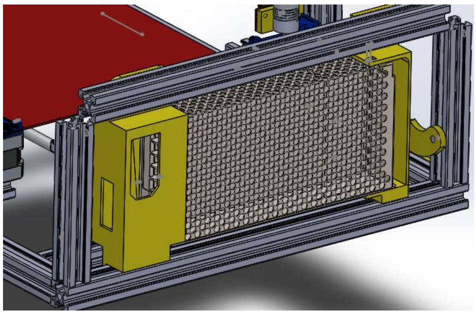

Fig. 3. Power supply holder

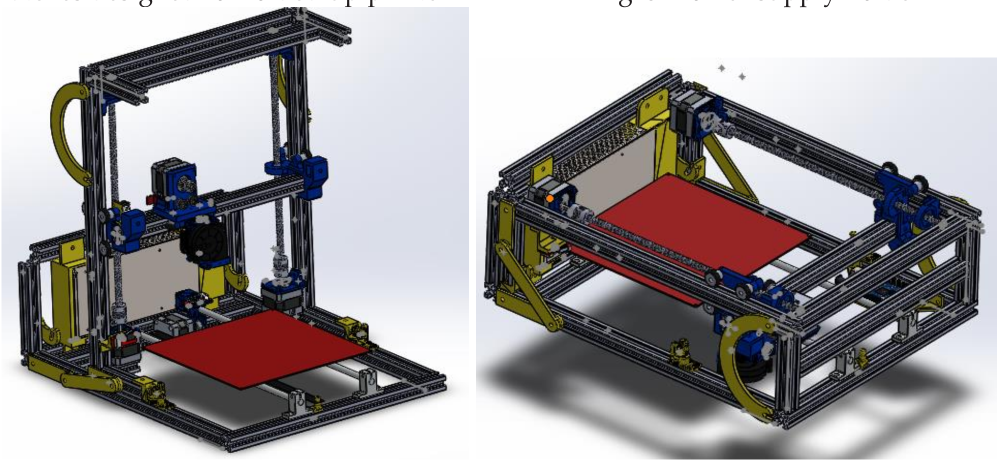

Fig 4 Full assembly of portable 3D printer structure design

After the CAD design of the 3D printer was completed, the assembly process was carried out, assembling all the mechanical parts, electronic components, and printed holders together. The major components were tabulated in Table 1 as shown below:

Table 1 Major Components Build of Material for 3D Printer

Item	Amount	Reasons
Arduino MEGA 2560	1	Act as the microcontroller for the firmware to be executed
Ramps 1.4 board	1	Arduino Shield specifically for 3D Printer or CNC purpose with all the required pins and ports for related equipment
NEMA-17 stepper motor	5	To generate motion and extrusion
Pololu A4988 stepper motor driver	4	Use to control stepper motor for each axis, including extruder
Timing belts and bearing	2 sets	Each for the stepper motors pulling at X and Y axes
12V 15A power supply	1	To generate power
Printing bed	1	The plane for the printing execution
E3D-V6 Single-Head Extruded Set 1.75/0.4M	1	Heater cartridge or print head to extrude material on the printing bed
End stop	3	Use for homing the axes for absolute positioning
Cooling fan	2	Use to cool down and control the temperature of nozzle
M8 linear rod	2	Moving axis with bearing

T8 Lead Screw with nuts	2	For Z-axis motion
2020 T-slot aluminium extrusion with T-nuts		Use as 3D printer gantry

2.2 Closed Loop System for Stepper Motion Control

The motion control system was comprised of NEMA-17 stepper motor, A4988 stepper motor driver, with an additional microcontroller Arduino UNO to perform the control system for the stepper motor. The basic concept was proposed as shown in Figure 5.

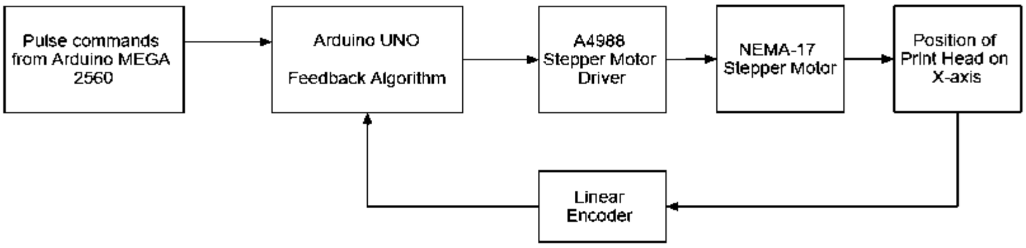

Fig. 5 The closed loop system concept for the motion control of stepper motor

The MARLIN firmware was coded inside the Arduino MEGA 2560 acting as the master controller for the 3D printer. In principle the firmware reads and interpret the "G-codes" from SD-cards. The 3D printing process would be initiated and the pulse commands were consequently sent to A4988 stepper motor to actuate the 3D printing mechanism which is installed or plugged onto the Ramps 1.4 shield. However, to interrupt the process of stepper motor motion, the motor driver is separated out from Ramps 1.4 shield and the pulse commands will be sent to Arduino UNO as the input for stepper motor execution. Then, Arduino UNO which acts as the additional motor controller will take the feedback of print head position from linear encoder then only generates the pulses commands to the A4988 stepper motor driver to drive the NEMA-17 stepper motor with the reference of the linear encoder.

2.3 AVAGO Optical Linear Encoder HEDS-9740

HEDS-9740 is an incremental encoder consists of a C-shaped emitter/detector module, coupled with an encoder strip. When there is a linear motion, the module translates the linear motion into digital output. The detectors are spaced such that the signals received are divided into channels A and B where the digital output of channel A is in quadrature with channel B (90 degrees out of phase). Quadrature output enables the direction sensing by knowing which channel is leading and which is lagging. The measurement of encoder position depends on three types of encoding which are X1, X2 or X4 using the formula:

$$\text{position(mm)} = \frac{\text{EdgeCount}}{\text{xN}} \cdot \left[\frac{1}{\text{PPM}}\right]$$

where xN = Encoding Type (for X4 encoding, xN = 4)
PPM = Pulse per Millimeter

X4 encoding is selected for the control system for higher resolution as it counts both the positive and negative edge of both channel A and B which quadruples the number of pulses counted and also the resolution of encoding.

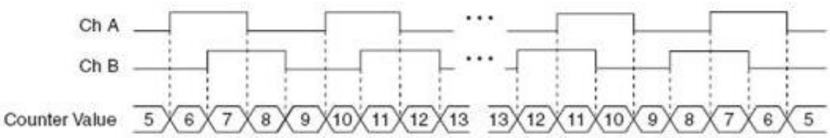

Fig. 6 The counting of X4 encoding pulses for both positive and negative edges of both channel A and B with channel A lags channel B

Table 2 Logic of pulse counting and direction for X4 encoding

When A Interrupt				When B Interrupt			
B	A	Pulse	Direction	B	A	Pulse	Direction
0	0	++	Forward	0	0	- -	Backward
0	1	- -	Backward	0	1	++	Forward
1	0	- -	Backward	1	0	++	Forward
1	1	++	Forward	1	1	- -	Backward

The linear encoder is installed on X and Y gantry with its holder being designed and assembled first in Solidworks program, where one is located at print head while another one is installed at the below of the printing bed which are shown in Figure 7 below.

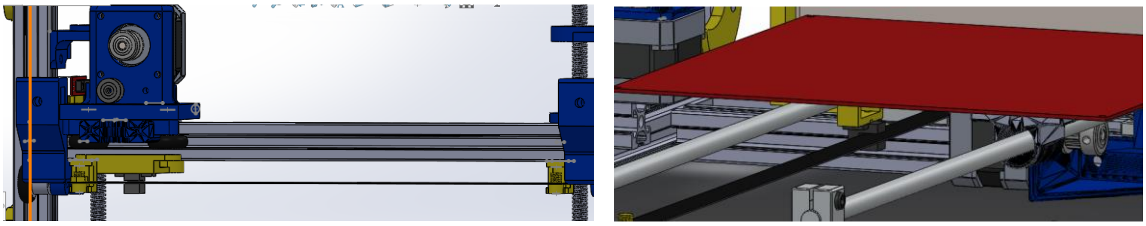

Fig. 7 3D assembly of encoder strip and linear encoder on print head and below print bed

4.0 RESULTS

Figure 8 showed the final design of portable 3D printer and the folded up suitcase printer.

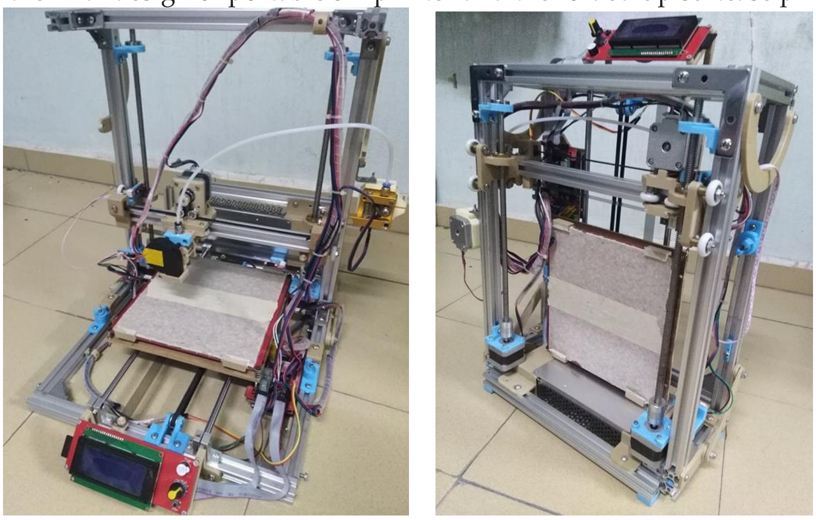

Fig. 8 Final design of portable 3D printer

5.0 RECOMMENDATION AND FUTURE DIRECTION

Auto-leveling system can be implemented in the printer using capacitive or inductive sensor to prevent bed leveling problem every time the printer is moved. Besides, the material for printed part can be changed to ABS instead of PLA for stronger strength.

6.0 CONCLUSION

3D printer is no longer limit for industrial operation, instead it has become available for community with more innovative design and lower cost. A portable 3D printer will ease the transportation and storage of device. This project utilized the mechanical design of folding mechanism into 3D printer structure. The application of CAD program Solidworks was studied in order to design and sketch the portable 3D printer by assembling the axes gantry in CAD program to study the dimension and fitness among mechanical parts, electronic components and 3D printed holders. The STL files were sent to be printed and then interconnected with the printer gantry. The latches for folded up suitcase were designed and tested in order to hold the printer frame together. Moreover, a closed loop motion control is proposed to help in compensation of layer shifting problem. A linear encoder helps in providing feedback of print head and print bed position making a closed loop system for stepper motion and coordination. The control system can be executed with additional microcontroller Arduino UNO to detect the stepper pulses and direction from printer firmware and position feedback from encoder in order to provide correct signal to the A4988 motor driver to drive the NEMA-17 stepper motor. This project is believed to benefit students in additional academic research from its mobility and convenience. Furthermore, a closed loop system approach in 3D printer motion shall benefit the user from the problem of missstep in stepper motor and provide a study of control system in 3D printing technology.

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