Control position of the double nozzles on the Y (+) and Y (−) axis of 3D symmetric bilateral printing using G-Code

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Abstract. The most widely used universal Cartesian 3-Dimensional (3D) Printing today is not fast enough. However, by applying double nozzles, the process for making symmetric bilateral product can be done in half of the time. A symmetric bilateral product is an object that has the same size on the right and left sides. So, the method can be implemented by having double actuators that are mounted by a nozzle on each side. Both nozzles, called as Y and -Y nozzle, move on the same time and distance but in different direction. Besides that, an appropriate mechanical support is needed to be prepared, so that the motors can move in different direction at the same time. Therefore, a design simulation for two Y actuators was carried out. The simulation and the data taking were using actuator simulation software. The simulation results shows that the G-code can control two Y actuators with 99.64% accuracy with average error of 0.216% for revolution speed, and 100% accuracy with average error 0% for distance. The motor can move in different directions with the same type of screw.

1. Introduction

The 3-Dimensional (3D) printing is one of the main technologies that can sustain the development of the industrial system 4.0 [1]. It can print complex components and make the production process short and simple. 3D printer is a machine that can create real objects from 3D designs using computer-aided design (CAD) software [2]. Therefore, a program is needed to translate images or designs which have been made by CAD into a G-Code file. The G-Code, in this case, will be processed by the microcontroller to then be translated into motion on stepper motors.

The most widely used universal Cartesian 3-Dimensional (3D) Printing. It is not fast enough because only using one instrument (nozzle) for making products especially of 3D symmetric bilateral products [3]. A symmetric bilateral product is an object that has the same size on the right and left sides. So, it is very important to develop a printing method or system that can serve bilateral symmetric product formation faster than the universal 3D. By applying double nozzles at Y axis as Y and -Y nozzle, the process for making symmetric bilateral products can be done in half of the time.

Double nozzles can be implemented by having double actuators that are mounted by a nozzle on each side and it has moved at the same time and distance but in a different direction. So that the movement of the double nozzles is coordinated, it is necessary a design simulation for control two Y actuators at a distance, movement, direction of movement, and speed of motion of the two stepper motors.
The purpose of this research is to accelerate the manufacture of bilateral symmetrical products and to support government programs in accelerating industrial infrastructure 4.0.

2. Literature review

2.1. 3D printing symmetric bilateral

3D printer is a machine that can create real objects from 3D designs using CAD software. CAD is the use of computers to assist in the modification, analysis, creation and optimization of a designs [4] and outputs in file format for printing, machining, or other manufacturing operations. CAD software can be used to design curves and drawings in two-dimensional (2D) space or in 3D space [5]. The 3D design is saved in the stereolithography (STL) format and then sent to 3D Printing to make the 3D design layer by layer until it becomes a real 3D shaped object [2]. The 3D printing symmetric bilateral machines can form bilateral symmetrical products with the same size, angle, and shape on the right and the left sides.

2.2. 3D printing slicer software

The slicer software is a computer software used in the 3D printing processes for the conversion of a 3D object model to a specific instruction for the printer. The conversion is carried out to convert a model in STL format to printer commands in G-code [6-8]. G-code uses computer numerical control (CNC) programming language. It is used in computer-aided manufacturing to control the automated machine tools. G-code instructions provided to a machine controller tells the motors where to move, what path to follow, and how fast to move [9].

2.3. Firmware 3D printer

The firmware manages all of the machine's real-time activities including sending movement coordinates to the stepper motors through the stepper drivers, controlling the sensors, the lights, the heater elements, and tracking the bed levelling [10]. Interfaces for 3D Printers and CNC software suite handles the printing process and allows direct control of the 3D printers.

2.4. Actuator simulation software and screw

Actuator simulation software is used to show the movement of actuator and uses mathematical models to replicate the behavior of an actual electronic device or circuit. Simulation software allows for modeling of the circuit operation and is an invaluable analysis tool [11]. The series animation of actuator simulation can be used to help understanding the series so that it have educational value. A screw is a mechanism that converts a rotational motion to a linear one, and a rotational force (torque) to a linear one [12].

3. Methods

The method can be implemented by having double actuators that are mounted by a nozzle on each side. Both nozzles move on the same time and distance but in different direction. Therefore, a design of simulation for two Y actuators has to be carried out.

3.1. Simulation procedure

Figure 1 shows the simulation procedure. CAD software is used to design a half of the bilateral symmetrical products. 3D objects from the STL format are converted in the G-code format using 3D printing slicer software. It is slicing objects into a layer by layer section. After the completion of the slicing, the slicing software needs to make information of slice of the object shape, size, and other related one into the G-code instruction which 3D printer is able to identify for finishing the 3D printing task. The G-code instructions provide a machine controller that tells the motors where to move. The firmware that is included in the microcontroller software will manage all real-time machine activities including sending coordinate movements to the stepper motor through the stepper driver. The interface for 3D
printers and CNC will handle the printing process according to the entered G-code. The simulation for the two Y actuators uses actuator simulation software.

The stepping motor used is capable of doing 1.8 °/step turn and it needs 200 steps per revolution (360°). The screw is used and requires one revolution to cover a distance of 2 mm. So the motor must be rotated in 360° for a distance of 2 mm. The steps of the motor must be set at 200 steps, but the settings on the step motor driver are at least 400 steps. Therefore, synchronizing the program is needed.

![Figure 1. Block diagram of the simulation.](image)

The calibration of the firmware 3D printer, where microstep driver is 400 pulse/rev and \( p \) is pitch of screw using equation (1).

\[
Firmware\ Kalibration = \frac{Microstep\ Driver}{p} \tag{1}
\]

Step settings in the program is as follows.

```c
//#define DISTINCT_E_FACTORS
/**
 * Default Axis Steps Per Unit (steps/mm)
 * Override with M92
 * X, Y, Z, E0 [, E1[, E2[, E3[, E4]]]]
 */
#define DEFAULT_AXIS_STEPS_PER_UNIT {160, 200, 160, 500}
```

3.2. Schematic of two Y stepping motors

![Figure 2. Schematic of two Y stepping motors in actuator simulation.](image)

Figure 2 shows the simulation circuit for the two Y motors using actuator simulation software. The controller uses Arduino Mega 2560, which has been inputted with the firmware software. The output of
the controller is used as input for the motor driver L297 and L298, which will regulate the movement of the two stepper motors. The output of actuator simulation is frequency and pulse. So the revolutions speed, that is Rotation per Minute (RPM) can be computed using equation (2).

\[ RPM = \frac{\Theta s^\circ}{360^\circ} \times f \times 60 \]  

(2) is used to ensure the revolution speed generated in the simulation is appropriate or not. The revolution speed is influenced by frequency. The greater the frequency, the faster the revolution speed of the motor produced. The pulse obtained using equation (3) and can be used as a basis for calculating the travelled distance. The setting step is 200 steps for 2 mm. Therefore, the setting is 100 step per mm.

\[ d = \frac{\text{pulse}}{100} \]  

3.3. The model of screws

Appropriate mechanical support needs to be prepared so that the nozzles can move in a different direction at the same time. Figure 3 shows the model of screws. When the shaft of the screw is rotated relative to the stationary threads, the screw moves along its axis relative to the medium surrounding it. So, the nozzles can move in different directions with the same type of screw. When the motors rotate Clock Wise (CW), the nozzles will move forward and head toward the center. Meanwhile, when the motors turn Counter-Clock Wise (CCW) the nozzles will move backward. The linear distance \( l \), a screw shaft moves when it is rotated through an angle of \( \alpha \) degrees can be found by using equation (4) where \( p \) is the pitch of the screw.

\[ l = \frac{\alpha^\circ \times p}{360^\circ} \]  

Figure 3. The model of screws.

Figure 4. The movement of the nozzles.
3.4. Planning motor torque in Y axis

The Y-axis weight is 2.95 kg (an HDPE pellets extruder), where Friction Coefficient of bearing ($\mu$) is 0.61, the outer diameter of the screw ($dl$) is 12 mm, the effective diameter of the screw ($de$) is 10 mm, the pitch of screw ($p$) is 2 mm, and the workload ($W$) is 2.95kg or equal to 28.2 N. So, minimum torque is found by using equation (5).

$$T = \frac{Fx de}{2} + \left( \frac{1 + \pi x de}{\pi x de - \mu x p} \right)$$  \hspace{1cm} (5)

$$T = \frac{Fx de}{2} + \left( \frac{1 + \pi x de}{\pi x de - \mu x p} \right)$$

$$= \frac{47,6492 x 10}{2} + \left( \frac{1 + 3.14 x 10}{3.14 x 10 - 0.61 x 2} \right)$$

$$= 255.771 \text{ N.mm}$$

$$= 0.25577 \text{ Nm}$$

Based on these calculations, the torque chosen for the Y-axis stepper motor specifications is 3.6 Nm or National Electrical Manufacturers Association (NEMA) 23, because it has met the minimum torque required.

4. Results and discussions

To show the performance of the two Y stepping motors, a simulation has been performed. The results are shown in Table 1 and Table 2 as well as in Figure 5. Table 1 shows the results of rotation speed simulation. The distance travel of the motors is set 100 mm and the revolution speed is set 500-1500 RPM. The greater the frequency, the faster the revolution speed of the motor is produced.

| Distance Travel Set for CNC (mm/min) | Linear Speed (mm/min) | Revolution Speed (RPM) | Frequency (Hz) | Revolution Speed (RPM) | RPM Error | Angle (°) |
|-------------------------------------|-----------------------|------------------------|----------------|------------------------|-----------|-----------|
| 100                                 | 1000                  | 500                    | 1665           | 499.5                  | 0.1%      | 305       |
|                                     | 1500                  | 750                    | 2491           | 747.3                  | 0.36%     | 24.3      |
|                                     | 2000                  | 1000                   | 3328           | 998.4                  | 0.16%     | 269       |
|                                     | 2500                  | 1250                   | 4158           | 1247.4                 | 0.2%      | 341       |
|                                     | 3000                  | 1500                   | 4987           | 1496                   | 0.26%     | 226       |

RPM error is used to determine the accuracy rate of the revolution speed and is computed using equation (6).

$$RPM \ Error = \frac{Input \ (RPM) - Output \ (RPM)}{Input \ (RPM)} \times 100\%$$  \hspace{1cm} (6)

$$Revolution \ speed \ Accuracy = 100\% - Highest \ RPM \ Error \ (%)$$  \hspace{1cm} (7)
So, the revolution speed set and Y-Axis motor simulation results have 99.64% accuracy with average error of 0.216%. These errors can still be tolerated because the software has not been used to represent the actual conditions of the circuit, especially those relate to the timing. Therefore, the error does not interfere the system performance. Figure 5 shows Y+ and Y- motors rotate CW with the same rotation angle. Based on these test results, it is certain that the Y+ and Y- motors can rotate together with the same frequency. Based on Table 2, when inputting the G-code programs G1 X9.554 Y2.00 E2.9917, it means to move at the Y-axis is 2mm. The distance sets and Y-Axis motor simulation results have an average error of 0%. The G-code can control two actuators with 100% accuracy, and the nozzles can move according to the G-code coordinates. Distance error is used to determine the accuracy rate of distance. Distance error is computed using equation (8).

\[ \text{Distance Error} = \frac{G\text{code (mm)} - d \text{ (mm)}}{G\text{code (mm)}} \times 100\% \]  

\[ \text{Distance Accuracy} = 100\% - \text{Highest Distance Error} \% \]  

5. Conclusion
The simulation results prove that the G-code programs can control two Y actuators with 99.64% accuracy, with average error as much as 0.216% for revolution speed, and 100% accuracy with average error of 0% for distance. The nozzles can move in different directions with the same type of screw.
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