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A Research on Conveyor Belt 3D Printer in Industrial Applications

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Abstract

A 3d printing technique is an additive manufacturing technique where 3D objects and parts are made by the addition of multiple layers of material.[1] It is a type of rapid prototyping. The layers are stacked up in a variety of ways depending on the technology being used. It can use a wide range of materials such as ABS, PLA, and composites as well. This technology allows the design of complex components, therefore, avoiding assembly requirements at no additional cost.

This paper presents research on 3D printer design with a conveyor belt, which can be applied in industrial applications. Firstly, a CAD model of a 3d printer has been created using SolidWorks. In this step, all the parts of the model are designed and then are assembled in the SolidWorks workbench to create the 3D printer assembly. Then, the electronics board which controls the entire printing process is studied and integrated into the mechanical structure. The electronics board compiles the STL file to a suitable form to carry out the printing process and is connected to the PC using a USB-to-serial converter. Finally, a portable 3D printer is built and tested with various types of models.

Key Words

1. Introduction

3D printing is a method of manufacturing known as ‘Additive manufacturing’, due to the fact that instead of removing material to create a part, the process adds material in successive patterns to create the desired shape. The designs for printing come from computer-aided design (CAD) software, such as SolidWorks or Inventor. The first working 3D printer was created by Charles W. Hull in 1984 and the technique was named Stereolithography(SLA).[2] In 1992, S. Scott Crump and his company. Stratasys marketed the first fused deposition modeling (FDM) machine.[2] FDM is a 3D printing process that uses a continuous filament of a thermoplastic material. Our printer is a variant of an FDM cartesian 3d printer.

Figure 1. 3D Printers with Conveyor

In this study, we developed a 3D printer that prints at a 45-degree angle onto a moving conveyor belt. By printing onto a conveyor belt and provided enough print material, there are no longer any limitations on the length of the prints along the axis parallel to the belt. This can be applied to prototypes for airplane wings, prosthetics and other parts that are longer than a typical 3D printer. And because the printer is equipped with a moving conveyor belt so it can print continuously. The printer can keep printing parts and they will move down the conveyor belt once they are completed. By printing layers at 45 degrees, we could be able to reduce the need for support material for overhangs compared to ground up layering. During the modeling process, our team took some inspiration from the BlackBelt 3d printer.[3]

2. Mechanical Design and Calculations

In this paper, we use Inventor to design the model (Figure 2 and 3).

The overall size of our machine is 600 mm x 420 mm x 350 mm. We separate this model in three main parts:

- The frame
- The conveyor belt
- The transmission

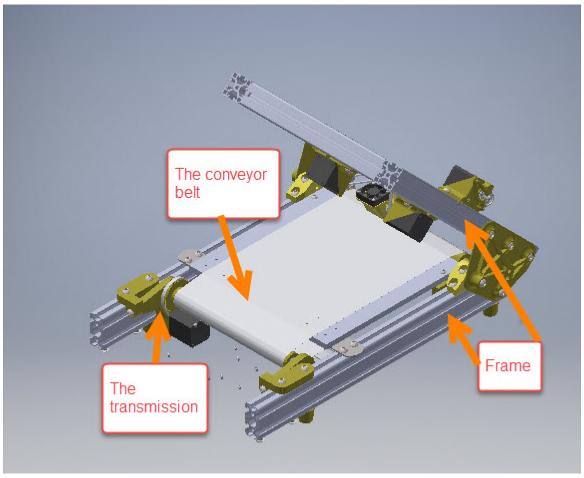

Figure 2. The model of printer in Inventor

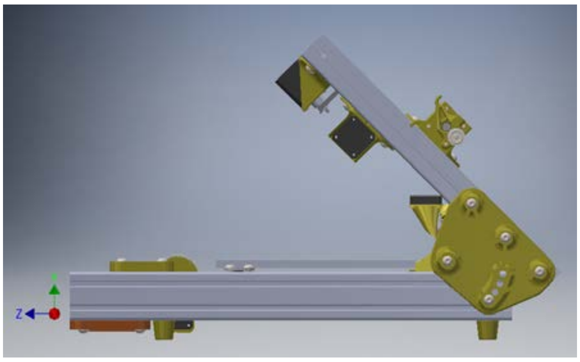

Figure 3. The model from the side

The upper frame is connected to the lower frame by an aluminum plate. The angle of two frames is kept at 45-degree.The Z-axis that aligned with the conveyor belt could have more freedom in length. As you can see in figure 3.

There were multiple approaches the team determined to be viable for the print angle of the printer, 30 degrees, 45 degrees, and 60 degrees. This allowed us to analyze the advantages and disadvantages of a lower angle, higher angle or something in between. The decision matrix we generated to compare these components is shown in Table 1.(3 – Great, 2 – Good, 1 – Normal, 0 – Bad)

Table 1. Decision Matrix for Print Angle

Print Angle	Software Compatibility	Build Height	Support Material	Sum
60	0	3	3	6
45	3	2	2	7
30	3	1	1	5

With a higher angle, less support material is needed, and a higher build height can be achieved. If we were to create the same build height for each angle, the 30-degree angle would cost the most as the top frame would have to extend much further to reach the same build height as the 45 degrees or 60 degrees. Based on these specifications, the 60-degree angle would be the most effective choice, however, open-source software is not readily available for 60-degree angled printing, limiting our choice to 45 degrees.

2.1. The frame of 3D printer

Many 3D printers can be constructed out of 3D printed materials. There are also possibilities in producing the frame through machined metals, such as aluminum profile, which is particularly useful for components of 3D printers as the aluminum profile allows for simple connections between the bars. Our machine is mainly conducted by 30×60 T-Slot Aluminium Extrusion Profile. The frame measurement is 600 mm x 420 mm.

Figure 4. 30×60 T-Slot Aluminium Extrusion Profile

2.1.1 Beam calculation

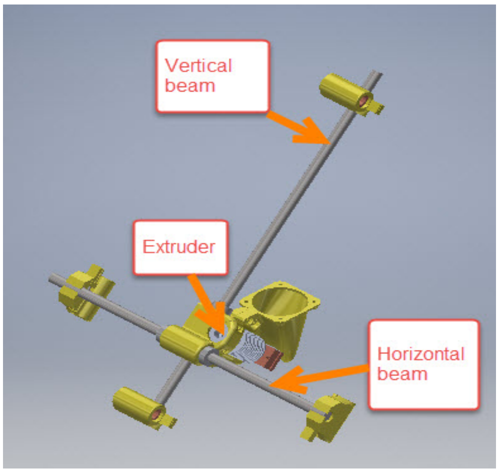

Figure 5. Extruder holder

We need to calculate the diameter of both beams to handle a 5-kilogram load from the extruder. Both of them are carbon fiber tube with a ultimate tensile strength of 350 MPa[4] . The factor of safety is 10.

The vertical beam length is 310 mm. It is subjected to an external force of 18 N and a bending force of 18 N. The horizontal beam length is 260 mm. It is subjected to a bending force of 25 N. The maximum bending moment is found by drawing the Sheer-Moment diagram[5] (figure 6 and 7)

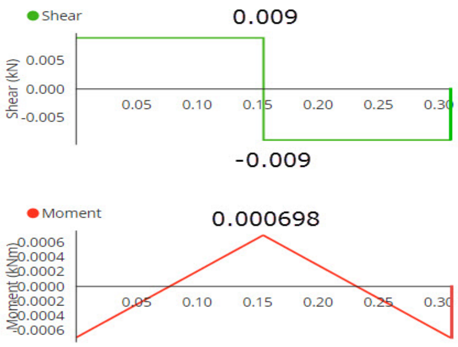

Figure 6. The vertical beam diagram

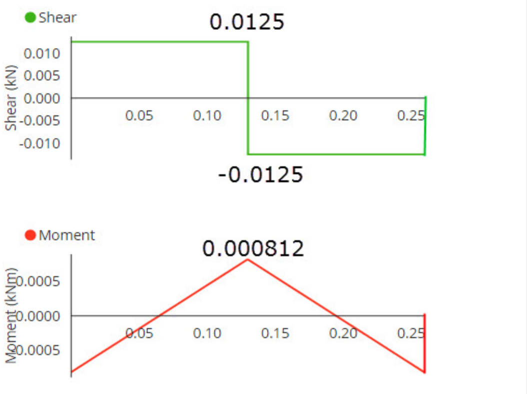

Figure 7. The horizontal beam diagram

The calculated vertical beam diameter is shown in equation (1)..

$$\frac{M_b \times y}{I} + \frac{P}{A} = \frac{S_{ut}}{f_s} \; with\, I = \frac{\pi d^4}{64}; y = \frac{d}{2}; A = \frac{\pi d^2}{4}$$

$$\Rightarrow \frac{32 \times 698}{\pi d^3} + \frac{72}{\pi d^2} = \frac{350}{10} \Rightarrow 35\pi d^3 - 72d - 2236 = 0$$

$$\Rightarrow d \approx 6(mm)$$ (1)[6]

The calculated horizontal beam diameter is shown in equation (2).

$$\frac{M_b \times y}{I} = \frac{S_{ut}}{f_s} \; with\, I = \frac{\pi d^4}{64}; y = \frac{d}{2}$$

$$\Rightarrow \frac{32 \times 812}{\pi d^3} = \frac{350}{10} \Rightarrow d = 6.2\,(mm)$$ (2)[6]

We chose d = 8 mm because 8 mm carbon fiber tube was more easy to purchase.

2.2. The conveyor belt

With the conveyor belt, the problem that we look into is the heat resistance and adhesion. Our machine now uses a 250 mm x 1000 mm green PVC conveyor belt. For a normal PVC conveyor belt, testing shows that the PLA was able to adequately stick to it. And the main problem left is heat resistance. So to see what happened during the contact of the extruder tip and the belt, we conduct a thermal study in SolidWork and the result is shown below.

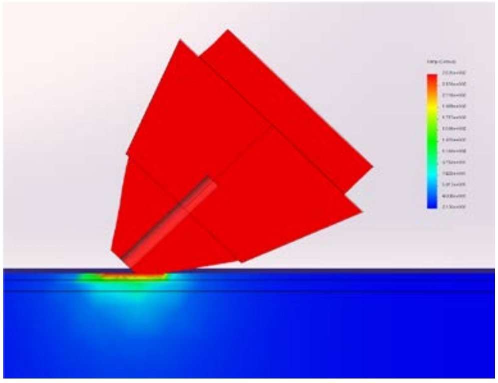

Figure 8. Thermal Study

Table 2. Maximum Belt Temperatures

Location	Value, **°C**	x, **mm**	y, **mm**	z, **mm**
14954	110.60	-1.587	3.048	3.968
118549	98.750	-1.587	3.048	4.365
134934	97.070	-1.190	3.048	3.968
134933	91.080	-1.984	3.048	3.968

From the result of table 2, the PVC belt will melt if the contact occurs. The ideal solution would be to use a carbon fiber belt. This would be a surface that PLA can easily adhere to and typical carbon fiber can withstand 3652° C, so the belt can easily withstand the roughly 250°C max temperature of our extruder. But for now, we secure the bell with a heat resistance tape.

2.3. The transmission

The transmission system that we use is a V-belt system. By calculating the torque required, we could choose the motor for the job. In equation (3), the torque required is calculated with the following parameter.

The total mass of load test is 1 kilogram, the gear ratio is 5:1. The Friction coefficient of the sliding surface is 0.05. The tilt angle is 0-degrees and the pulley diameter is 31mm with the efficiency of the system is set at 90 percent

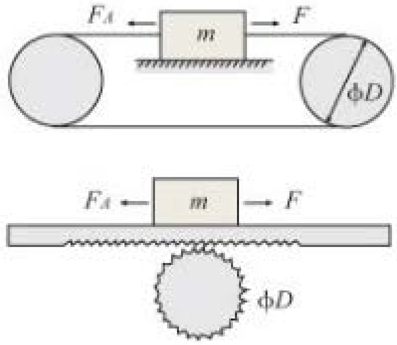

Figure 9. Torque calculation

F: Force of moving direction

μ_0: Internal friction coefficient of preload nut

η: Efficiency

i: Gear ratio

F_A: External force

m: Total mass of the table and load

μ: Friction coefficient of sliding surface

θ: Tilt angle

D: Final pulley diameter

g: Gravitational acceleration

$$T_L = \frac{F}{2\pi\eta} \times \frac{\pi D}{i} = \frac{FD}{2\eta i} \qquad (3)^{[7]}$$

$$F = F_A + mg(\sin\theta + \mu\cos\theta)$$

$$\Rightarrow T_L = \frac{0.05 \times 1 \times 9.8 \times 0.031}{2 \times 0.9 \times 0.2} = 0.042\,(Nm)$$

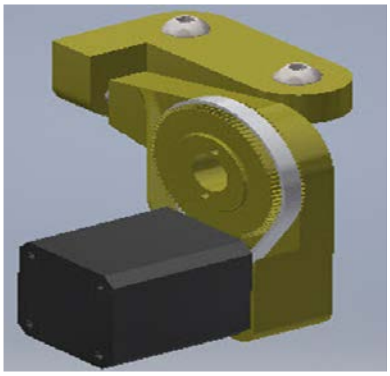

Figure 10. V-belt system in Inventor

2.4. Other parts

Some other parts are designed and machined to assembly the main parts together.

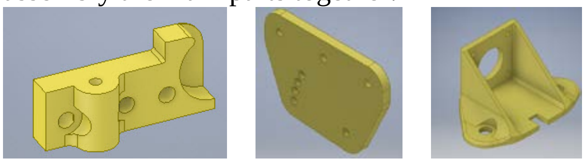

Figure 11. Roller mount, frame connect and stepper motor mount

3. Electronic Parts and Control

In order to operate the 3D printer smoothly and flexibly, we need to integrate electronic part and controller into the 3D printer mechanical design.

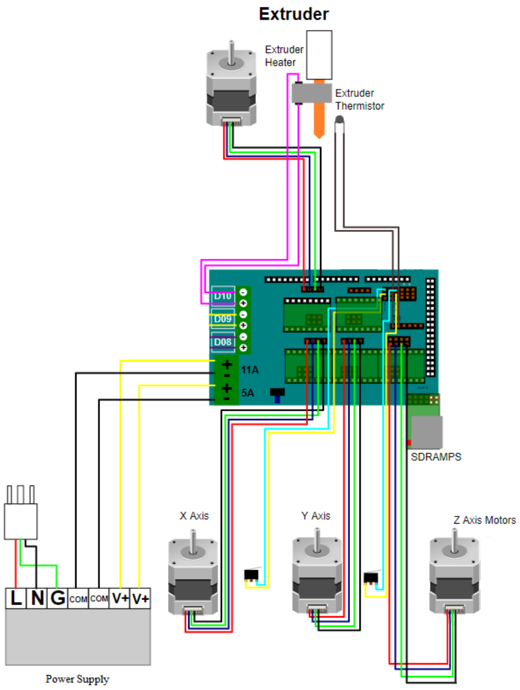

Figure 12. Connection diagram

3.1. Main controller part

In this project, we used board Arduino Mega 2560 – a type of Single-board microcontroller. Because of its high efficiency, easy to work with and is commonly used in many 3D printers.

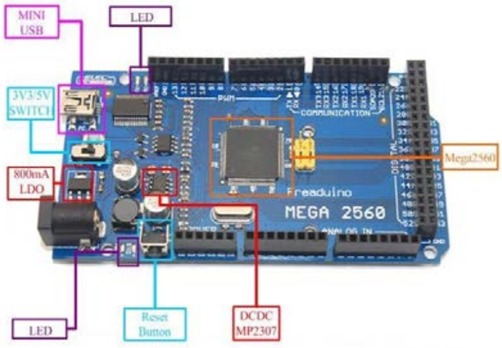

Figure 13. Arduino Mega 2560

Along with board Arduino Mega 2560, we used RAMPS 1.4 motherboard. RAMPS 1.4 is a board that serves as the interface between the Arduino Mega — the controller computer — and the electronic devices in the printer. The board is accessible, reliable, easy to replaced and it comes with all the necessary components to run most 3D printers.[8]

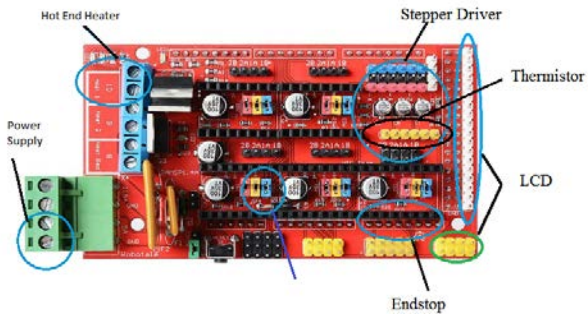

Figure 14. RAMPS 1.4

3.2. Stepper driver

A stepper drive is the driver circuit that controls how the stepper motor operates. Stepper drives work by sending current through various phases in pulses to the stepper motor. The driver has only two primary functions: sequencing the phases and controlling the phase current. The two most commonly used driver is driver A4988 and DRV8825. We used A4988 in this project

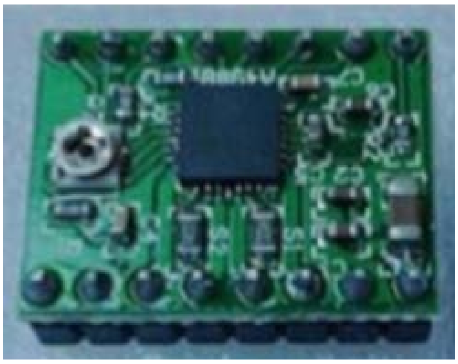

Figure 15. Driver A4988

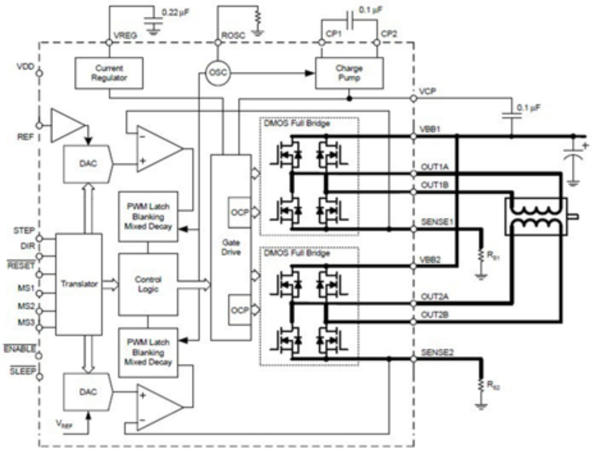

Figure 16. A4988 blocks diagram

3.3. Thermal monitor and control

The thermistor allows us to monitor the temperature in the nozzle and the heat bed (optional) before and during printing. With that information from the thermistor, we control the output of another thermistor to heat the nozzle. Both thermistor and heater are controlled by Arduino Mega. The heater can be set to a specific temperature.

Figure 17. Thermistor NTC 3950 100K

Figure 18. Cartridge Heater 12V 40W

3.4. Program and control

G-code is a language in which people tell computerized machine tools on how to make something. The "how" is defined by g-code instructions provided to a machine controller (industrial computer) that tells the motors where to move, how fast to move, and what path to follow.[9] And slicer, also called slicing software, is computer software used in the majority of 3D printing processes for the conversion of a 3D object model to specific instructions for the printer. In particular, the conversion from a model in STL(Standard Tessellation Language) format to printer commands in g-code format. [10]

Our team's plan for software is to use the open-source BlackBelt Cura Slicing software that has compatibility with Blackbelt's printer and printer with similar design like our printer[11]

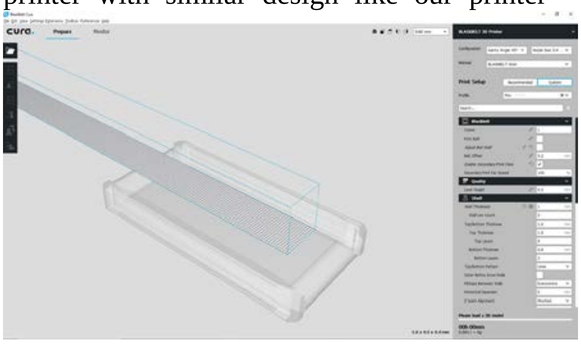

Figure 19. BlackBelt Cura

Arduino IDE is an open-source software that is mainly used for writing and compiling the code into the Arduino Module. It is available for operating systems like MAC, Windows, Linux. It comes with inbuilt functions and commands that play a vital role in debugging, editing and compiling the code in the environment.

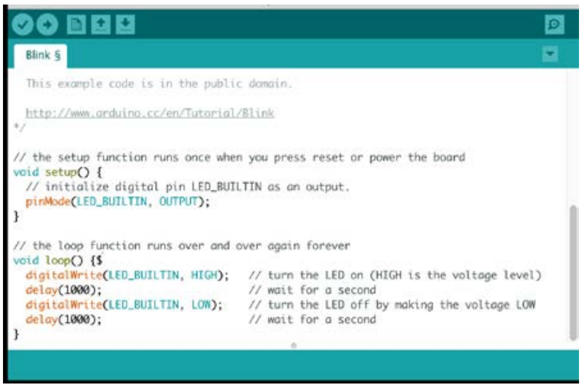

Figure 20. Arduino IDE

Marlin is the software that is embedded in the 3D printers control board. It controls everything from heaters, motors,.. and abstract concepts such as exploration, speed limits, thermal regulation, and safety. To adapt marlin to our printer, we change the setting to fit our needs. We calculate the XYZ steps-per-mm by using the motor, pulley, and belt characteristics, limit the nozzle temperature, test and tune the extruder steps

4. Assembly and Testing

Figure 21. Final product

The size of the final product is 600 mm x 420 mm x 400 mm. The weight is 12 kg. With its large size and heavyweight. The machine can be quite cumbersome and it is not mobile. It is quite a disadvantage in assemble and transport

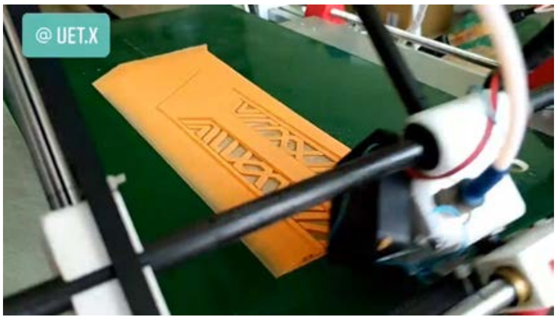

Figure 22. During operation

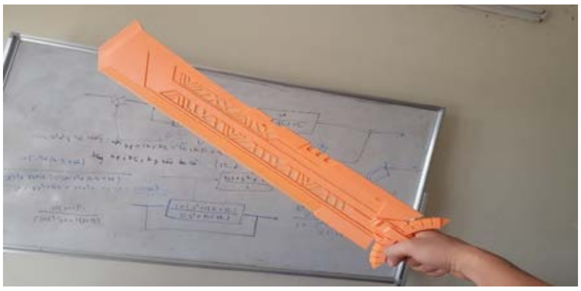

Figure 23. Printed sample

The sample size is 101 mm x 803 mm x 6 mm. It proved the ability to print object which its length is longer than the machine. And we also test with multiple objects printing function.

Figure 24. Multiple objects print test

We also print the 20mm Calibration Cube to check the precision of our printer.

Figure 25. 20 mm Calibration Cube

The printed result parameter is Z = 20.25 mm, Y = 19.7 mm, X = 19.7 mm. The percent error of Z is 1.25%, Y is 1.5% and X is 1.5 %.By visually, the surface texture is not smooth. But we could not determine the actual average roughness of the surface texture because of our lack of precise tools.

5. Conclusions

At the end of this project, we were able to construct a working prototype of the conveyor 3d printer. We had grasped the technology of designing and printing 3d objects. The printer has shown the potential in multiple objects printing and printing long objects. It opens a new way to create faster and easier prototype. And with some improvement, it could become a a semi-mass-producing tool.

References

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