Design, Development and Analysis of FDM based Portable Rapid Prototyping Machine

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Abstract- 3D printers are devices that can create a three-dimensional object from a digital model. In this modern world, Fused Deposition Modeling (FDM) based printers are the most commonly used printers. They create an object by adding material layer by layer and fusing these layers together. These machines are very costly and have limited print area. This paper focuses on designing and fabricating a portable fused deposition 3D printer with cheap and easily available components. Among different types of 3D printers, fused deposition 3D printers are considered to be the cheapest and they are considerably small in size. This is mainly due to its axial movements and type of material used for 3D printing. It's a 4 axis machine whose x, y and z axis make up the first 3 axis, and the extruder is the 4th axis. The raw material used for printing is plastic such as ABS, PLA or ninja flux, etc. However a certain amount of calibration is needed to fine tune the temperature sensor used for the extruder depending on the filament used. In this work, a FDM based 3D printer is developed and analyzed for further development.

Keywords – ABS, PLA, Extruder, 3D printer, axis

I. INTRODUCTION

3D printer is a machine which capable of doing complex and difficult tasks in one long step and it only requires a 3D model of the object to be made with a defined set of parameters and scaling ratios, which can then be converted into G-code. This data is then used for controlling the motors and extruding plastic based on the g-code generated. This approach towards fabricating contrasts with the traditional way of manufacturing, where an object is formed by removing excess material or folding and shaping materials based on certain dimensions. It also eliminates the needs of tools and machinery for cutting, shaping and fabricating. It also reduces the time needed for reproducing a prototype when making changes to it.

Fused Deposition printing is one of the most widely used 3D printing technique. In fused deposition process a plastic polymer in the form of a filament is used as the raw material for printing. Its structure and mechanics is similar to that of a CNC machines and its print head is known as an extruder. The tip of the extruder has a nozzle that is heated to a certain temperature, as the filament reaches this nozzle it softens to a semi solid state. This molten polymer is then pushed through the nozzle and deposited onto a heat bed, layer by layer. Some machines work by using of acrylonitrile butadiene styrene (ABS) polymer as its filament. Some of the printers use a biodegradable compound called PLA or polylactic acid or a plastic made from food starch.

One of the advantages of fused deposition over Digital Light Processing (DLP) and other printers is that it can have multiple "extruders". Making it possible to print in different colors simultaneously, similar to how normal inkjet printers work. The methods also have some limitations to it, regarding its resolution, and printing of overhanging structures that will require supporting frames to be printed along with it. The resolution of these printers depends on the type of nozzle being used. The resolution of the newer commercially available 3D printers is now down to 75 microns, which is getting close to the limits of the plastic. At this resolution the layers are no longer visible. The most commonly used axis mechanism for an fused deposition type 3D printer is to move the extruder along the linear trail from one point to another. The extruder will be moved along the X and Z axis, and the bed plate or base along the Y axis. One of the disadvantages of moving the Y plate is that, the total space occupied by the printer will be more. However the precision and the troubleshooting options offered by this method is of greater uses and hence it is more preferred over other types.

A. Purpose of 3D printers

The purpose of this work is to develop a FDM based 3D printer that not only corrects the errors found on other FDM printers but also provide higher resolution and print size. Another factor to be considered is the cost of making a printer. FDM printer was chosen since the relative cost of making it and the cost of raw materials is very less. Fused deposition process also offers a great deal of customization, in terms of resolution as well as materials used. For different material types only the temperature of the hot end need to be adjusted. This way different material with different properties can be mixed together in a single printed object when required.

II. LITERATURE REVIEW

Wittbrodt, et al., (2013) described that current work has shown home-based 3-D printing is cost effective, enabling everyone to fabricate products to meet their own needs. Kreiger et al (2014) analyzed the high density polyethylene 3-D printed filament. He added in his article that the 3D printing will reduce the material usage in material manufacturing. Mohammed R.F. and Mahmoud A.S.(2002) emphasized the advantage of 3D printing in packing design.This research includes an experimental study to produce a package sample using 3D printing machine. They assured that 3D printing will dominate in packaging products especially in plastic products. Feeley et al (2014) analyzed market opportunity for producing ethical 3D printer filament. They have given basic guidelines for an ethical product standard for 3D printing filament to improve supply chain management for 3D printing materials. Michael Molitch-Huo, 2014) points out the different possibilities of an integrated electronics in 3D printer .With the integration of proper electronic control, a fully functional object can be printed out with electronics and other components already embedded along with the model itself. According to him the convergence of 3D printed electronics. 3D fabrication is inevitable and the portfolio of materials that can be used for 3D printing makes this possible. It can enable engineers and students the ability to create physical objects from a CAM design and with the possibility of these different materials, it would be possible to create antennae, touch sensors and even cell phone circuits. Gael Langevin, 2012 who is a French model maker and sculptor, created “InMoov” the first life sized humanoid robot that can be 3D printed and animated. It can be replicated on any home or industrial type 3D printer with a minimum print area of 12 x 12 x 12 cm. Over the year’s 3D printing technology have taken its place in different areas of engineering including Robotics, Architecture, Fasion, Automotive and even in food and medical areas of modern society.

III. METHODOLOGY

A. Flow Chart

After doing relevant research and literature review a basic idea of the machine, and a list of required components is developed. After identifying the required components a design of the entire system is to be created using CAD application to further aid in fabrication process. For this each of the parts will have to be integrated into the design with their exact dimensions after the design is completed. It can be used for getting the dimensions of other parts such as frame and printed parts. Using these dimensions the frame can then be fabricated.

After gathering all required components assembly and testing begins, first the mechanical assembly needs to be completed so that it can be tested and modified as required. This is crucial since changing the mechanical assembly at a later stage will be more difficult after mounting the electronics, motors and other components. After completing mechanical assembly, the fabrication and assembly of electrical components can be started. Based on current design and requirement of the mechanical assembly of the printer a sample circuit can be designed. The circuit should then be tested with the printer. After getting favorable results from those tests a PCB can be designed and fabricated. When both the mechanical and electrical assembly of the printer is completed successfully, the printer can then be assembled together adding electrical components and modules to the mechanical assembly. So that, the fabrication process can be completed without error. The last step is final testing and calibration. During this process, testing is performed which will help in determining how the printer is responding to the commands that are sent to it. Depending on the results, software settings can be fine-tuned and changes are made to the assembly of the machine if required. A flowchart of the planning and strategy followed in the development of 3D printer is shown in figure 1. It also gives a general idea of the approach taken towards this work.

B. Block Diagram

A Block Diagram of the machine is shown below. It explains the working process of the machine and different tasks that are carried out during print run. The stepper motors connected to stepper driver 3 and 4 (Refer figure 2) will turn the ball screws though couplings and the ball screw and its nut transform the rotational movement of stepper motors to transition movements of plates. The power module consists of PTC fuse's with current sensing functionality and a 5V voltage regulator that supplies 5 volts to Arduino micro controller. The current needed for the stepper motors, heaters and Arduino is provided through a 12V OEM power supply and fuses are connected in series to it. Fuses ensure the safety of each of these components and also to avoid damage to machine and its user. Atmega also gets signals through its digital ports, though its analog ports. It receives electrical signals corresponding to the temperature reading of the thermistors. Arduino uses this data and determines the temperature of the hot end and heat bed using the look up table provided inside its firmware. Using these look up tables, Arduino controls that MOSFETs to regulate the temperature on heaters, using PWM it maintains a constant temperature. It then writes the status of the heaters to the serial port as well as the LCD screen though Serial data transfer method. And the statuses of these MOSFETs are directly shown to the user though LED's that light up when a MOSFET is working. Other GPIOs are used for sensing the states of the end stops which is then used for determining the home position of the extrude.

IV. EXPERIMENTAL SETUP

A 3D model of the printer was designed in Sketch up which included all the Mechanical and electrical components. When designing the model, all the parts where drawn to exact dimensions and the parts that were to be 3D printed were directly taken from its finished CAD model. Standard parts that where discussed in previous section were also taken into consideration when designing the model. To make a proper movement in different axis, X,Y and Z axis configuration is very important. The following sections will explain about the axis configuration.

A. X Axis configuration

For getting a print size of 40 x40 the smooth rods on the X axis had to be 50cm long and the belts should have a length for 103 cm. so that enough length will be there for it to go around the pulley and radial bearing. The belt is fixed on to a 3D printed part that is mounted on to these smooth rods using linear bearings. 4 bearings are used to give enough support even when heavier extruders are mounted on to it. 3D rendered images of X and Z axis Assembly is given in figure 4.

B. Z Axis configuration

For the Z axis, smooth rods are fixed in place using printed parts that are mounted on to the frame. And a threaded rod is then threaded into the nut mounted inside the small pocket on the X axis idlers. One of end of the thread rod is clamped on to a motor shaft using a flexible coupling. So that it turns with the motor. Z axis Assembly is given in figure 5.

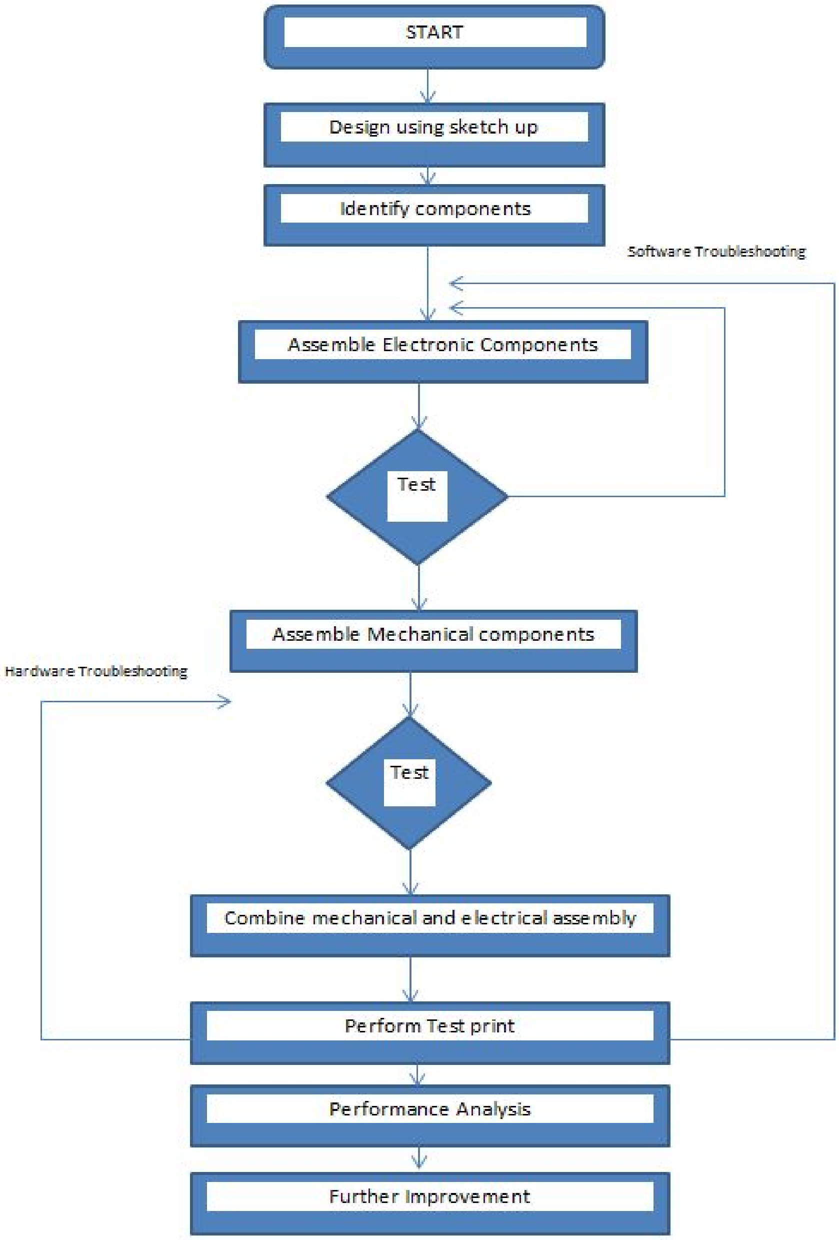

Figure 1. Flow Chart of the proposed technology

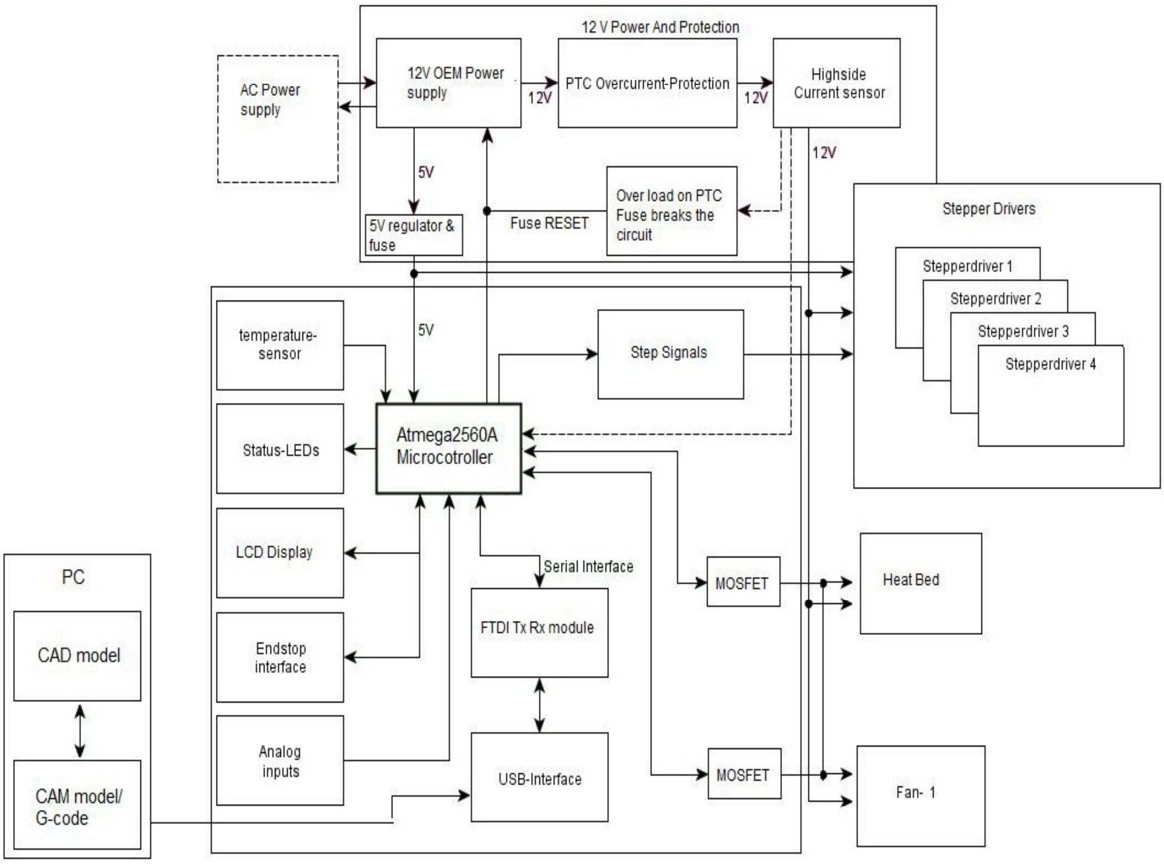

Figure 2. Block Diagram

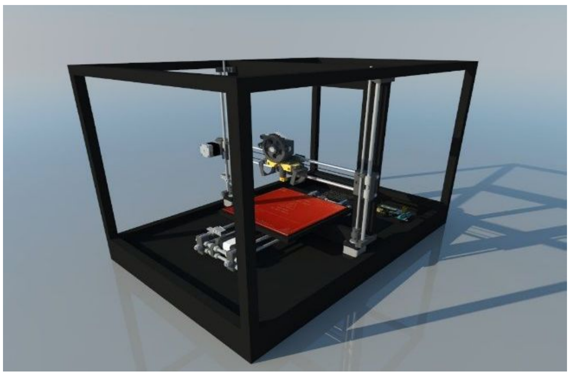

Figure 3. 3D view of the proposed model

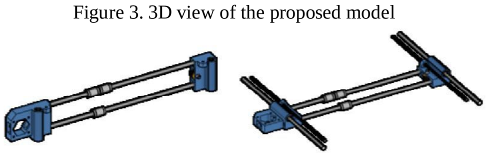

Figure 4. 3D rendered images of X and Z axis Assembly

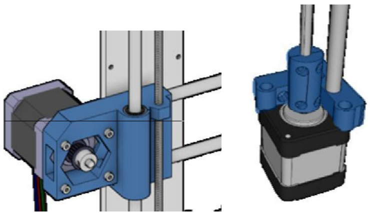

Figure 5. Z axis Assembly

C. Y axis configuration

A second linear motion system is designed for the Y axis, unlike the X and Z axis Y axis is independent and moves in its own axis, like shown in the figure above. Since the base plate acts as the print surface of the printer, it should be of the same size of the print area along the X and Y axis. Hence a 40x40 ply wood was cut and the bearings attached to its printed parts. The plate is then mounted on to the smooth rods through these linear bearings and the belt is attached to this base plate and the pulley on the motor. Y-axis assembly is given in Figure 6

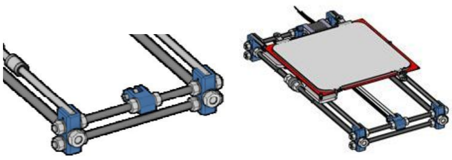

Figure 6 Y-axis assembly

D. Circuit Design and Schematic Diagram

After identifying the various electrical parts of a 3D printer, a schematic diagram was drawn using Upverter communities online schematic designer. It's a free and open source designer that can be used for making schematics needed for electronic circuits. It is on part with CADSOFT Eagle with a vast range of available components that can be used for designing simple or complex circuitry. One of the advantages of Upverter's schematic designer is that it has a good user interface and is very user friendly. When designing the schematics various factors were taken into consideration, such as safety of the components and reverse polarity protection for mains power supply. The schematic diagram (Figure 7) includes different parts of the stepper driver

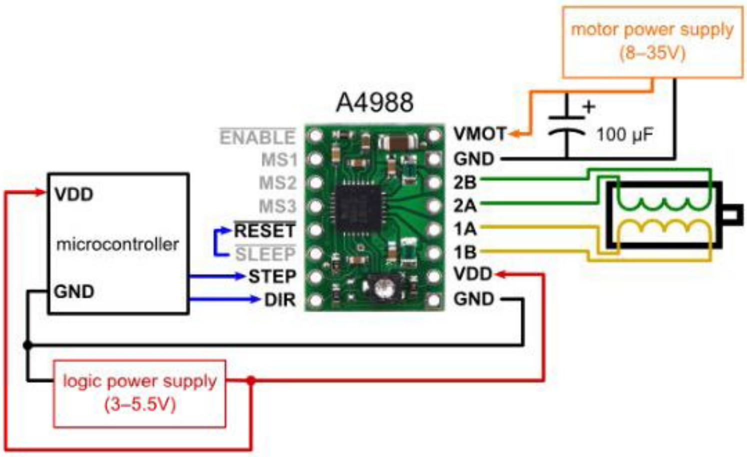

Figure 7 Schematic Diagram of Pololu stepper driver (Ref: http://www.pololu.com/product/118)

The schematic diagram of A4988 stepper driver is based on Pololu stepper driver requirements. For a Pololu stepper driver the MS1 pin needs to be low at all states so that the pin state may not drift even when no power is given to the module. For this the pin is connected to the ground though a 100K resistor which will work as a pull down resistor. The Enable pin is inverted and pulled high to 5V using a Pull up resistor so that the motor stays off even when there is no signal to this pin. The motor doesn't move when the Arduino board driving the stepper. VDD and GND is connected to the 12V power supply connectors through a 100uF capacitor. This capacitor helps in reducing the spikes in the power supply and also helps in dealing with back EMF coming from the stepper motor coils. Pins MS1, MS2, MS3 are connected to a header pin which can then be given a high when using the module at 1/16 step mode. Reset and sleep are both connected together. Pins Enable, Step and DIR is connected to Arduino GPIO. Once the schematic diagram is completed and a PCB layout was designed which is shown in figure 8.

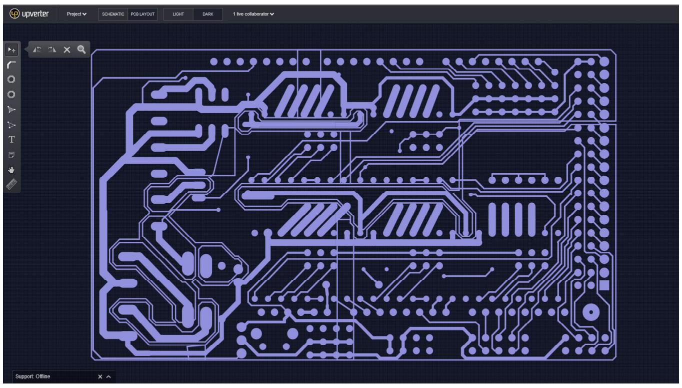

Figure 8 PCB layout for stepper motor drive

V. RESULT AND ANALYSIS

After making the circuit in Fritzing, the next challenge was in calculating the required thickness of each of the tracks connecting the components. A PCB Trace Width Calculator was used to find the required thickness of each tracks (Figure 9).

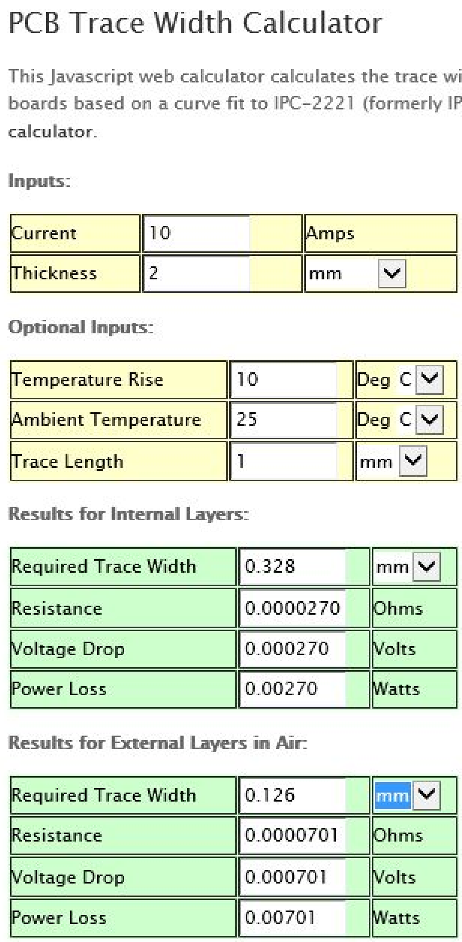

Figure 9. Thickness calculation of each track to connect the components

When adjusting track thickness on Fritzing a lot of problems were noticed. So, further designing was done on Upverter's Online designing tool. Once the circuit was completed a PCB with assembled components were collected. The resistance obtained theoretically differed slightly form the resistance measured though a multimeter. It is important to give a certain amount of tolerance when designing such PCB so that changes in resistance and conductivity during production won't affect the performance of the board.

Another factor affecting the performance of the printer is the power supply, the Chinese PSU used for the printer rated for 12V at 30A, however when measured though a multimeter, at 12V when a current of 19A or greater is being drawn by the heaters and motors, the voltage drops to 11.6V. These PSU's also come with a Trimpot that can help readjust the voltage. But increasing the voltage to 12V at 20A means that when the heaters are not working the machine will be operating at a voltage greater than 12V which could damage the stepper drivers, hence an intermediate voltage between 11.6V and 12V was selected. However it was clear that a better and reliable power supply was needed with less voltage drop. PC' power supplies seemed to be just the right power supply for needs.

To calculate the number of steps needed by the stepper motor to move the axis 1mm, the formulae given below was used.

Steps per mm = ((360°/Motor step size°) * (1/Driver micro stepping))/(Belt pitch * Tooth count)
80 = ((360°/1.8°) * (1/(1/16)))/(2 *20)

After finding the number of steps it is entered into the firmware. Once the machine is fully assembled a few test moves were made to analyses its performance and accuracy. For this a pen was attached to the head of the printer, and a paper was attached to the base plate. So that, when the print head moves it leaves/draws a line on the paper which can then be measured using a scale/ vernier caliper to find and fine tune the number of steps needed by the stepper to move 1 mm. The head is moved 10mm along X-axis and 10mm along Y-axis. The length of the line drawn can then be measured to find the distance moved by the axis head. Using this value exact steps required can be found using the formulae

Required Steps = (Steps used / distance moved) x 100

For the first print a 20x10x10 cube was designed and printed. Figure 10 shows image of the first layer being printed.

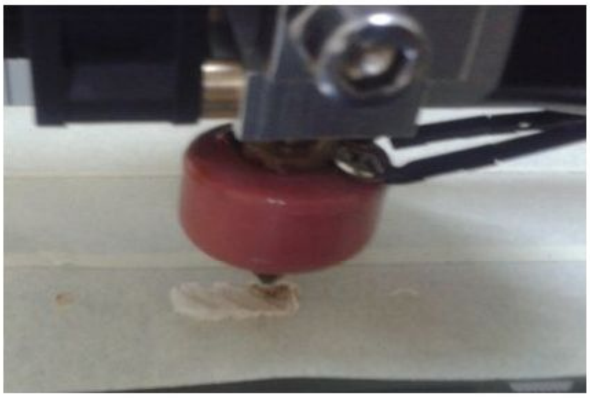

Figure 10 Initial Test Print

During the print a few minor problems were noticed in the machine. One of it includes the Z axis being too high from the base plate causing, extruded plastic to harden before it touches the bed plate causing the prints to distort. Positioning the head at exact height from the base plate was really challenging. Once the extruder head was positioned properly a second test was performed. During this print the plastic was being laid down properly however it was not sticking to the base plate, since glass has a smooth surface and is a bit cold at room temperature. Another factor affecting the stickiness is the air around it, since most of the printers frame is open, air around is acting as a coolant, and hardens each layer very quickly. Double sided tape also known as painters tape can be used for increasing the stickiness of the first layer. The tape is laid over the glass surface and prints are made on this sticky side of the tape, this will help layers properly stick to the surface.

VI. CONCLUSION

A rapid prototyping machine was successfully fabricated with respect to the conception design that was developed. Stepper motors were used for controlling each axis and timer belts were used for X and Y axis since they offer greater speed, for the Z axis threaded rods were used since it required greater precision and higher torque. For X and Y axis the ends of the timer belts were attached to the moving part namely the X carriage and Y carriage so that it moves along with the belt when pulled by the stepper motor. GT2 belts were used as timer belts since they have a tooth profile that works better with linear positioning systems. 5 stepper motors were used for driving the belts pulleys and the extruder gears, of which 2 of the stepper motors are used for two Z axis threaded rods and one stepper each for other axes. The stepper motors are controlled using A4988 stepper driver and the signals needed for the stepper are sent from an Arduino MEGA micro controller. Arduino gets its instructions needed for controlling these stepper drivers through a serial port that is connected to a computer. A serial data transferring software is run on PC that uses slicing software to slice the model into layers and convert those vector data into G-code. A firmware is burned into Arduino’s memory that can intercept the G-codes that are received and generate instructions based on it. It also uses analog data from thermistors for sensing the temperature of the hot end and uses it for regulating the current to the heater. Other sensors include mechanical end stops that are used for sensing the absolute positions of the carriages on each axis. The entire system runs on 12V and requires up to 20A current that is provided by an OEM power supply. Appropriate calculations and required assumptions were made when choosing the power supply. Once the printer was completed multiple tests were performed which proved some flaws in the extruder design and assembly. Some of these problems were corrected and some of them were beyond the scope or changing, since it required redesigning of the entire extruder assembly. It also had some advantages to its design, which enabled it to work as a plotter as well as a CNC machine.

This design can further be modified by changing the frame with a laser cut birch plywood, that greatly helps in damping the vibrations from the motor and it also helps in reducing the bulkiness of the frame. Other features such as SD card or wireless printing can eliminate the need of any physical connection to the computer for printing. Automatic calibration can also be added using laser sensors or opto sensors eliminating the need of calibrating the printer every time.

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