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Design and Manufacturing of Fused Deposition Modelling 3d Printer

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Abstract- *The purpose of this venture, or study, was to design and manufacture a 3-D printing [2] machine while placing an emphasis on making the printer very cheap and maintaining high accuracy at the same time. Additive manufacturing machines that are currently available on the market that feature a large build volume complemented by high accuracy of the finished product cost on average approximately Rs. 40,000-70,000 (700-1200 USD). The challenge confronted by this study was to overcome this price point by building a printer that maintained high accuracy and built volume while being as cheap as possible to manufacture. Therefore, the parameters that were set for this project were a budget of approximately Rs. 25,000 (380 USD) in order to manufacture a machine that provided a built volume of 25 x 25 x 20 cm. The machine also had to provide a high accuracy of finish and the baseline for accuracy was set at 100 microns.*

Keywords- *3D Printing, additive manufacturing, fused deposition method*

I. INTRODUCTION

The field of additive manufacturing [2] is a rapidly advancing field. It has effectively revolutionized the manufacturing industry by putting conventional methods into perspective with respect to the cost and efficiency with which various products can be made. Continued growth and innovation in the field has not only reduced the cost of making products, but also the time needed to manufacture them. Objects that would take days to manufacture using traditional methods now simply take a matter of hours using an industrial 3-D printer. The flexibility offered by 3-D printing is also endearing because unlike conventional techniques, there is no longer a large restriction placed on the geometry of the product that can be produced. Through three dimensional design data, additive manufacturing allows for the production of various complex shapes and structures with relative ease and quickness. These foundational pillars served to support the purpose of this study.

II. DESIGN CONCEPT

The printer that was designed has three axes along which motion occurs. The bed on which the ABS material is deposited was given motion in the X-direction. A timing belt and pulley apparatus coupled to a stepper motor was used in order to impart motion to the bed in the X-direction. The timing belt was connected to the bed with the help of a fixture that is located at the center of the underside of the bed. In order to guide the motion of the bed along the X-axis, guide rods made of hard stainless steel were coupled to bed with the help of a fixture mounted on a linear bush. The motion along the Y-axis was imparted to the nozzle and extruder arrangement. The nozzle and the extruder arrangement were mounted on the linear bush fixtures which slid with the help of HSS guide rods powered by a timing belt arrangement similar to that of the X-axis. Due to the use of a heavy gantry for the Y-axis, a better and more stabilize alternative for motion along the Z-axis was required. If timing belt was used in a similar fashion such as that used for the X-Y motion, it would have resulted in a high risk of the occurrence of slip due to the weight of the gantry. This is the reason behind the need of a self-locking system which could be obtained with the help of a lead screw. A lead screw was used and it was coupled to the linear bush and powered with the help of stepper motors. The use of lead screws inherently also increased the accuracy of the machine. In order obtain the same high level of accuracy with respect to the timing belt arrangements used in the X-Y motions, belt tensioning was taken into consideration during the design and assembly phases.

III. MATERIALS AND METHODS.

The materials used in manufacturing this 3-D printing machine were carefully considered based on the criteria of low cost, light weight, and ease of manufacturability. Considering these parameters, aluminum was mainly used for the manufacturing of the fixtures in the machine because is a light weight, low cost material and can easily machined.Several other fixtures in the 3-D printer were manufactured using the process of laser cutting. The material used for these particular fixtures was stainless steel because of its high strength and ability to withstand rust. The laser cutting process was used because it provides a precision finish to the parts so as to facilitate the fit of these parts during the assembly phase.

In order to provide adequate clearance to the print bed to support a built volume of 25 x 25 x 20 cm, the overall outer dimensions of the machine were considered to be 50 x 50 x 45 cm. This provided enough clearance on both sides of the bed to support the aforementioned built volume. A standard 3-D modeling software was essential in designing the 3-D printing machine, because it provided a clear picture of the final product and its individual components in an assembly. SolidWorks was used in order to achieve this purpose. (Fig.1)The design obtained using this software was critical from a manufacturing perspective because it provided clearer dimensions of different component with respect to each other in the assembly.

A.Parts needed The 3-D printing machine that was built consisted of various components that were readily available on the market, as well as parts that were designed and manufactured using obtained raw material.

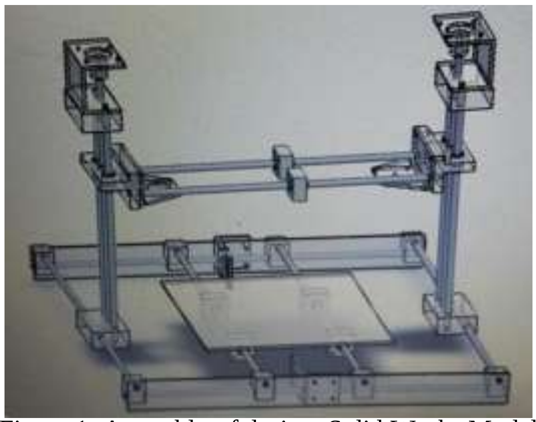

Figure 1: Assembly of design, Solid Works Model

The components that were designed and manufactured using raw materials were fixtures and laser cut extrusions.The fixtures were made up of aluminum in order to maintain light weight. They were designed using the SolidWorks modeling software and produced using standard machining processes such as turning and milling depending on the requirement. The laser cut extrusions were made up of a sheet of stainless steel that was 2 mm thick and was produced with the aid of a laser cutting machine. They were designed using the sheet metal drawing function in SolidWorks. The use of laser cut extrusions enhanced the precision of the machine by increasing the rigidity of the printer and facilitating assembly. The total cost of the raw material and machining the fixtures used in the assembly was approximately Rs. 3500 (53 USD). The laser cut extrusions used in the assembly cost approximately Rs. 1500 (23 USD). As mentioned before, a few components in the 3-D printing machine were bought from the market. They mainly consisted of various electronic components as well as mechanical parts. These components are listed as follows:

1. RAMPS 1.4 including stepper motor drivers: Approximate cost Rs. 3700 (55 USD):RAMPS is short for Reprap Arduino Mega Pololu Shield[10]. It is mainly designed for the purpose of using pololu[10] stepper driven board. Ramps can only work when connected to its mother board Mega 2560 and 4988/DRV8825 (drivers)[10]. Due to its operation stability and compatibility with most 3-D printing machines, the combination of RAMPS 1.4, MEGA2560, and DRV is becoming a common application in 3-D printer control boards. This component controls the motions provided by the stepper motors as well as drawing of filament by the extruder.(Fig 2.)

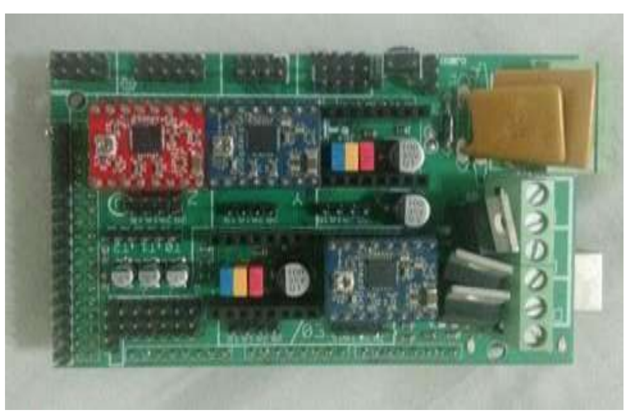

Figure 2: RAMPS 1.4 with drivers

2. Power supply of AC 230 volt, 5 ampere current, 50/60 Hz frequency: Approximate cost Rs. 600 (10 USD): A lightly used power supply was purchased to power the RAMPS board connected to it.

3. Nozzle and extruder: Approximate cost Rs. 6000 (100 USD): This component can arguably be considered the most essential. The function of this single nozzle extruder is to draw the filament with the help of an included stepper motor, while the nozzle that comes coupled with a heating element melts the filament and deposits it on the print bed.

4. Four Stepper motors: Approximate cost Rs. 540 each (9 USD each): NEMA-17 stepper motors were used to deliver motion in the X, Y, and Z axes. The motion along these axes was divided into steps and the amount of steps utilized at any particular point was commanded through the motor drivers connected to the RAMPS board. This function was of great benefit towards increasing accuracy.

5. Hot-bed: Approximate cost Rs. 780 (13 USD): Once the filament is heated and extruded through the nozzle, it immediately begins to cool and shrink. When this shrinking process does not occur evenly throughout the plastic, it leads to the phenomenon of warping. When the filament is deposited on a heated surface such as a hot-bed, this allows shrinking to occur in a more uniform fashion and the build quality of the final product very good.

6. Miscellaneous components: ABS filament: Approximate cost Rs. 1200 (20 USD),Belts/Pulleys: Approximate cost Rs. 1500 (25 USD),Linear bush and bush rods: Approximate cost Rs. 3000 (50 USD),Lead screws: Approximate cost Rs. 300 (5 USD),Mechanical small accessories (nuts, bolts, etc.): Approximate cost Rs. 900 (15 USD),Electronics small accessories (wires, connectors, etc.): Approximate cost Rs. 600 (10 USD).TOTAL EXPENDITURE: Approximate cost Rs. 25,740.00

   Final 3 D printer Model is as shown in figure 3.

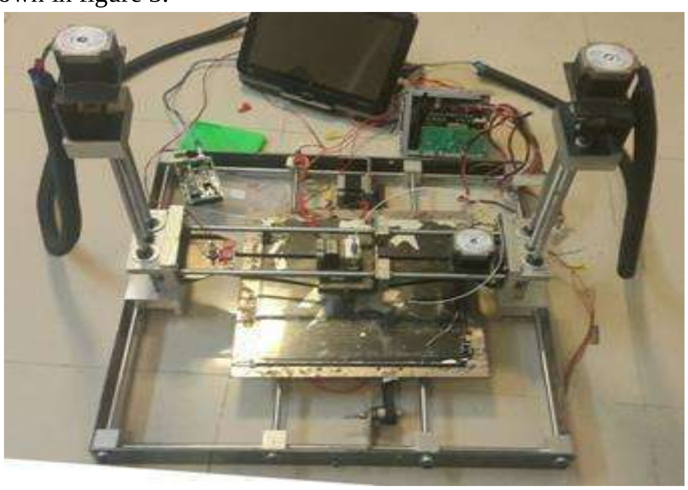

Figure 3: Final assembly of machine

B. Functioning of 3 D Printing Model:
After assembling all the aforementioned components appropriately, a functioning 3-D printing machine was achieved. Stepper motors coupled with belt and pulley arrangements drove the printer hot-bed as well as the extruder gantry in the X and Y axes respectively. Lead screws were used, which were also driven by stepper motors, to provide motion along the Z axis holding the entire extruder gantry. Hit switches, also known as end-stops, were mechanical elements that were fitted at the limits of all the three axes and served to provide a point of origin, or home position for the printing command as well as a boundary condition for the motions. The stepper motors were controlled by drivers connected to the RAMPS 1.4 board. Commands to RAMPS [10] board were given through an open-source G-code sending application known as Print run. It is comprised of a dumb G-code sender known as print core, a featured command line G-code sender called pronterface, and an assortment of helpful scripts. A tool chain known as skein forge is also implemented because it is made up of Python scripts that help in converting 3-D design data into G-code instructions. A software component called Slic3r is also used to essentially divide a 3-D model into small horizontal layers and generate tool paths to fill these layers based on calculations of the amount of filament required. An effective printing tool chain is formed when print run is complemented by skein forge and Slic3r.

ABS plastic filament was the material used as the printing medium in this machine. ABS (Acrylonitrile Butadiene Styrene)[7,11] filament is considered to have very good plastic properties. It solidifies quickly and provides a smooth finish to the printed part. It is also durable and difficult to break, making it ideal for producing mechanical parts. It can be melted within the range of 210o-250o C. The extruder drew filament from a spool with the help of another integrated stepper motor and the filament was deposited in a partially molten state onto the hot-bed. The filament is melted by a heating element coupled to the nozzle which heats the material at high temperatures close to 240o C. As mentioned before, the hot-bed provides the critical function of ensuring a heated surface for the deposition of filament. A 2 mm thick glass plate was fixed on top of the hot-bed and was heated through contact with the hot-bed. This was in order to prevent warping in the final solidified product forming on top of the glass plate. Due to the coded commands, the 3-Dmodel was cut into multiple horizontal layers. Incidentally, this also serves as a path of motion for the extruder to print the model because it deposits filament one layer at a time. The filament begins to cool and solidify immediately after leaving the nozzle. The time required to completely print the part is dependent upon the complexity of the part geometry, as well as the speed of motion controlled by the stepper motors, and the infill rate specified by the user.

C. Assembly and Difficulties:

During the assembly phase, various difficulties were encountered, especially regarding the mounting of the hot-bed, axis alignment, and timing belt tensioning.The hot-bed was one of the components that were purchased readily available from the market. However it did not come available with provisions for mounting it on the 3-D printer. Therefore, a laser cut mounting was designed and manufactured in order support the glass plate and hot-bed while being connected to the fixture providing motion along the axis. The laser cut mounting also ensured that the hot-bed and glass plate on top of it were kept level throughout the printing process.

The build quality of the final printed part is a byproduct of the alignment of the axes. Due to thoughtful design and precision in the manufacturing processes, the axes in the 3-D printing machine were aligned to a high degree. A contingency was provided where a standard spirit level could be used in order to make small recalibrations in the alignment. These recalibrations were controlled by tightening of bolts specially incorporated in the design for the aforementioned purpose. Adequate belt tensioning is also considered to be equally as crucial in order to produce a printed part of high build quality. This is because insufficient tension will induce the risk of slip during the printing operation. If slip does indeed occur during the deposition of a particular layer of filament, every subsequent layer will also include that error and final product will be deformed. To prevent this phenomenon, an adjustable idler pulley arrangement was used to maintain adequate belt tension, where the position of the idler pulley was varied to obtain the desired tension.

IV. CONCLUSIONS

1. Build volume: The primary goal of this endeavor was to design a 3-D printing machine with a large build volume at a lower cost as compared to a similar machine available on the market. The 3-D printer that was designed incorporated a fairly large build volume of 25 x 25 x 20 cm.

2. Low cost: As mentioned before, the 3-D printers readily available on the market with a comparably large build volume cost approximately within the range of Rs. 40,000-70,000 (700-1200 USD). The 3-D printer manufactured in this endeavor provided a large build volume of 25 x 25 x 20 cm at a reasonable cost of ~ Rs. 25,740.00.

3. Silent operation: The implementation of lead screws in the design of this 3-D printer provided the distinct advantage of relatively less noise during operation, as compared to other contemporary models found on the market.

4. Ease of assembly and disassembly: Care taken during design of the printer ensured that the final product could be considered simple during assembly or dismantling. This means that the machine could be set up at any reasonable location through easy assembly and disassembly.

5. Accuracy:The use of lead screws, adequate belt tensioning, and designing to accommodate sufficient axis alignment resulted in the build quality of printed parts to be relatively high. This could be further controlled through the user interface and software by specifying print speed and infill rate.

V. DRAWBACKS

1. Lack of casing: One particular drawback of the 3-D printer developed in this study is its lack of appropriate enclosure, or casing. The absence of this component in the design led to the increased risk of warping in the printed part. This was due to uneven distribution of heat caused by the lower surrounding air temperature as compared to the very high temperature

of the filament extruded through the nozzle. The implementation of an enclosure would have been beneficial towards prevention of this error.

2. Aesthetic appeal: Due to the strict budget parameter imposed upon the design of the printer, appropriately low cost materials were used in design and manufacturing of the machine. The use of raw materials such as stainless steel and aluminum contributed towards maintaining the low overall expenditure. However, the byproduct of this decision was a reduced aesthetic appeal. Another unintended consequence of this was an increase in the overall weight of the printer.

Scope for Potential improvements:
The endeavor discussed in this study had a specified set of goals. These goals were to design and manufacture a 3-D printing machine at a budget limit of Rs. 25,000 (380 USD), with a build volume of 25 x 25 x 20 cm, while maintaining a relatively high accuracy of a printed part. While these specific goals were achieved, room for improvement also remains.With respect to the design of the printer, the incorporation of an enclosure for the printer in the future design could prove beneficial for the aforementioned reasons of preventing the phenomenon of warping and improving the finish quality of the printed part. In terms of manufacturing of components such as the aluminum fixtures and stainless steel laser cut extrusions, the reduction of weight can be achieved in future designs of the printer. The use of ABS material in manufacturing of fixtures rather than aluminum and the use of glass fiber instead of stainless steel laser cut extrusions would be conducive towards reduction in the overall weight of the machine.

During assembly of the printer, it is essential to provide adequate belt tension in order for the operation to avoid the risk of slip error. To eliminate this risk entirely, future designs could potentially replace the belt and pulley arrangements by implementing lead screws, not just in one axis of motion, but rather in all the axes of motion. Another restriction imposed by the current design is that the extruder used is not capable of printing support material alongside the filament. Support material is required in order to print parts that may contain overhanging or cantilever elements. Improvement to this can come in the form of implementing a dual nozzle extruder that prints support material along with the filament material, thereby expanding the range of complex geometries that can be printed. Future designs can also consider providing provisions in order to print PLA (Polylactic Acid) material along with ABS. The overall cost of the printer can also be lowered by designing and manufacturing the controller board and the motor drivers. These potential improvements to the current 3-D printer will ameliorate the existing features of this model and increase the quality of the parts it produces.

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