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# *Cost-effective, Custom-made, 3D Printer Design and Fabrication for Educational Purposes*

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***Abstract*—The potential to transform consumerism makes the technology of 3-D printing a significant one. Being versatile in its use in many fields of science and technology makes it a relevant topic. This 3D-printer assists undergraduate and postgraduate students to build their prototypes and designs in a much easier way. In this research paper we have used open source software Repetier, to control the working of the 3-D printer. Linear rails with ball bearing roller sliders are being used in the design which gives it a smooth motion and thus results in high accuracy. Since Repetier is being used as the software controller, positioning of the 3D model to be printed becomes effortless. Apart from that the user also gets the privilege to frame a design through manual control of the system and visualise the progress in the task. The mechanical, electronics and control modules are designed in such a way that it will be easy to learn and fabricate even by bachelors and masters students which would help them in understanding basic concepts of 3D printing along with the experience in mechanical design and fabrication.**

***Keywords—3-D printer; Repetier; G-code;***

## I. INTRODUCTION

The proven practicality of 3D printing has enabled engineers to come up with large number of advancements in the field of engineering and design. This project aids the student community to build a low cost 3D printer which has high potential to print complex designs. This research paper revises the traditional economic chain which consist of raw-material, manufacturers, wholesalers, shops and consumers to raw-material, 3D printer and consumers, thus expecting huge economic impacts on the mass manufacturing and designing sectors. The 3D printing mechanism which is also called as the additive manufacturing (AM) was first introduced in 1980s and got shaped over the past 30 years. There are many 3D printing processes available today. Some of them are Stereo lithography, Digital Light Processing, Fused deposition modelling, Selective Laser Sintering, Selective laser melting, Electronic Beam Melting, Laminated object manufacturing. Stereo lithography (SLA) is the most commonly used and the oldest among these techniques. This method can be used by any enthusiast starting from an engineer who designs a prototype up to a person who does artistic designs. The 3D printer discussed in this research paper also uses the same technology. Today we can see a large hike in the use of this technology in many fields such as fashion and interior designing, medical field, creating prototypes and in creating tools and parts for outer space by the astronauts. The ability of customisation of the designs with the help of CAD software makes it even more useful. The simplicity of the design and fabrication makes this a popular 3D printing machine among students. All these uses including the customisation of the designs can be achieved more precisely using the 3-D printer discussed in this paper. This 3-D printer varies a lot from the existing models in its design. The use of linear rails with ball bearing roller sliders is one among them. This system provides the user with a 15 cm*15 cm workspace. The 3-D printer discussed in this paper works with the open source software Repetier in which a 3-D design in STL file format from a CAD base software is given as an input and these are converted into G-code from where we get the x, y, z coordinates and the extruder moves accordingly. Since this 3-D printer uses a very simple design and open source software in its working this becomes more cost efficient and thus helps in rapid prototyping in labs and at a personal level. The rest of the paper is organized as follows: The first two sections presents a brief introduction and ideology behind this project work. In the related works section, we can find the research works related to this ideology. This is followed by system architecture section which describes about the procedure, firmware and electrical modules involved. The next section design and implementation gives details about the design tools, components of printer and implementation. The next section involves software integration procedure. The mathematical modelling section divulges the theoretical calculations of z-axis motion and x-y axis motion. The next section experiments and results includes the printing time duration of varies models and interpretation. This is followed by future works, conclusion and acknowledgement.

## II. MOTIVATION

Three dimensional printing is a rapidly advancing technology with wide applications in a lot of fields. With rapid advancements in technology, all the components required for the development of a 3D printer can be easily procured at a low cost. In addition, the availability of large number of open source software for computer aided design makes the development of the system more inexpensive than ever before.

3D printed parts can be used as sample models for proof-reading in robotic structures before they are replaced with stronger and durable metallic structures. Hence it can be extensively used as a technology for prototyping. It also plays a crucial role in education and artistic streams because students can improve their creativity by designing their ideas on a computer screen and then later bring those ideas into reality. It would enable the students to understand and conceptualize with a hands-on-experience.

## III. RELATED WORKS

Three dimensional printing reported in research work [1] introduces an open source powder based rapid prototyping machine. The potential to use 3-D printing technologies for printing ceramic membranes and reactors are investigated in the paper. The machine can print parts from various powdered particles like gypsum, alumina, zirconium etc. Binding of parts is carried out by standard inkjet ink. In the research work published in [2], the author provides an overview of the features and applications of 3-D printing. Its advantages as an additive manufacturing process is compared with other mass customization and manufacturing process. Various limitations of 3-D printing technologies like higher production cost, lesser choice of materials, precision and accuracy of finished products, strength and durability etc are discussed in depth and its adaptability as a better choice of manufacturing is explored. The paper in [3] discusses the challenges and recent trends in these technologies. It gives a detailed literature review of additive manufacturing techniques, various substances with which printing can be achieved and its practical application in various fields of science and technologies. In the research paper [4], the author proposes a 3-D printing method in the Solid Freeform fabrication system. This method could reduce post process and increase the strength of manufactured part. The authors in [5] have developed a 3-D printer which is operated using RepRap console in the RepRap distribution software. An open source metal 3-D printer is discussed in research work [6]. The open source firmware 'repetier' is used to convert G-code commands into stepper motor signals. The research work in [7] proposes a study aimed at developing algorithms to slice a STL file in order to generate G-code files. These G-code files are fed into the 3-D printer to get the output product. The research work in [8] proposes the design of a drawing robot in which images are converted into G-codes. These G-codes are fed into the CNC machine resulting in synchronous movement of actuators. A PLC based controller simulation for a precision laser driller is discussed in research [9] whereas the G-code conversions for a 3d printer are discussed in research [10]. The research paper[11] aims at creating effective design machine which is controlled by a computer and capable of building 3-D models. The paper shows the machine in control system design which consist of mechanical, electrical and electronic system. A comparative study in the paper [12]on oscillatory based manipulator address the problem of controlling the attitude of two links and its end effectors positioning by introducing two robust controllers named as H-infinity and sliding mode controllers. The performance of these two controllers are evaluated through simulations and the results demonstrate that sliding mode controller is more efficient than H-infinity controller.

## IV. SYSTEM ARCHITECTURE

The system architecture of 3D printer is depicted in Fig.1. The system architecture primarily consists of 6 parts. The intent model is designed using the software Solidworks and then the model is given as input to 3D printer firmware so that it can position and slice the model. The firmware controls the motors and end effectors via micro controller unit with respect to the positioned model. The motors cause movement in the belt arrangement. The movement of the belt guides the end effector synchronously.

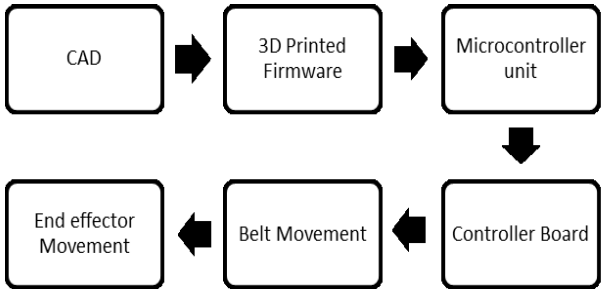



Fig. 1. Block diagram of 3D printer

### A. *Solidworks*

Solidworks is computer aided design software and makes use of parametric feature based approach. It is used to design solid components. Parametric approach refers to the fact that we can set the shape or geometry of the model. Parameters can be either numeric or geometric parameters and associate with each other through the relations to obtain expected design. In this feature-based approach shapes and operations are the building blocks of the intent model. Further operation based features include features such as shells, chamfers, fillets, draft. Shape based features includes holes, bosses, slots, extrude cut etc. Typically the model begins with 2D sketch which contains lines, conics, arcs. After that, intent dimensions are added to the model. Relations define attributes such as parallelism, concentricity, perpendicularity etc. Solidworks facilitates assembly mates very quickly. It also includes an additional library which consists of various number of components such as gear, bolt, nut etc.

### B. *3-D printer Firmware*

3D printer firmware works with all RepRap boards which are compatible to Arduino. The firmware used in this research is Repetier-Host. In this firmware STL file of intent model can be added and the model can be positioned. Slicing can be done by inbuilt slicer. It can handle up to 16 end effectors with various filaments, colours and simultaneously load many components which fit to print-bed area. It contains 4 different slicers. All extruder movements are visible after slicing.

### C. *Microcontroller unit- Arduino Mega 2560*

Arduino Mega 2560 is a micro-controller based on ATmega2560. It has total 54 pins (digital input/output pins) of which 15 are PWM pins, 16 analog inputs, a 16MHz oscillator, 4 serial ports, an ICSP header, a reset button, a AREF. It can be powered via the USB connection or external power supply. The micro-controller board can operate on an external supply of 6-20v. It has 128 KB of memory for storing code, 8 KB of SRAM, 4 KB of EEPROM. The total 54 digital input/output pins can provide or receive maximum of 40mA. In addition, there are few pins having some special functions like Serial RX (pin 0,19,17,15), Serial TX (1,18,16,14), External Interrupts (pin 2,3,18,19,20,21), PWM (pin 2 to 13, 44 to 46), MISO (pin 50), MOSI (pin 51), SCK (pin 52), SS (pin 53), SDA (pin 20), SCL (pin 21).

### *D. Motor Driver A4988*

The A4988 is a complete micro stepping motor driver. It operates stepper motors in full, half, quarter, eighth, sixteenth modes with output drive capacity of 35v,2A. It can operate in slow or mixed decay modes by fixed off-time current regulator. It has adjustable current control which lets you to set maximum current output.

### *E. Stepper Motor NEMA 17*

It is a Phases-2 motor with 200 steps/revolution and 5% step accuracy. Other specifications include shaft load-20,000 hours at 1,000 rpm, Axial 25N push, 65 N pull, IP rating-40, insulation resistance-100megohms,4-wire bipolar stepper has 1.8 degrees per step for smooth moment.

### *F. Limit Switches*

Limit Switch is an electromechanical device that consists of an actuator mechanically linked to a set of contacts. It is generally used to make or break the electrical connections between the set of contacts when an object comes into contact with the actuator.

### *G. Thermister*

Thermistor senses the temperature of end effectors and offers numerical assistance to observe in 3D printer firmware. It predicts the temperature corresponding to change in resistance value. A good quality thermistor accurately divulges resistance value at every temperature. Thermistor is classified into two types based on the resistance change with respect to the change in temperature, these are PTC and NTC. PTC increases resistance value with increase in the temperature and NTC increases resistance value with decrease in temperature.

### *H. Extruder Motor*

Extruder Motor is a part in material extrusion printing for melting raw material to form a continuous profile. Extruder Motor mainly involves cold end and hot end. The cold end is responsible for controlling feed rate by supplying torque to the material. Generally the cold end is mostly geared or roller based motor. The hot end consists of heating chamber and nozzle. The hot end is an active part in extrusion of raw material which melts the filaments and it also allows the molten filament to exit from small nozzle to form a thin layer that will adhere to material laid on. The nozzle has a diameter between 0.3mm and 1mm.

### *I. 3-D Printer Controller Board*

CNC Stepper motor driver shield ramps 1.4 is a stepper motor driver adapter. Ramps can only work when it is connected to Arduino Mega 2560 and motor drivers like DRV8825. This design includes extruder control electronics and plug-in stepper drivers on an Arduino Mega Shield. It has two stepper motor plug-ins for Z-axis in parallel, a compatibility of 5 stepper driver boards, an ability to control other accessories, a standard interfaces, a reserved GCL like I2C and RS232, a SD Card add-on, a type B receptacle USB. MOSFET 3 MOSFET is applied to the heater/fan and thermistor circuit. The blinking MOS (LED) can indicate the status of the heater.

## V. DESIGN AND IMPLEMENTATION

The mechanical design of the system is depicted in Fig. 2. The design encompasses three separate belt arrangements which facilitate movement in x-y directions as shown in Fig. 3. The x-direction is controlled by two parallel belt arrangements. Movement of the belts results in the displacement of a profile in x-direction. Two separate motors works simultaneously in the same direction to get the desired movement. The y-axis is controlled by the movement of another belt and motor that causes relative movement of a slider which incorporates the end effector. The z-direction is controlled by three parallel guide rods which facilitate the motion of the print-bed. The mid guide rod controls the motion of the print-bed and the other two guide rods assist to eliminate the instability of the print-bed. The guide rod is incorporated in such a way that it can control the z-direction by another stepper motor. The slider which causes motion in y-direction consists of four rollers. The rollers are arranged in such a way that they can roll on v-shaped aluminum rod. Furthermore, the end effector is attached to the roller arrangement.

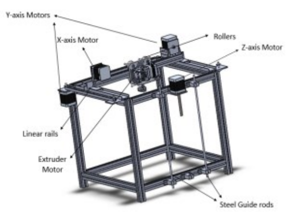



Fig. 2. Mechanical Design

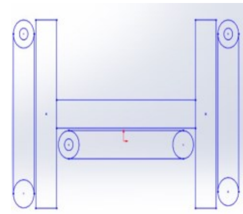


Fig. 3. Belt Arrangement

The mechanical design consists of a frame which is made-up of aluminum which gives support to the system. The cubical frame provides strength to the entire setup. The profile in the x-direction is incorporated with linear rail with ball bearing roller sliders on both sides. The roller is connected to linear rail with ball bearing roller sliders on both sides so that system can reach every point in the specified work space. The print-bed is connected to three guide rods which are controlled by stepper motors resulting in displacement of the print-bed.

The extruder is integrated to a L-shaped holder and it is further attached to the roller. This provides movement in x-y direction. The print –bed acts as a platform on which printing takes places. It has a provision to move up and down which constitutes the movement z-direction. Fig.4. to Fig.13. depicts various parts of the 3-D printer.

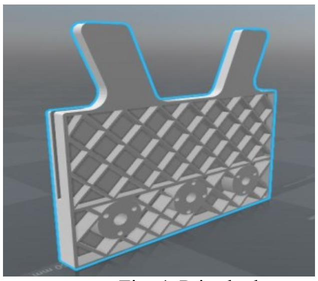


Fig. 4. Print-bed

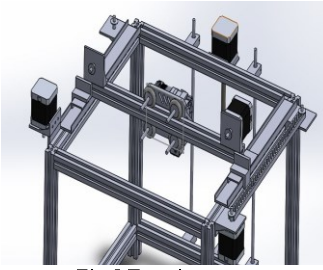


Fig.5.Top view

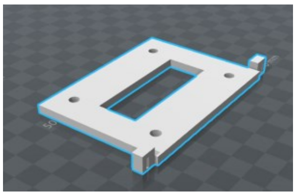


Fig. 6. Extruder Holder

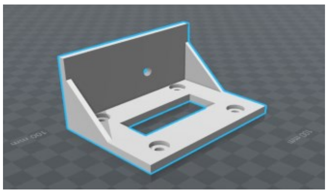


Fig. 7. Extruder Holder 1

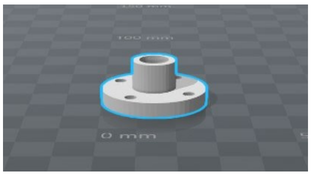


Fig. 8. Rod Holder

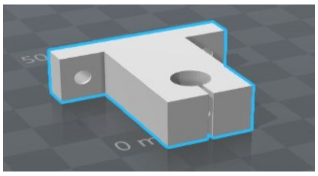


Fig. 9. Rod Holder

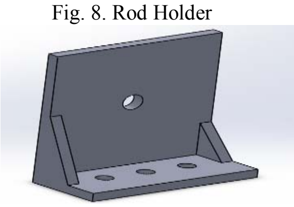


Fig. 10. Motor Holder

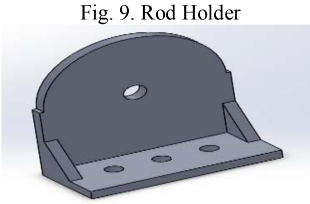


Fig. 11. X-Y Rod Holder

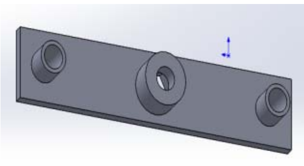


Fig. 12. Rods Supporter

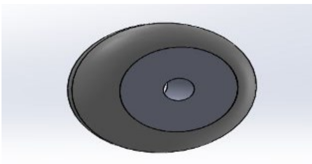


Fig. 13. Roller

## VI. SOFTWARE INTEGRATION

To get the best possible results from the 3-D printer we have used open-source software Repetier, CAD software Solidworks and the Arduino IDE to control the micro-controller. A 3-D model in the software solidworks and Repetier are depicted in Fig. 14. and Fig. 15. Repetier supports any 3-D models which are in the STL or OBJ format. The generation of STL files are done with the help of Solidworks where we have the provision to modify the existing 3-D models. These STL files are sent to the Repetier software and they are arranged in a virtual printing platform. Then the slicing process happens, where the 3-D model is made into layers and thus helps the system to arrange a path for its motion. In this project we have used Slic3r as the slicing software. All other information regarding the printing such as temperature of the extruder, the required workspace, the information regarding the speed and quality can also be given as input to the Repetier. Finally, this software sends the g-code to the printer and can even be copied to a SD-card. These g-codes are then sent to the CNC machine and the motor rotates accordingly. In-order to integrate this software with the printer, we use Arduino, an open source computing platform. In-order to achieve presize communication between theArduino and Repetier we have added an appropriate library called 'Marlin' to the Arduino IDE software.

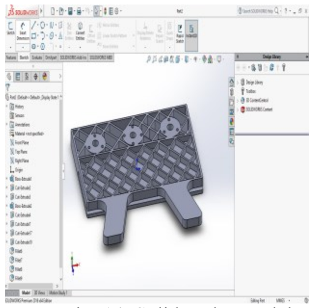


Fig. 14. Solidworks Model

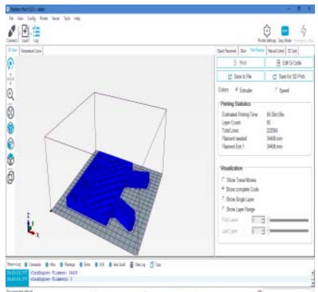


Fig. 15. Repetier 3D Model

## VII. MATHEMATICAL MODELING

### *A. Z-axis positioning*

The movement of the print-bed is controlled with the assistance of linear actuator which converts rotational motion into linear motion. The precision of linear motion lies in the thread pitch of the screw which is integrated to the rotor. By preventing the screw's axial rotation, the linear movement can be attained as the motor turns. This conversion can be achieved by the combination of ball bearing nut and screw with the rotor. The inhibition of screw axial rotation can be achieved by the combination of ball nut and screw, which offers anti-rotation effect to screw's rotation. For most of the applications, ball bearings are not the effective solution because of its sensitivity in alignment. But the durability can be achieved with motors having simple brush-less design. The advancement in technology has led to newer methods to mate screw, ball nut and motors. The long established linear actuators made by integrating the internal threaded hallow shaft with it. The screw can be either v-thread or acme-thread. The v-thread facilitates to machine and roll form, but it is not a viable option for transmission of power. The acme-thread has efficiency to reduce certain losses like friction.

The linear actuator works on the ground rule of nut and bolt mechanism. Typically, one rotation of the motor causes one lead development. Clockwise and anti-clockwise rotation of the actuators decides the lifting and lowering of the load. The length of the thread can be determined by unfolding the thread and considering the unfolded thread length as the hypotenuse of the triangle with lead and circumference of the mean diameter as other two sides as shown in Fig. 16. The behavior of the linear actuator can be analyzed by lifting and lowering mechanism of the axial load. Using trigonometric operations,

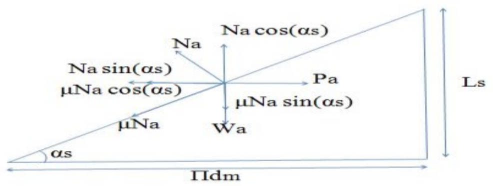



Fig. 16. FBD In Equilibrium Conditions,

$$\tan\alpha_s = \frac{L_s}{\Pi d_m}$$

$$P_a = \mu N_a \cos\alpha_s + N_a \sin\alpha_s$$

$$W_a = N_a \cos\alpha_s - \mu N_a \sin\alpha_s$$

$$N_a = \frac{W_a}{\cos\alpha_s - \mu_s \sin\alpha_s}$$

$$P_a = \frac{W_a(\mu\cos\alpha_s + \sin\alpha_s)}{\cos\alpha_s - \mu\sin\alpha_s}$$

$$P_a = \frac{W_a(\mu + \tan\alpha_s)}{(1-\mu\tan\alpha_s)}$$

$$\mu = \tan\varphi_s$$

$$P_a = \frac{W_a(\tan\varphi_s + \tan\alpha_s)}{(1-\tan\varphi_s\tan\alpha_s)}$$

$$P_a = W_a \tan(\varphi_s + \alpha_s)$$

$$Torque = \frac{W_a d_m}{2}\tan(\varphi_s + \alpha_s)$$

$\alpha_s$ = Helix angle of the threaded rod.
$N_a$ = Normal force acting perpendicular to the surface.
$W_a$ = Axial Load.
$d_m$ = Mean diameter of the thread screw.
$\mu N_a$ = Force opposing the movement of the axial load (Frictional force).
$P_a$ = Imaginary force acting at the inclination point due to movement of the axial load.
$L_s$ = Development of the screw caused by one rotation of the motor.
$\mu$ = Coefficient of friction.
$\pi d_m$ = Circumference of the screw with mean diameter.
Torque=cross product of the radius vector and force vector at the axial point.

*B. X-axis and Y-axis positioning*

X-axis and Y-axis movement is controlled by motor and timing belt. The linear actuator contains pulley, motor and timing belt. The rotations of motor causes a corresponding linear movement in timing belt. The movement of linear actuator mainly depends upon number of pulley tooth and timing belt pitch. The modeling can be done by considering the rotational angle of pulley and circumference of the pulley.

$$l_s = \frac{360°}{\theta_s} \times 2\pi r_s$$

$\theta_s$ = Angular displacement by the pulley which is connected to shaft of rotor
$r_s$ = Outer radius of the pulley
$l_s$ = Displacement of the linear actuator

## VIII. EXPERIMENTS AND RESULTS

The Arduino mega 2560 is programmed with Marlin library to perceive the g-code commands and facilitates interaction with CNC shield. Initially, the component to be printed is designed using Solidworks and the designed component should be saved in .STL file format. Saved part is imported into the Repetier-Host software. Once the 3D model is imported into the software, it is placed in a virtual 3D plane. Basically three steps should be followed to print an imported 3D model. They are Object Placement, slicer and print preview. Fig. 17. depicts the different steps involved in printing.

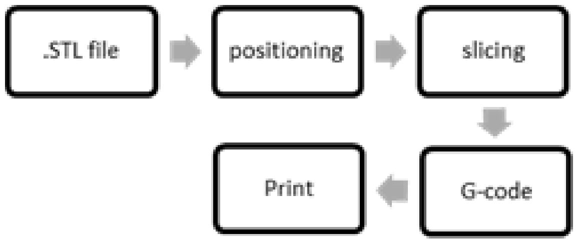
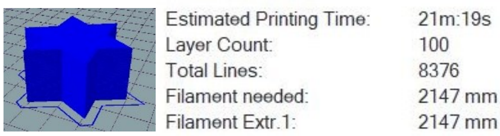
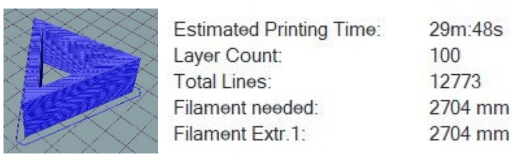



Fig. 17. Block Diagram of Procedures For Printing

We have to arrange the part in such a way that the sides of the part which has a greater flat surfaced area should be pointed earthward in object placement procedure. Use 'Slice with CuraEngine' option to slice the 3D part into many 2D layered G-code file. We use 'Print preview' to monitor the filament requirement, speed, time demanded to complete the print. Temperature needs to be adjusted in the printer settings according to filament material and if everything is within control then we execute print. Once the print is started, the printer calibrates its origin and then melts the filament to the adjusted temperature. It starts execution of g-code commands and prints the design. Different models created to 3D print are shown in Figure 18 along with the response timings. The 3D printer as implemented by us is shown in Figure 19.



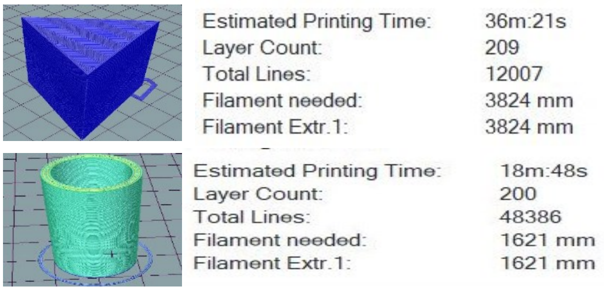



Fig 18. Various 3D models created

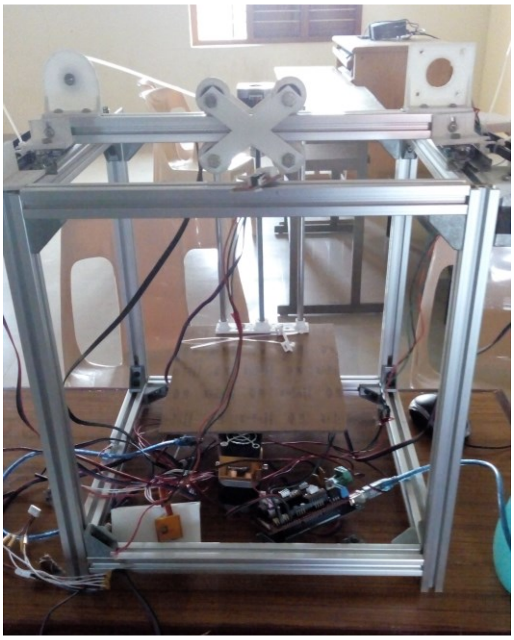


Fig 19. 3D Printer prototype

## IX. FUTURE WORKS

Our future works mainly focuses on enhancing the productivity of the current system by strengthening its performance. We wish to incorporate better algorithms into the current system to increase its efficiency. We wish to explore the possibilities of remotely control and oversee all details of the 3D printer and the printing work via web interface. We aim to investigate technologies that can be incorporated into the current system in order to expand it into a multi-material 3D printer. In addition we aim to explore the capabilities of developing a printer with multiple extruders. This would enable the printing of multi-color three dimensional models.

## X. CONCLUSION

In this research paper we have incorporated all the present-day demands in the field of designing and prototyping on this versatile machine called 3-D printer. Our entire project aims to transform the industrial model to a desktop version and this reconstruction has helped us in bringing down the cost. Various experiments conducted on validating the efficiency of the system yielded promising results. These results that we have obtained prove that the system does not compromise in its desirable working.

## XI. ACKNOWLEDGMENT

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