Development and fabrication of fused deposition modelling 3D printer

Samson Wilson, Rahul Thomas, Nimmi Mary, Eric Tom Bosco, Ajith Gopinath*

Department of Mechanical and Automobile Engineering, Christ Deemed to be university, Bengaluru

*Email: ajith.gopinath@christuniversity.in

Abstract. The usage of 3d printing has been a widely applicable in various branches such as aerospace, medical, food industry and recently even in construction of houses. As we can see 3d printing has become a revolutionary invention and is becoming very common in manufacturing of various machining parts. So as we know there are various forms of 3d printing technologies and each of them have their own advantages and disadvantages. One of the main disadvantage is the quality of finishing on the 3d printed parts. Apart from this the cost of 3d printing has been one of the major disadvantage. The purpose of this projects is to design and fabricate a 3d printer which would increase the quality of the parts manufactured and also make it cost efficient. This quality product can be achieved by decreasing the layer thickness. The other ways to increase quality of the product is fabricate the 3d printer in such a way that the temperature of the nozzle is within the given range all through the process. This project is expected to result in the fabrication of the 3d printer considering all the above features.

Keywords: 3D printing, Aerospace, Manufacturing, Design, Fabrication

1. Introduction
Manufacturing of difficult parts has become a major issue in the industries. The accuracy and precision of the parts made by the use of subtractive processes isn’t up to the level which company desires. Hence to eradicate these difficulties additive manufacturing is introduced which helps in conversion of 3D design models into actual physical objects. The author explains how the Fused Deposition Modelling (FDM) cartesian co-ordinate based 3D printer should be designed and developed. PLA (Poly Lactic Acid) is used in this project for the 3D printer because of it’s often use. The 3D Modelling is done using CATIA V5 R20 software is converted into STL (Stereo lithography) file. CURA software is used to convert the STL file into G-codes which id then sent to PRONTERFACE software. The PRONTERFACE software guides the instructions to the Cartesian coordinate based 3D printer and 3D Modelled design are printed to physical part as a result [1].

3D printing is a method of non-traditional machining and a technique becoming popular nowadays. Additive manufacturing is a way in which object by laying successive layers of material till the entire object is made. There are many different kinds of 3D printers and they make use of different kind of printing methods, technologies and also different kinds of materials. This paper explains in detail about
5 different kind of 3D printers. They are: Stereolithography (SLA), Fused deposition modeling (FDM), Selective Laser Sintering (SLS), Laminated object manufacturing (LOM) and Digital Light Processing (DLP). The research paper gives a basic introduction to the concept of various 3D printers with their advantages, limitation, and application and compares each of them to different standards such as dimensional accuracy, surface finish, material used and post processing requirements [2]. Additive manufacturing (AM) has been nowadays widely used in many industries like aerospace, automotive, biomedical, and energy industries. Presently, with the quick growth of this technology, there are a huge number of 3D printing approaches in the market. Each and every method has its own advantages, disadvantages and applications. Materials used for printing too are divided into many groups such as ceramics, metals, polymers, and cements. In this paper they discuss on how to build a 3D printer based Fused Deposition Modelling technique. They divide all the process involve in building of FDM based 3D printer into many steps and study on it. They also used Arduino Mega as a microcontroller in this project [3]. 3D Printing or Additive manufacturing is an innovative method of manufacturing parts right from CAD design model by using layer by layer material approach. This manufacturing technique can produce fully condensed metallic parts in a very short time with high precision. The main features of additive manufacturing are part complexity, part consolidation, freedom of part design and light weighting are gathering specific interests in metal additive manufacturing for aerospace, oil and gas, marine and automobile applications. Directed Energy Deposition and Powder Bed Fusion Technologies are mainly used in mainly Metallic 3D printing. Powder bed fusion is a technique in which each powder bed layer is carefully fused by using energy source like laser. This is the most auspicious additive manufacturing technology that can be used for manufacturing small, complex and low volume metallic parts. This review grants outline of 3D Printing technologies, applications, advantages, challenges, disadvantages, materials and economics of 3D metal printing technology[4].

The research paper on 3D printing has become a distinguished topic in today’s technological conversation. In the paper, author explains how a 3D printer works and discuss on additive manufacturing or 3D printing. The paper explains of the advantages of 3D printing compared to conventional methods of manufacturing. The author explains in detail about different application of 3D printer and how it is affecting our life presently. It also clarifies how 3D printing has become an essential part in various industries and the way in which solved many existing problems. Lastly the imminent potential of 3D printing or additive manufacturing has been drawn by the author [5]. Fused Deposition Modelling (FDM) is an Additive Manufacturing Method for printing 3D designed objects layer by layer successively. The key objective of this research is to develop a low-cost 3D Printer using readily accessible materials and traditional methods for fabrication which can be used to print the objects confined in a 300 x 250 x 300 (in mm) printing space. According to the market survey done by the authors, they arrived at an inference that 3D printers are available at a price about Rs.50,000 to Rs.60,000 in Indian market. Originally, they designed a 3D Printer entirely in 3D Modelling Software SOLIDWORKS and studied each part and chose a readily available material suitably to develop a cost effective 3D printer. The researchers have explained step by step on making a cost effective FDM 3D printer[6]. This research paper is on various types of 3D printing and several materials used in 3D printing. It also explains in detail about 3D printing and its significance in today’s world. Selective Laser Sintering, Fused Deposition Modelling, Stereolithography and Laminated Object Manufacturing are some of the several processes used in 3D printing explained in the research paper. It gives a detail description on the concept and principle of each 3D printing process. It also elucidates on different types of materials used in 3D printing process. They are: Acrylonitrile Butadiene Styrene (ABS), High Impact Polystyrene (HIPS) and Poly Lactic Acid (PLA). It clarifies on the properties, advantages, limitation and application of the several materials used in 3D printing [7].

The 3D printing technology is widely used in the current manufacturing industries. The 3D printer although efficient has its disadvantages. It takes 4-12 hours to complete a work piece and almost a day for printing a complex or a big shape. The paper talks about the methods proposed to improve the overall speed and accuracy of the printer [8]. 3D printing usually works in a way that whatever the feeding material, it will get printed. If the material needs to be changed, the whole filament needs to be changed. The paper proposes to create new materials and designs like composites using fused fiber deposition method by using a drop down platform which will allow the printing of new materials [9].
The 3D printing technology has revolutionized the engineering industry and many other industries like medical and construction industries. The paper depicts the different processes involved in the 3D printing and the different types of options available in the market based on price, workspace, accuracy and speed. The advantages and drawbacks are also mentioned [10]. The manufacture of small components, big components, printed biological tissues etc. The 3D printer plays a huge role in the current manufacturing industry. Yet there are some imperfections like structural defects and pore formation associated with it. The paper talks about the methods to find such irregularities and to re-solve the problems with some modifications [11]. The paper elaborates about the concept of 3D printing and the advantages of 3D printing over conventional methods in the engineering field and other industries and how the end product is superior to conventional methods like machining, casting. It also mentions the ways adopted to print in low cost methods [12].

2. Methodology for the Study
The given flowchart displays the methodology used in the construction of FDM 3D printer. The initial step is to select one of the additive manufacturing processes among many described in the literature survey. Then a suitable mechanism is selected for X, Y and Z axis movements, considering various factors such as simplicity of design, cost of fabrication, accuracy, synchronization etc. Once the mechanism is carefully chosen the following step is integration of electronics and software. Finally, the machine is fabricated. The final step is, synchronization of electrical, mechanical and software elements of the machine.

![Flowchart for the functioning of the 3D printer](image)

**Figure 1.** Flowchart for the functioning of the 3D printer

3. Apparatus
3.1. Process Selection
The next step is to decide which coordinates are supposed to move in which direction (X Axis, Y Axis, Z Axis). This selection would depend on the same factors earlier considered such as cost, capacity etc. After the mechanism is selected the next process is to choose the appropriate electronics, materials for the fabrication and finally then synchronizing all the components together so that they work in tandem. The FDM starts with a CAD Model where a required model to be manufactured is designed using a
CAD designing software such as SolidWorks or CATIA. This model with the required dimensions is converted into a STL file format. The designed model is then sent to slicing software’s such as CURA, Astroprint, Craftprint etc. where the model is divided into small layers up to which the nozzle can print. These layers decide the surface finish of the manufactured model. Lower the layer thickness better the surface finish it will have. Now after all these processes the model is ready to be manufactured, the manufacturing starts with a thermoplastic material in a loop is fed to the nozzle through a PTFE Tube. THE hot end heats this thermoplastic material to a glass change temperature and then exits out through the nozzle. The Thermos plastic material used in our 3d printer is PLA type filament.

3.2. Mechanism Selection
There are different ways in which the mechanism of a 3d printer can be built, some of them are SCARA, Cartesian, Polar, Delta and various other mechanism. We have decided to go with a Cartesian type of mechanism as it is easier to fabricate and also cost effective. In this type of mechanism the bed moves in Y-Axis, the hot end moves in the X Axis and the 2 Lead Screw moves in the Z Axis up and down. All these Axis’s must move with great precision in order to get good accuracy and repeatability. The Z Axis moves at very low rpm as it has to complete fabrication of each layer by layer. The bed is of the type Mk2 heat bed where the bed heats up to a certain temperature so that the base layer of the model must stick to the bed so that the foundation of the model is rigid. This heat bed is bolted to a wooden piece and is also provided with a spring in order to make in more flexible. Both Z axis lead screws must move in tandem with each other otherwise the precision will be affected. The construction of a Cartesian mechanism type of 3d printer in simpler than the rest of the mechanism making it one of the most preferable type of mechanisms for an FDM type of 3d printer.

The components used for the project are considered with the following factors:-
1. Reducing the fabrication cost of the 3D Printer
2. Making the 3D printer economical for household applications
3. The product manufactured provides good dimensional accuracy
4. To achieve repeatability

The components are classified based on the following criteria.
1. Electronics
2. Mechanical
3. Softwares

3.3. Electronics

3.3.1. Controllers. The main part of the electronics list is the controller which is brain of the system, this decides which and when the Axis’s should move depending upon the desired model. 44 This basically controls all electronic components used in the 3d printer. The 3d printing technology uses Arduino microcontroller as their basic choice of microcontrollers. In this project we have used Arduino Mega as our choice of controller as it is easier to program the codes and also provide good response to the input given.

3.3.2. Stepper Motor. The stepper motor plays a vital role in the working of thee 3d printer as it help in the movement of the axis to required precision. The type of 3d printer we have used is a NEMA 17 type of stepper motor. The main significance of a NEMA 17 stepper motor is that it provides more torque than other variants of the NEMA stepper motor. The motor is selected depending upon the specifications we need for the working of the 3d printer. For this project we have used 5 NEMA-17 stepper motor’s (1 for Y-Axis, 1 for X-Axis, 2 for Z-Axis and 1 for the extruder). Some of the specifications of the NEMA 17 are:
- Rated Voltage = 12V DC - Current = 1.2A - Step angle = 1.8 degree - Holding Torque = 3.2 kg-cm

3.3.3. Endstops. The end stops we have used for this project is a mechanical type of end stop. The reason we have used a mechanical type of end stops is because it is cheaper than other type of end stops such as Optical end stops. The purpose of using an end stop is to define the maximum distance the axis are
supposed to move. Once it touches the mechanical end stop it stops the movement of the motor. There are other types of end stops such as read switches where the contact is cut off once a magnet is present in front of it. The end stop is easy for connection as it requires only 2 wires that is to be connected at the normally open and the Common points.

3.3.4. Heated Bed. One of the major disadvantage of using FDM type of 3d printer is warping. The use of a heated bed reduces the formation of warping and improves quality of the model. The type of heated bed we have used is an Mk2 heat bed, the heated bed comes with a thermistor which helps to distribute the heat evenly throughout the heat bed. The temperature of the heat bed is around 110 degree-Celsius which helps to create a rigid base for the model. The dimensions of the heat bed is 214x214mm which will provide enough work area to create medium sized models. The heat bed can be used for the working of various materials such as ABS, PLA. One of the major advantage of the heat bed is that it provides heat throughout the model all through the process thereby not allowing warping to take place.

3.3.5. Hot end. A hot end is the part in the 3d printer which heats the filament (PLA) and pushes it to the nozzle. The temperature of the hot end is around 230 degree-Celsius and also contains a 100k thermistor which can be used for high temperature performance. It comes with a cooling fan which helps to maintain the temperature throughout the process. The nozzle 47 present in the hot end has a diameter of 0.4 mm which also contributes to the accuracy and surface finish of the product. This hot end is capable of working with materials such as PLA, ABS and PETG. There is a heat sink present behind the hot end for the excess heat to escape to the environment.

3.3.6. Stepper Motor Driver. Stepper motor drives are small components which act as a medium of communication between the Arduino controller and the stepper motor. The signal for the stepper motors are given by the motor drive. There are 4 motor drives (1 for X-Axis, 1 for Y-Axis, 1 for Z-Axis and finally 1 for the extruder) these motor drives are connected to the Ramps. A heat sink is stuck to the top of the stepper motor drives so that the heat emitted from the drives can escape to the environment and thereby not damage the circuit board.

3.3.7. Power Supply. The power required for the working of the 3d printer is provided by using an external power supply which provides a voltage of 12V and current of 30A. The Normal AC Power supply of 220 V cannot be used to power the 3D printer as it will damage the circuit board, hence an external power supply is used.

3.4. Mechanical

3.4.1. Timing belt. A Timing Belt is a belt containing teeths which mesh with the teeths of the pulley. The main purpose of a timing belt is to provide a linear motion which converted by using a rotational movement of the pulley. Each tooth of the timing belt should match with the tooth of the pulley otherwise this may cause slipping of the belt leading inaccuracies. The belt we have used has a Pitch of 2mm, width of 6mm and a length of 2m which is sufficient for the movement of the Y-axis and X-axis.

3.4.2. Pulley. A Pulley is a disc like structure which helps to convert the rotary motion into a linear motion. They are used usually to carry heavy loads making them easier to lift. The pulley consists of teeth’s which mesh with the the teeths of the timing belt thereby avoiding slippage. The bore diameter of the pulley is 5mm having 20 teeths.

3.4.3. Lead screw. Lead screw are long rods which have threaded pitch all through the rod. The Z-axis movement for the 3D printer works with the help of this lead screws. They provide uniform motion on both sides of the Z-axis. The lead screw we have used has a diameter of 8mm,length of 300mm and a pitch of 2mm. The material of the lead screw is stainless steel.

3.4.4. Smooth shaft. Smooth shafts are used for the smooth movement of the X and Y axis, they provide
the linear motion. The smooth shaft we have used has a diameter of 8mm, length of 400mm and the material is made up of mild steel.

3.4.5. **Linear bearings/Radial bearings.** Linear bearings are bearings which are meant to slide along the shaft. The bearings we have used have a Bore diameter of 8mm and an outer diameter of 15mm. These bearings consist of lubrication inside providing lesser friction with the surface of the rod. The radial bearing unlike linear bearing reduces rotational friction and also help in radial and axial loads. The bearings we have used have a diameter of 8mm and the dimensions are 8mm*22mm*7mm.

3.4.6. **PLA Filament.** There are many filament materials which could be used but we have used PLA filament. The reason for using PLA filament is that it has many significance than other materials. Some of these significance are they are easier to print as they can flow through the nozzle easily. Also the printing temperature of PLA is much lower making it convenient to print. The surface finish offered by PLA filament is better compared to other materials such as ABS. Other materials find it difficult to do the after processing while it is easier in the case of PLA filament. They are also considered to be environmentally friendly making them Biodegradable and also less toxic than other materials.

3.5. **CAD Tools**
The tools used for designing the part which is to be manufacture are called as CAD tools (Computer Aided Designing). There are various designing software’s available which will help in the designing of the parts, some of them are SolidWorks, CATIA, and CREO etc. The sole purpose of these tools are to design a part which is to be manufactured to a given dimension. The Computer Aided Design is used to increase the designer’s efficiency to develop a model to their required configuration. These designing software’s also help in achieving interchangeability of parts in a machine. These software’s help to provide dimensional tolerance and also check for any faults in the design without actually having to build a prototype model. Hence they help in saving time and also reduces the wastage of material. These software’s not only provide a deep insight about the model to be manufactured but also help in making any changes.

3.6. **CAM Tools**
The computer Aided manufacturing tool is used to convert a CAD file to a format with which the machine will be able to understand and proceed for manufacturing. The software used for this project is a slicing software, this software will divide the designed model into very fine layers. Slic3r is the software used in this project. Slic3r mentions the layer thickness while it is 3D printed material is manufactured, the surface finish will depend on the layer thickness. The nominal thickness given while manufacturing is 0.1mm. The CAD model is converted into an STL file and contains G codes to make it machine friendly.

3.7. **Prototype & testing**
The testing of the 3d printer on basis of the objective can be done by checking its dimensional accuracy. The model which has been printed is compared with its CAD model for its dimension. The model created is measured using a scale and the difference between the actual dimensions will show us the efficiency of the 3d printer to print with accuracy. The other testing would be for the surface finish of the model which has been created. The tested model would be compared to a Model which had been created on a High 54 Prized 3D Printer. Achieving a surface finish similar to that of the high prized 3D Printer will decide whether the objective is achieved or not. One other Testing method will be to check for any Warping. Warping is a problem associated with temperature difference causing the edges to bend. Achieving highly finished edges without any bending will give the result of the test.

4. **Results and discussion**
For the fabrication of Fused Deposition Modeling (FDM) 3D Printer the budget is calculated and estimated to be Rs 12198. The whole project budget only consists of material cost. Aluminum Frame is obtained from scrap material to reduce cost of production. Freeware software’s like Arduino, Slic3r and
Pronterface were used to avoid expensive cost. Creality 3D Ender is a 3D Printer which has a Build Volume of 220 x 220 x 250 mm cost Rs 21,000 and is one of the cheap 3D printer currently available in the market. We have built the FDM Printer which works with maximum efficiency and minimum budget. We have used Arduino Mega 2560 and Ramps 1.4 as the microcontroller. Our project cost atmost Rs. 12200 which is even Rs 7000 less than the product present on the market. This result helps us in achieving our 1st prioritized objective of fabricating a low cost 3D printer. The part which was printed in the 3D printer was compared to a high cost 3D printer and checked for its surface quality. We were able to see an accuracy similar to the one of the high cost 3D printer hence satisfying our objective of achieving good surface finish and dimensional accuracy. It was also observed that there was no cases of warping leading to uneven edges while printing the parts.

The fabricated fused deposition modeling 3D printer is shown in the figure 2. All the components are labelled for the easy identification. The total cost incurred for the project has been mentioned in detail in the table1. Table 1 shows the cost effectiveness of the 3D printer manufactured. If taken up in a large scale the cost can be further reduced and 3D printers will then be a regular household equipment.

Table 1. Budget of the project.

| No. | Item                         | Price | Quantity | Amount |
|-----|------------------------------|-------|----------|--------|
| 1.  | Shaft Coupler                | 215   | 2        | 430    |
| 2.  | Timing Belt                  | 379   | 2 meters | 379    |
| 3.  | Stepper Motor Nema 17        | 650   | 5        | 3285   |
| 4.  | Smooth Rod                   | 650   | 4        | 2600   |
| 5.  | Screw Thread                 | 599   | 2        | 1198   |
| 6.  | Endstop                      | 100   | 3        | 300    |
| 7.  | MK8 Extruder                 | 549   | 1        | 549    |
Table 2 is the specification chart of the 3D printer fabricated. The build volume, method and nozzle diameter and many other specifications are mentioned in the table 2.

### Table 2. Specification of the 3D Printer

| Specification          | Details                        |
|------------------------|-------------------------------|
| Build Volume           | 200mm x 200mm x 150mm         |
| Method                 | Fused Deposition Modelling     |
| No. of Extruders       | 1                             |
| Power Supply           | DC 12V 30A                    |
| Connectivity           | USB                           |
| Filament Diameter      | 1.75mm                        |
| Nozzle Diameter        | 0.4mm                         |
| Filament Material      | PLA                           |
| Print File Type        | STL, G-Code                   |
| Machine Size           | 450mm x 530mm x 430mm         |
| Machine Weight         | 5kg                           |

### 5. Conclusion

A Cost Effective 3d printer was developed and fabricated. 3mm thickness aluminum frames were assembled together using multiple bolts and nuts for the fabrication of the 3d printer. The softwares used for the development of the 3d printer are Arduino software, CATIA for the creation of the 3d MODEL, SLIC3R software for slicing the CAD models in various layers, Pronterface for calibration and execution of the 3D printer to print the models. The Build Volume of the 3D printer is 200mm*200mm*150mm. The number of extruders used in this 3D printer is one. The machine size is around 450mm*530mm*430mm and weighs around 5 Kg. As the 3D Printer is light weight, it is portable and easy to handle. The 3d model was printed and compared to 3D objects printed on a High Cost 3D printer. The nozzle of diameter 0.4mm used in the fabrication of this 3D printer gives it more dimensional accuracy. The printing material used in the 3D printer is PLA as it provides better strength and operates at higher temperature. The cost effectiveness makes the 3D printer affordable and desirable to more customers. In the era of additive manufacturing advancements a cost effective, affordable and efficient 3D printer can pave way for new opportunities and even the ordinary people could reap the benefits of the same.
References

[1] D. Dev Singh and Gopi Rahul 2018 *Int J of Mechanical and Production Engineering Research and Development*. 8, 263-270

[2] Shiwpursad Jasveer and Xue Jianbin 2018, *Int J of Scientific and Research Publications*, 8, 2250-3153

[3] Ngoc-Hien Tran, Van-Cuong Nguyen and Van-Nghia Nguyen 2017, *Int J of Engineering and Advanced Technology*, 6

[4] Thomas Duda, L. and Venkat Raghavan 2016, *Int Federation of Automatic Control* 49, 103-110

[5] Siddharth Bhandari and B Regina 2014, *Int J of Computer Science and Information Technology Research*, 2, 378-380

[6] Vinod G. Surange and Punit V. Gharat 2016, *Int Research J of Engineering and Technology* 03, 2395-0072

[7] Vinod G. Gokhare, Dr. D. N. Raut and Dr. D. K. Shinde 2017, *Int J of Engineering Research and Technology* 6

[8] Kalpesh Dapurkar, Rahul Singh, Sitaram Gawas, Rahul Ugale and Dipak Shelar, 2019, *Int J of Engineering Research and Technology* 06

[9] P. Dudek 2013, *Archives of Metallurgy and Materials*, 58

[10] Taha Hasan Masood Siddique, Iqra Samiy, Malik Zohaib Nisarz, Mashal Naeemx, Abid Karim, Muhammad Usman 2019, *Second Int C on Latest trends in Electrical Engineering and Computing Technologies*

[11] Alexandru Pirjan and Dana-Mihaela Petrosanu, *Romanian Economic Business Review*, 7, 360-370

[12] Evgeniy G. Gordeev, Alexey S. Galushko and Valentine P. Ananikov 2018, *Russian Science Foundation*