Design, Fabrication and Computational Analysis 3D Rapid Protyping Machine

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ABSTRACT

3d printing is a thriving technology trending today among science community. Lots of research is being done to use the technology to its full potential. 3D printing will continue to provide low- cost effective solutions in various sectors. In this project our aim is to design and fabrication of Delta 3D printer, it mainly aims to manufacturing 3D ceramic objects by successively placing layer on layer. For creating 3D Printer prototype model we used CREO and Unigraphics design software's. To print 3D component G-codes and M-codes are automatically generated with the help of "CURA Software". These G-codes and M-codes will be copied to the SD Card Module for the movement of the extruder. The Arduino code has been Written in order to control the movement of the extruder with the help of Stepper Motors. We wish to construct a universal 3D printer. In this printer, many techniques are employing to print 3D objects like CAD Model Designing, Stereo lithography (STL), Ceramic Extruding, Stepper motor controlling etc. By universal we mean that most of the techniques to print 3D objects can be integrated in one Machine so that a standard is established. We also wish to make the machine Cost effective and most reliable so it will provide benefits for the Society.**Process:** Clay deposition modeling.

Key Words: SD card module, 3D printer, Aurdino, STL, 3D CAD Models.

APPLICATION: Tea cup, Pots, constructing of houses, Prototype models etc..

1.INTRODUCTION TO 3D PRINTER

Making our homes to manufacturing hubs, 3D printing has made lot of changes in making our ideas to real. The word *Rapid Prototyping* is mostly known by the industry people, this is a concept used by the designers to make prototypes in design labs. Rapid Prototyping machines have capability to print any object in the world, this capability of replicating things made them to be on our desktop. Once they were only used by prototype makers in industry, but today it's a pie of every DIY hobbyist and spread over every industry from making food to building homes and cars. Almost every educational institute have one of it. Need for rapid implementation of ideas made to enter them into our workspaces.

Traditional Manufacturing and production processes uses conventional molding or casting process and subtracting manufacturing process. Making of molds is expensive and, these molds need to be replaced with the new ones if there is any change in the previous designs. In contrast,

3d printers use additive manufacturing technique which can be suitable for any kind design changes. Moreover, subtractive manufacturing processes results in wastage of 90% of material used. Whereas additive process uses only required amount of material to print, this make it most efficient way to prototype a design.

The Additive Manufacturing (AM) process, the name itself conveys the process what it does. Process goes by slicing 3d model designed by a designer, then printing the slices and the property of material used to combine it form a 3d model. It's just a 2d printer adding layer upon layer coined the name additive manufacturing and also a printing in 3D. 3D printers are customized prototyping machines suitable to work at any place.

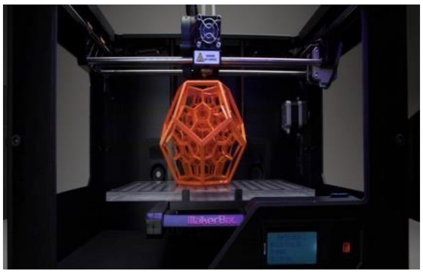

Fig 1.1 3D printer

Stereo lithography is the oldest method developed by 3D system Inc. which uses lasers to harden the resin, laser is moved according to the input. This results in 3d object.

- **Digital Light Processing(DLP)** is the process which uses DLP projectors to project light on the resin, then layer of the 3d image is produced with each projected image.
- **Selective laser melting** technique uses high power laser beams and metallic powder. When metallic powder is exposed to laser it starts melting and forms a solidified 3D structure.

- **Electronic Beam Melting** technique uses electron beam instead of laser beam used in SLM, rest process remains same as SLM,
- **Fused Deposition Method(**FDM) used production grade thermoplastics to build parts. This the one of the most widely used technique because it is less expensive compared to the other techniques. It simply heats the thermoplastic material and extrudes according to the input CAD model provided. FDM is the prime example for usage of additive manufacturing technique.

2.HISTORY OF 3D PRINTER

In late 1980, the first 3d printing technology (additive manufacturing) was evolved which was known as rapid proto-typing. This is first invented by **CHARLES HULL.** This is developed because for any usage of the product as prototype it is very cost effective to develop in industry. So, the idea of inventing this was the major reason. The 3d systems rapid prototyping was introduced in 1987, which was tested and sold which was made by **SLA** (stereo lithography apparatus). Within the same year there was another rapid prototyping machine which used the other technique of printing the object that is **SLS (**SELECTIVE LASER SINTERING**).**This was invented by the scientist named **CARL DECKARD** who was professor at the university of Texas in USA. In the year 1989, there was another prototyping machine which was developed by the **SCOOT CRUMP**. This is the other technique of making the 3d object that is **FDM** (fused deposition modeling).
Additive manufacturing processes for metal sintering such as selective laser, laser melting.in early

1990's the metal working was done by fabric ion and welding which uses automation was the welding purpose and all. But the idea of making the 3d objects was started by many people by making use of the raw material and making the required shapes instead of using the metal as the material.

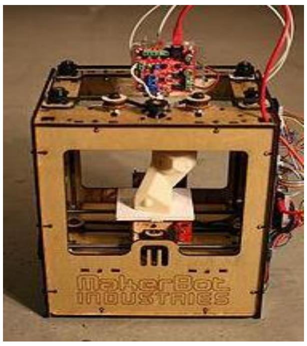

Figure 2.1 First 3D printer made by Makerbot industries

Other 3d printing technologies was also evolving this now a day like ballistic particle manufacturing, laminated object manufacturing and solid ground curing and three dimensional printing. Many of the competitors was growing day by day but the three main companies which was remain until today was EOS, Stratasys and 3d Systems Inc. Europe, 1989 the EOS formed in Germany which was founded by **HANS**

LANGER. After the invention of laser sintering the EOS R&D department was focused on the laser sintering. Today they were one of the company recognized for the quality output of the production of 3d printing objects. Stratasys is one of the company which developed the FDM (fused deposition modeling). This is used by many people now a day by an open source software RepRap.3d systems was the one invented the SLA machine which is one of the largest 3d printing organization.

3. SCOPE OF 3D PRINTER

In recent years, 3D printing has truly begun to capture the imagination of the masses, as low cost printers for personal use begin to make it possible for hobbyists and aspiring designers to create objects designed in CAD software right on their desks.

The Additive Manufacturing, or 3 Dimensional printing, goes beyond the capability of printing in the conventional sense of ink on paper, allowing for objects to be physically printed before your very eyes. 3D printers allow you to create models, prototypes and products out of materials such as plastics and metals. 3D printing allows individuals and companies to rapidly prototype ideas for new products and also promises to cut down costs on the creation of products through savings in supply-chains, product waste and storage.

The benefits of 3D printing are likely to revolutionize many industries. The automotive and aerospace industries benefit from much shorter lead times than with associated traditional engineering methods such as casting or machining, allowing for much faster development and testing of components. In the future, it may even be possible for large components or even entire cars to be entirely 3D printed, as recently demonstrated by Local Motors at the 2014 International Manufacturing Technology Show in Chicago, USA.

The 3D printers has ability to print electronic circuitry which adds a feature for consumers to 3D print electronic products like mobile phones, or the possibility of producing highly customized products based on individual consumer preferences. Google has recently partnered with 3D Systems Inc. to develop Project ARA, a modular phone which will allow customized 3D printed personalized features, which could point to a future of consumer electronics mainly shaped by 3D printing.

The food industry is also set for a revolution, thanks to 3D printing. NASA has invested in this technology in the hope that one day its astronauts will be able to print their food whilst in space. Whilst printers currently exist that allow for 3D creations of foodstuff such as chocolate and pasta, 3D printing may in the future be able to allow fine control of the nutritional content of many types of food, which in turn could help tackle several health problems such as obesity and diabetes or even world hunger.

4. LITERATURE REVIEW

4.1 RESEARCH: Delta analysis and Kinematics of delta printers

Steve graves had completely described about the inverse and forward kinematics of especially delta 3d printers; he is one who had given a clear cut visualization on working of deltabot. Paper also focuses on stabilization of structure for each input and ends with the error calculation. This helped us in understanding the kinematics of printers and give us a way think intuitively about the movement on them.

4.2 RESEARCH: REPRAP project

Open source hardware project accelerated 3d printers use by everyone, as we know open source projects grow rapidly because of number of developers. This project created worlds 1st open source hard and software for 3d printers. They integrate all their electronics onto a board and named it as RAMPS motor shield which compatible for Arduino MEGA. Dev group made it as successful, that they today compete with commercial printers. They added each new printer developed by devsto their inventory and call them as RepRap printers, they are almost of 40-50 printer designs available with a little span of time. This helped us a lot to understand about electronics and gave us clear idea of making a printer from scratch.

4.3 PROJECT: Self build 3d printer

Jonathan kept is an Artist and designer. He designed printer with commonly available components, this helped us to make the printer from components which are easily available. We replicated his design to make our project successful. He is also a creator of ceramic 3d printers, he makes many sculptures they stood best in UK art exhibition of art. Design of printer is easy and this is a delta printer.

4.4 MARLIN Firmware

One of the industry standard Firmware, which is used by almost every commercial 3d printers today. This is complete firmware which has support for Cartesian, delta, SCARA Kinematic motions. It even supports for 49 Extruders which is a full-fledged color 3d printing. It also supports on board LCD and Bluetooth support for your printers. We inherited our code flow and implemented our own logics to make our boot work according to code

5.COMPONENTS OF 3D PRINTER

5.1 ELECTRONICS:

5.1.1 Arduino:

Arduino is the open source platform used for the building electronic projects. This is of both hardware which is a microcontroller and a software. Which runs on the computer to write and burn the code in the hardware. Like the other controllers it does not need the code burner it has the USB cable to get contact with the computer. we can directly burn the code in to the hardware.

We can say Arduino on mini system on a single printed circuit board (PCB) which consists of basic required circuitry and components to use a microcontroller in extreme usage. Where the hardware is embedded with the unseemly easy software, where the targeted users are from any departments and even easily used by a school kid.

The Arduino consists of microcontroller, required circuitry, on board Analog to Digital converters, testing LEDs, USB connect port, and regulator for different onboard voltages like 3.3 and 5 volts.

They are many Arduino boards available according to their special features. They were made for different users to meet their requirements such as some need more number of General- purpose input/output (GPIO's) and some need small and compact designs. Here are some Arduino boards Arduino Uno, Arduino due, Arduino MEGA, Arduino Leonardo and Lilypad. We added Arduino MEGA 2560 in our project for its extended GPIO ports.

We need almost 20 GPIOs to interface all our components. The Arduino shields was also provided to get the extra features to the Arduino boards like wireless network access, cell access and any prototype circuits

- Wireless shield
- GSM shield
- Ethernet shield
- Proto shield

6. PRINCIPLE OF 3D PRINTER

6.1 Design in CAD:

One can implement their ideas by designing them in Computer Aided Design software's. When we save them they form a STL (stereo lithography) file format, which has information of your 3d design as points, which is helpful for reproduction or any other purposes.

We use this generated. stl file for further step known as slicing. Used online CAD stl generator called CREO. Easy for beginners to design things in 3d, it is very useful for new users, GUI based interface help in making the cad files in minutes

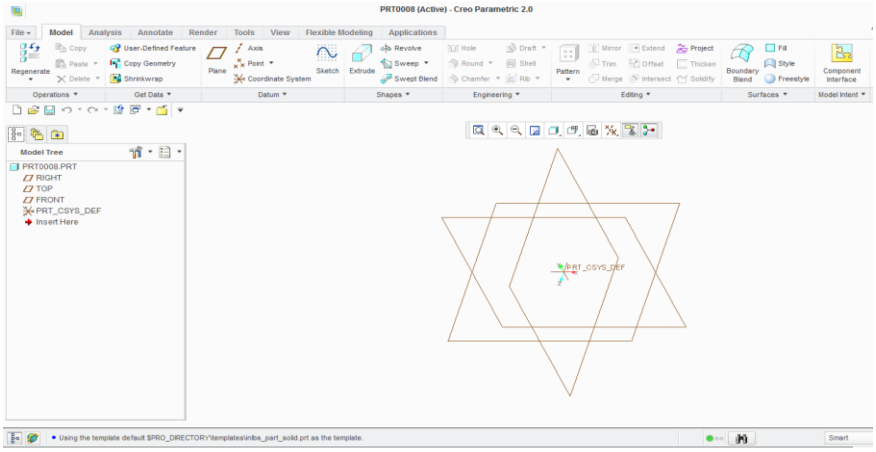

Figure 6.1 CREO CAD user interface

6.2 Slicing:

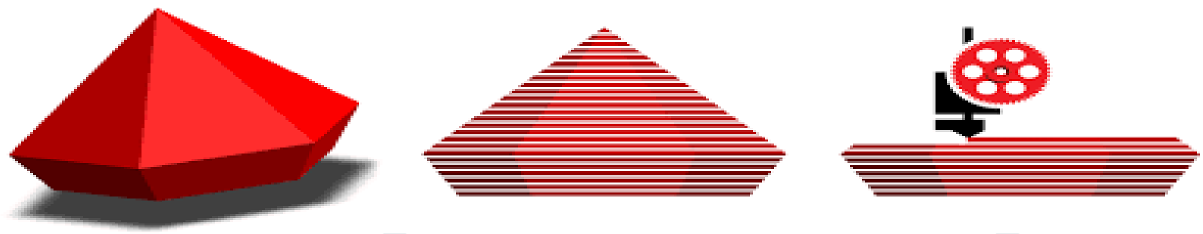

Figure 6.2 Slicing of a 3D model

We were focused on fused deposition kind of printers , where slicing is the most important task to make 3 plane then to a 2d plane and at last to usable Gcode .The slicing technique helps in determining the part to be filled with material also where it should be ideal. This is more helpful for making the trajectory of the extruder end of the printer.

This reduces your complex 3d image to a layers of 2d image, this is helpful in determining in extrusion speed, head speed,temperature and fan off and on.We also have the power to decide size of wall, pattern of movement, thickness and is area where is make you 3d file to meet your printer settings. Such as work area, length of axial rods, max stepping angle. We used **Slic3r** for our project. We also adder our own printer adding new setting some of them delta bot printer has radial work area, we had fixed the axial rod length, constant extruder speed.

6.3 WHY DELTA…?

` It very easy to work with Cartesian coordinates, we fell easy to imagine in with them because we were trained to do that from long time. Every cad software also store same format to store them to a file.

They are many types of 3d printers available according to coordinate system they use. We usually see Cartesian, polar and Delta coordinate system with these printers .Cartesian printers are almost the most used among all of them , as they are easily conceptualize for makers, easy to calibrate and each axis can calibrate independently.

Now let's talk about what it lags, it is comparatively slow as compared with delta. Here are some points which are the reason behind to choose delta printer.

- **EASY** to build than Cartesian.
- **FAST** than Cartesian, moving from point to point.
- **3 Steppers** are enough for complete movement, even same load on each stepper.
- **NO** need of **moving bed**, many printers do it this which makes print to deform to another shape.
- **REDUCED** parts which results in low maintenance.
- **TALL** built volume.

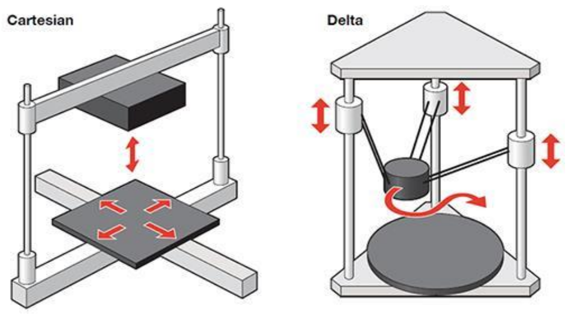

Figure 7.1 Working of Cartesian and Delta Printers

7.1 Introduction to Delta Printer:

The delta is a type of configuration normally used by pick and place robots in industries, this results in a fast and accurate positioning. It has three legged mechanism to reach a circular workspace in a plane . Total work space look as a *Cylinder*.They came around 2005 having principles adopted from industry level delta bots, first delta printer is developed by Kossel. Which is a good move towards large volume and easy build printers. It's also same concept of tri linearization as all three moving axial rods concentrate to reach a point. Best part about delta is that it just needs very small movement when compared with others. This uses three linear axis, where a joining end results in reaching each point of the work space. Three linear axis are kept at each vertex of triangle. Usually for motion in z, we need to move all the axis. Motion in X, Y are done by different motion rate in each axis. Different rate can by Pythagorastheorem.

Figure 7.2 Delta 3D printer

8. DELTA PRINTER KINEMATICS

We used reverse kinematics to derive the equations to the printer, our goal is map each Cartesian point to the motion of three motors. We then making the motion onto center extruder portion. To find the relation between Cartesian and rod movements, we had taken some constants to figure out the location of the required points. Firstly, we get values from G-code, which we print using a delta printer. Our main objective to find the motion of steppers started by making a coordinate system on the printer base and we assumed that each pair of rods parallel to each other. All three set of rods are arranged with a phase difference of 120 degrees. Rods are at 90˚,210˚ and 330˚.

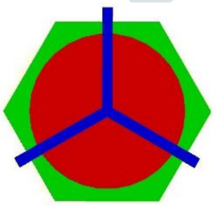

Figure 8.1 Axis of Delta printer

In the above picture blue line gives the position of rods to be placed, which is at the end of it. Now we are done with the arrangement of rods. We calculated them in our code by following lines of code.

```
////////////////////////////////////////////////////////////////////////

const float R = 135 ;

const float one_rodx = R * cos (90*0.0174532); const float
one_rody =R * sin (90*0.0174532); const float two_rodx=R *
cos (225*0.0174532) ; const float two_rody =R * sin
(225*0.0174532); const float three_rodx =R * cos
```

```
(315*0.0174532);    const    float    three_rody    =R    *    sin
(315*0.0174532);
//////////////////////////////////////////////////////////////////////////
```

Above line of code for initialization of your printer work area radius then, finding the values of each center of pair of rods. Then we need to find the distance between every point to the three points that we calculated. We can easily solve this by using Pythagoras theorem below diagram is helpful in visualizing that known length of axial rod, distance between the point and the rod then finding the other side.

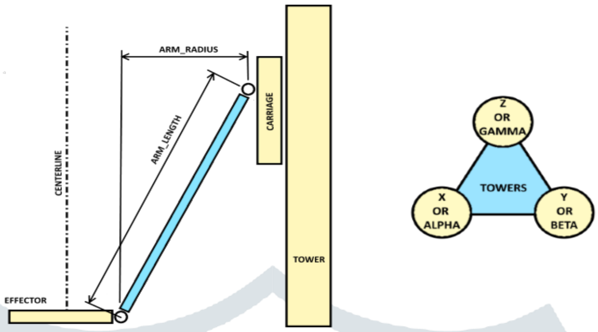

Figure 8.2 Axial rod alignment in delta printers

Above logic is to apply for all three xyz coordinates to get new coordinates points ,which are helpful in finding the distance from linear bearings to the ground of printer, Then we find the required amount of motion from subtraction the total length.

9. PROCEDURE FOR DELTA 3D PRINTER

9.1 Conversion of xyz to delta:

- Finding distance from point to center of pair of rods.
- Calculating distance from bottom to extruder.
- Subtracting from total height to get the delta coordinates.

9.2 Motor conversion:

We have done a quite good effort to run all the motors simultaneously. We converted all values acquired from Gcode, We normalize all the values to the scale of 0-1.where all the values are divided by maximum value of the three coordinate. Below steps could help to get make the pattern of energizing the coils of steppers.We will get the values from G Code, information of required movement in each axis.Then converted by xyz to delta function which are the required movement for the each motor to move.

9.2.1 Implementation:

Distance

(pow(pow(a-c,2)+pow(b-d,2),0.5));

Pythagoras theorem

xmov=pow((pow(axial_rods, 2)-pow(d1, 2)), 0.5);

9.2.2 Algorithm For Motion Trajectory

Input as values Xout, Yout,and Zout which are values generated from xyz2delta function. Aim that, we need to start all our motors to run at single point of time and end their motion at same time. Some steps should be missed in middle with equal gap for each missing step. We have a constraint that only a motor can run at a time.

1. Finding ***Maximum***of all three values

2. ***Normalization*** Dividing max value with all,scale reduced to (0-1).This give us value having 1 is going to run all the time and less the value need to move for less amount of time.
3. Finding ***Off time*** the value for non-motioni.e., just subtract the one from the previous value.
4. Dividing that with one gives the number of steps for each missing step is found. i.e., if the value says that motor should ***next miss step*** for each 7 steps. This makes our motor to on at same time and off, covers required distance.
   Importance is it that it creates same rate of change motion in each axis as almost equal to a derivative function.

9.2.3. Implementation:

Finding of delta value to ***next miss step.***

x_=1/ (1-(x/maxvalue))

Check code for is this step is your ***miss step.***

for (float i=0;i<=maxvalue;i++)

{ if(i!=x_1)
motorx(direction_x); else
x_1=x_1+x_ ;

}

9.3 Calibration:

This part is most important in case of calibration of printing. It helps printer to move its end effector to home location. This helps to make us to estimate the trajectory from home location. This helps us know the location of the end effector.
We used limit switches to find the end of each axis .It is polled every time, when limit switch is set then we get to know that it reached the end of axis.

>> Start of motor.

>>Polling of limit switch.

>>When it is set then stop the motors.

9.3.1 Implementation:

while(stopendx==1)

{stopendx= digitalRead(limitx);}

10.SOFTWARE USED FOR GENERATING G-CODES

10.1 CURA 2.3.1:

Step 1: open Stl File which is at the left of the window

Step2: load the .stl file, you get a preview at left corner of window. You can select your slicer engine according to your requirement weather it may be solid or light or hollow. Automatically it will generate G-code according to the parameters.

Step 3: After completion of slicing ready to save option will be highlighted in the desktop just by clicking ready to save G-codes and M-codes will be saved In notepad

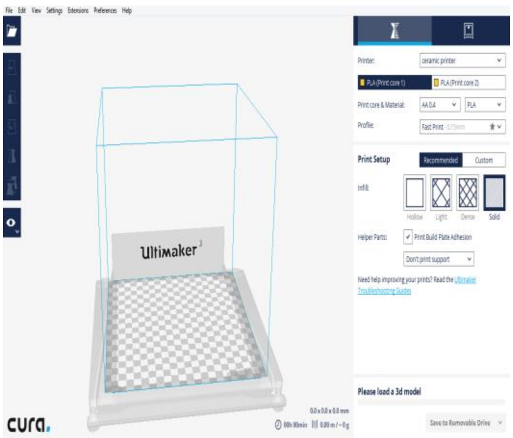

Figure 10.1 User Interface of CURA 2.3.1

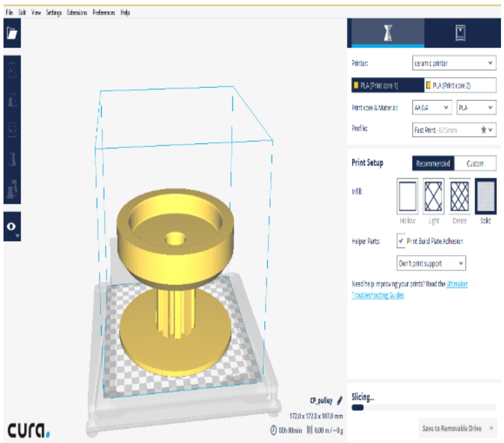

Figure 10.2 Loading. stl file to the software

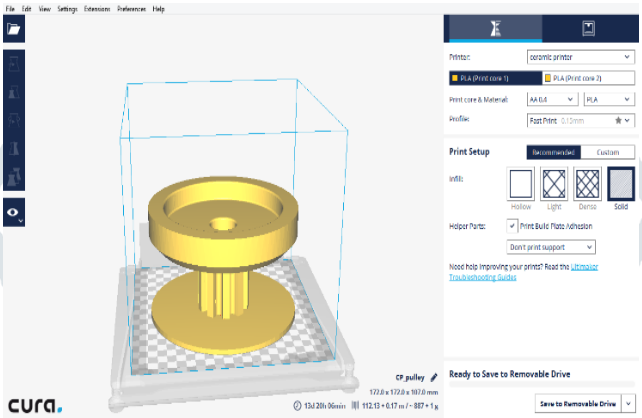

Figure 10.3 Ready to G-codes and M-codes files

11 WORKING OF 3D PRINTER

11.1Flow Chart Diagram:

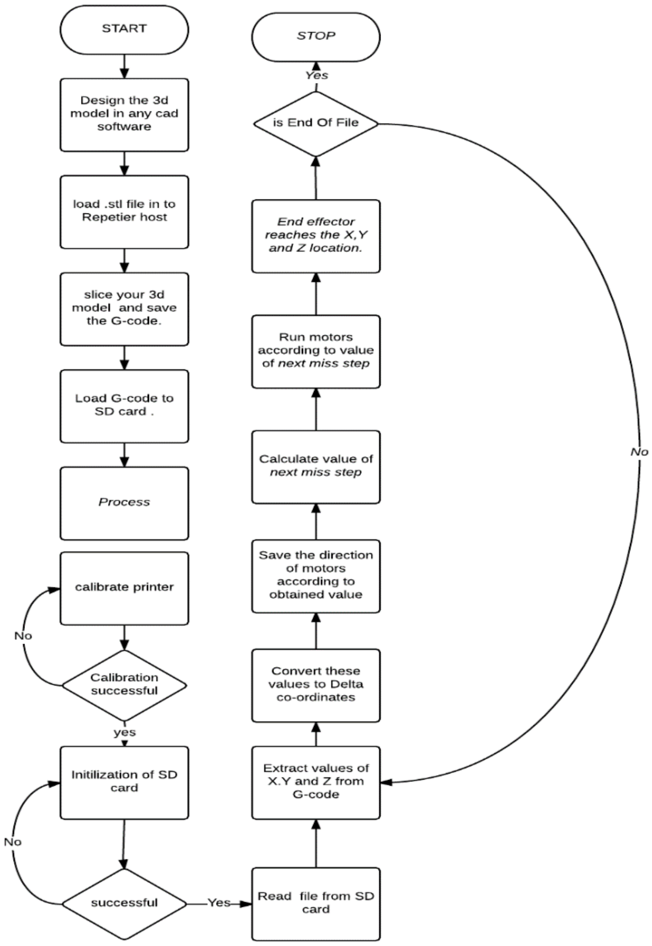

Figure 11.1 Flow Chart

12 DESIGN of 3D CAD Models and ASSEMBLY

12.1 Designs:

We have used the following designs in making the structure of the printer.

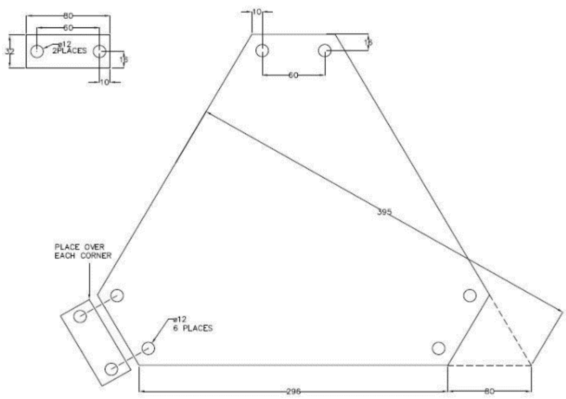

Figure 12.1 Design of Base and Top of printer

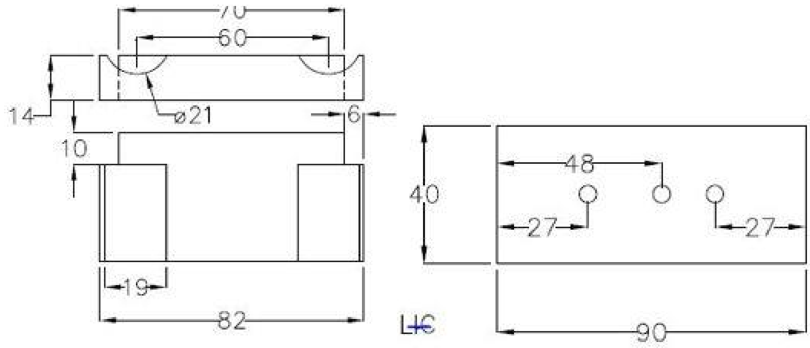

Figure 12.2 Design of Linear and Circular Bearing holder

12.2 Assembly of the printer:

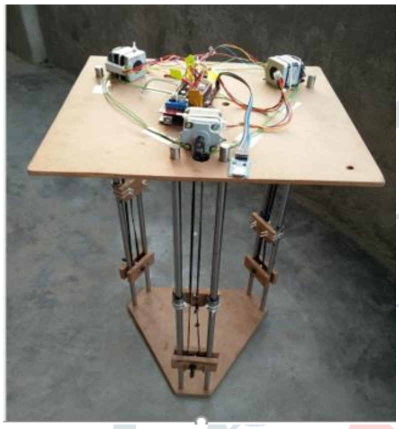

Figure 12.3 Assembly of the printer Figure 12.4 Assembly of 3D CAD Model

CONCLUSION AND FUTURE SCOPE

In our project we tried to mimic the functionality of full-fledged commercial 3d printers. Our main goal is to cut down the cost of printer. Our research in finding best of structures gave us good knowledge about them. We then end up our things by choosing delta structure. We get know about complexity of its kinematics, our hard work results in converting the concepts to code and then to a working model. We added features like calibration that makes our printer to calibrate in seconds.

We had succeeded in making a low cost printer using delta configurations that, our printer cost only around Rs.10000. We also moved down our precision slave to micrometers.

Future scope:

Today we see plastic and clay are used widely for making the products. We expect the teleportation of object is achieved by recognizing molecules in an object breaking down into atomic size and reshaping them back they appear.

Many doctors are using printers to make organs, making them from cell level. This make humans to replace their damaged organs with the new one. They also moved to consumer user products like dresses, shoes and even jewelry.

We also heard the news about building homes with giant mega cement extrusion printers. This would lead to interesting stuff like sending printers to space, printing colonies at moon and mars. It is best example of bringing your dreams to real word, if you can make an objects in cad they bring them to real word.

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