UNIVERSITY OF NAIROBI

DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING

DESIGN OF 3D PRINTER USING J-HEAD V6 BOWDEN HOT END 0.4MM NOZZLE FOR 1.75MM FILLAMENT AS AN EXTRUDER

BY:

ISHMAEL MWANGI FRIDAH

F17/35519/2013

SIGNITURE: ……………………………. DATE …………………………………..

This research proposal is submitted with my approval as University Supervisors**:**

PROJECT SUPERVISOR:

MR. SEGERA RENE DAVIS

SIGN ………………………………………DATE…………………………………

Engineering project report submitted in partial fulfillment of the requirements for the award of the Degree of Bachelor of Science in Electrical Engineering in the University of Nairobi.

Declaration

NAME OF STUDENT: ISHMAEL MWANGI FRIDAH

REGISTRATION NUMBER: F17/35519/2013

COLEGE: Architecture and Engineering

FACULTY/ SCHOOL/ INSTITUTE: Engineering

DEPARTMENT: Electrical and Electronic Engineering

COURSE NAME: Bachelor of Science in Electrical Engineering

TITLE OF WORK:

1. This report has is my original work and has not been published or presented for an award of degree at any University there before. Where other people's work has been used there been acknowledged and referenced in accordance with the University of Nairobi requirements.
2. I understand what plagiarism is and am aware of the university policy in this regard
3. I have not sought of used the services of any professional agencies to produce this work.

Sign ………………………….

Date………………………….

Dedication

I dedicate this project to almighty God for making it possible for me to do this project

This project is heartily and sincerely dedicated to my beloved parent and siblings and friends for their support.

Acknowledgment

Would like to sincerely recognize the support and contribution I have received from various persons and institutions that have ensured the successful completion of this project. First I would like to sincerely thank my supervisor Mr. Segera Rene Davies for his professional guidance while doing this project. I appreciate it very much. Secondly would like to thank the science and technology park and fab-lab community for providing me with the resources to work on this project. And above all, I give God the honor for wisdom strength and good health that he gave to me in order to successfully complete this project.

Abstract

A three-dimensional printer (3D printer) is a machine that allows creation of physical objects from a three-dimension digital model typically by laying down many thin layers of materials in

succession by additive manufacturing. Additive manufacturing can be divided into the following types of printing, fused deposition modelling (FDM) a common additive method used for modelling and production application, stereo lithography method (SLA) additive method of manufacturing that employs a vat of liquid ultraviolet curable photopolymer “resin” to build parts’ layers one at time. Selective laser sintering (SLS) additive manufacturing that uses high power laser to fuse small particles of plastic metal ceramic among others into a mass that has a three-dimensional shape, it’s the most additive technic most of the 3D printers headed to because it doesn’t require special tooling as traditional method. There many method being used in the 3Dprinting industry for production many of which are being explored and applied differently in areas such as prototyping, specialized parts such biomedical science , hobbies and home use, future application such as medical building among others

Recent development on additive has focused on building better, faster larger and more capable machine and extending to the range of new materials. As this is being done, also industries having in mind that capabilities of 3D printer will not be meet by simply building bigger and better machines but understanding the key to unlocking the next industrial transformative understanding of which technology benefit in AM technology. In other words, ask not what this machine can do but what the machine can do for you. The trends that most companies are trying is to increase the machine automation thus having less and less human interaction from the design phase to printing to manufacturing of the 3d object phase. Another big trend developing is the metal 3D printing both in lowering cost and increasing adoption. It has become more and more important in in solving specific problem and challenges in manufacturing and creating customized complex end use products. This is realized by ACTech Company, a German manufacturing company specialized in metal 3D object printing.

However, in all this accomplishment three-dimensional object is facing many problems when it comes to manufacturing this printing machine. Some of the most problem include

Cost of the 3D printer. Due to expensive parts and high cost labor involved in manufacturing, it lends to this machine becoming expensive to own one. The ones that are available at a less price have a poor output in terms of prints and objects being printer

Resolution of the prints usually maters when it comes to prototyping. Most companies spend lots time trying to improve on this, trying to make the object look as real as possible.

Cost of materials, quality and complexity comes at cost thus it is not surprising to see system equipment and cost of materials to be reported as a burrier in 3d industry

Part quality as mentioned earlier involves strength integrity aesthetic among others, is a challenge that many manufacturers face. While others are doing fine other haven't moved past prototyping to part of production trying to solve this part.

Limited selection of material as most printers use limited material available and not expanding thus ending to use old fusion methods.

Technology limitations in the available for production and manufacturing in an area or even the country, this may limit in getting design majorly in the next level

Difficulty in scaling operations. This comes due to lack of funds to move to production or lack of the idea of scaling up from prototype this leading the idea to stagnate and no moving forward or even the idea dying away.

Printing speed, this is determined by how the complex the design is and how big the design is. A smaller object would print fast while a bigger object will take more time to print. Also the printer set up would also determine a lot when it comes to printing fast. Also the arrangement of the printer and also its calibration would determine how fast the printer would print and how fast.

In this project we look building a printer that is less expensive form both production and acquiring of parts. This is to be achieved by using locally available materials and to some extend recycling of parts from already used machine which are not necessarily 3D printers. To reduce cost of manufacturing we are also looking to partner with local production companies that have that have spaces to do this process

We also seek to improve the printing quality of the object or CAD object to be printed. This is achieved by designing of a functional 3D printer that uses a nozzle of 0.4mm to print a quality object. And in doing so also seek to improve the printers speed by reducing the steps of calibration of the machine.

Table of Contents

Abbreviations and Acronyms

3D object – three-dimensional object

CNC – Computer numerical control

FDM - Fused Deposition Modeling

CAD - Computer Aided Design

AM - Additive manufacturing

List of figures

CHAPTER ONE

INTRODUCTION

1.1 Background

A 3D-printer uses additive process, one may compare 3D printing to milling which uses a subtractive process that is taking away the unused part of the material used. Using an additive method (adding mass to form a model), it's able to use a variety of materials such as plastics, polymer, metal, and composite materials. 3D printers have improved life, allowing many types of products to be designed faster, and more effective and easier right where they needed to be. It can be transformative in the prototyping world, introducing it at the electrical and information community level offers the potential to localize manufacturing, as well as the idea of CNC-milling machines. The technology used is fused deposition modeling. Scott Crump, the founder of FDM technology was instrumental in its development and revolution. The main technology used in FDM technology is the thermoplastic example include wax nylon ABS plastic and PLA plastic.

In printing industry, most common printers are the office type for duplicating documents and allowing to copy a two dimensional objects. As technology is advancing most people found the need to move from 2 dimensional printing such as paper printing into a physical form that would enable visualize things clear. To some extend this technology has been adopted in the learning institutions for education purposes which is highly appreciated. Moreover as it is for other office printers, also this can be potential form of income to most who uses this form of technology. Advantages are unlimited it’s upon the user to tap into the correct potential and utilize it.

1.2 Problem statement:

According to the research, the cost of one 3D printer for use of rapid prototyping range from kshs80000 to as high as kshs800000 or higher. The variety of printers available locally is limited and the ones available are at high-end prices that cannot be afforded.

However, for rapid prototyping printers are supposed to be locally available for both viewing and purchasing at affordable cost

In this research, we seek to build a low-cost 3D printer using J-Head V6 Bowden hot end 0.4mm nozzle for 1.75MM filament as an extruder. This is to improve the quality of 3D printer outputs using locally available materials as well as reducing the time of troubleshooting. This thus creates a reliable workflow for the end user.

1.3 Objectives

From the problem statement, the objective of this research, it was conclusive to work with this targets for[r this project. They include the following:

- Build a cost-effective 3d printer using locally available recycled components both for mechanical parts as well as electronics
- Analyze the additive process of manufacturing techniques available in the market facing the manufacturing industry and innovation by studying the research communities in the context of these technologies in particular reference to the printing materials as a function of possible applications
- Understand the working of a 3D printer and the types that are existing in the market
- Manipulate the printer be able to print a visual 3d objects for prototyping of objects such as small casing or housing

1.4 Justification

Use of 3D printer makes it possible to increase rapid prototyping at the lower cost. One can model any layout of a device first hand and can be able to correct any mistake of any model system being presented as a prototype and this enables the user to update any system being built at a cost-effective and at the faster rate. Thus cost effective thus building a cost-effective 3d printer will enable rapid prototyping at first hand reducing the cost of the user both at purchase and at use thus ensuring efficiency effectiveness and convenience at usage

1.5 Research

This researched was majorly based on the consumers as the user group. Based on this, the evaluation process is based on:

- Hardware familiarity with the 3D printer and its specification such as print time, resolution of print that is how print looked
- Cost of purchasing printer local and as well importing of the same
- Availability of the printer for consumer; both the 3D printer and the other tool of use such as its material
- The efficiency of use: how easy is it to use, for 1st timers and which software interactions are available for the same.

1.6 Scope of work

The project involves setting up a printer with x y and z-direction for printing 3D objects controlled by Arduino mega as its brain. The printer is limited to 21cm by 21cm by 27cm in height in size of printing objects, any object bigger than this the printer cannot handle. The printer is also limited to use of recycled objects which are prone to failure at any moment of use. C-programing language is used to create a program for running the printer. The printer will use only the two printing materials PLA and ABS for this experiment of the size 1.75mm. Printers described here includes what the writer has interacted with and not more.

1.7 Organization of work

Chapter one: an introduction of 3D printer concept is done here, the problem statement is also done here entailing the need for a cheaper and affordable 3D printer.

Chapter two: A detailed literature review of the existing additive process. Different types of printers are reviews in details having their functionality, effectiveness and cost in the market

Chapter three: procedural of the approach is outlined in this area detailing the mechanic's electronics and also the program involved in the operation of the 3D printer entailing the programming language involved

CHAPTER TWO

LITERATURE REVIEW

A 3D printer is a machine that allows the creation of a physical object from a three-dimensional object (3D object) by laying it down many layers of material in succession. This is aided by use of Computer Aided Design model to perform rapid prototyping. While traditional 2D printers use ink to print digital information onto paper in two dimensions (x and y-axes), 3D printers have the ability to print three 3D objects (x, y, and z-axis)

The processes of 3D printing modeling involve additive manufacturing methods. This is achieved by the use of software such as SolidWorks, AutoCAD or Maya which are industry standard for designing or amination software. Then through a slicer (program) which divides the model into cross-sectional regions, interpreted as g-code, the printer is able to interpret the object coordinate and print the model. To gain a better understanding, one may compare 3D printing to milling, which is a subtractive manufacturing method. Rather than take away from a model, a 3D printer adds mass to form a model. Utilizing cutting-edge technology,

It has the ability to create a model using many types of materials, such as plastic, polymer, metal, and composite materials. 3D printing is currently being used in many professional career fields, especially those associated with engineering and biology.

In additive manufacturing, [1] [2], a term used to describe a set of technologies that create objects in 3D by adding layers upon layers of materials, A 3d printer uses this technology for printing objects, that is an additive process, one may compare the 3D printing to milling process which uses a subtractive process that takes away un-used part of the material used. Some of the technology adopted in 3D printers that are recognized include fused deposition modeling (FDM), stereo lithography(SLA), selective laser sintering(SLS),selectivelasermelting(SLM),and digital light processing (DLP), but new additive processes continue to be developed and commercialized (Petrovic et al., 2011).

In the printing process, printing material such as PLA or ABS is heated up, thermoplastic material, to a semi-liquid state usually at a temperature 110 degrees. Then the 3D printer uses digital modeling data from CAD files to create a 3D object layer by layer. These layers are usually created using software which slices the CAD files into layers that are a fraction of a millimeter. The thermoplastic usually has a filament size in diameter of around 0.25mm to 0.75mm which benefits heat transfer and it’s easy to move with a print head that moves both in x and y directions. After each layer is printed, a piston moves the extruder up, in the z-axis, the distance of the thickness of the printed layer. The process repeats itself until the entire object is printed.

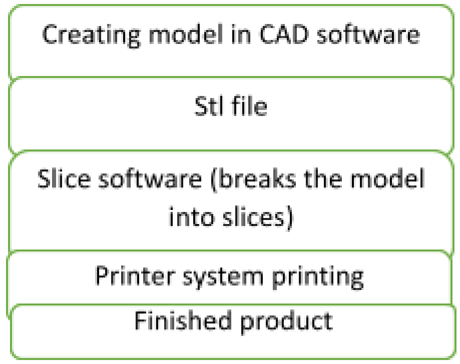


Figure 1: showing the steps in 3D printing process

Table 1 showing technology and material used for 3D printer

Types	Technology	Materials
Extrusion	Fused depositionmodeing(FDM)	Thermoplastic example PLA ABS, eutectic metal edible material
Granular	Direct metal laser sintering(DMLS) Electron bean melting (EBM) Selective laser sintering(SHS) Selective laser sintering(SLS) Powderbed and inkjet head 3d printing, plaster-based 3d printing	Any metal alloy Titanium alloys
lamination	Laminated object Manufacturing(LOM)	Paper metal foil plastic film

Light polymerized	Stereo lithography (SLA) Digital light processing(DLP)	Liquid resin

2.1 COMMONLY USED PRINTERS

There are different types of a printer of printers in existence that uses the same above process, some using complicated technology and some using simple technology depending on the manufacturer. Some of the printers in existence include:

1. Maker-bot replicator 3Dprinter
2. XYZprinting da Vinci Jr
3. MakiBox 3D printer
4. Solidoodle 3D Printer Printrbot Jr. (v2) 3D printer
5. Raise3D N2 Plus
6. XL 3D Printer Assembled
7. Z Corporation 3D Printing Technologies
8. Original Prusa i3 MK3
9. Zortrax M300
10. Rize one 3D printer
11. Uprint SE plus

Some of the printers descriptions are as below (based on the printers I was able to interact with) this is based on the size of the printer, print quality, size of the filament used and the cost of the printer:

2.1.1.Maker-bot replicator 3Dprinter

Maker-bot replicator [3] uses an additive process when it comes to printing. Major specifications we are going to look at from this printer is the printing time, the quality of the print that is resolution and the downtime of the printers, as well as the portability of the printer. The maker-bot [3] works on the fused filament fabrication technology, with a build volume of 11.2in length x6.0in wide x6.1in height. The printer has 3 resolution layer setting, either high (100 microns) medium (270 microns) and low (340 microns). The resolution in determining the quality of an object and how smooth it appears. Compared to other printers it produces much fair quality prints out for modeling. The filament diameter if the filament used by this printer is 1.75mm with a nozzle size of 0.4mm.The software used by this printer is Maker-bot maker are bundle 1.0 which is designed to accept the file types of the format .stl, .obj, .thing which is supported all across Windows, Linux and MacOs platforms.

The physical dimension of the printer and the weight matters because of the movement and portability of the same. Its dimensions are about 19.1 inches x 12.8inches x 14.7 inches with a weight of 11.5 Kilograms. To control the printer chose a file of your favorite design then using the control panel which allows you to drag and drop files right onto the virtual build space After choosing your design, material, and color -it's time to print.

The control board in use is called the might board on which it's designed to take their own software for controlling the 3D printers. The software is known as Replicator-0040-installer [3] and firmware is Mighty Board Firmware-master [3]

Figure 2: showing Maker-bot replicator

2.1.2. XYZ Printing da Vinci Jr

XYZ printing was founded in 2013 [5], with an objective of bringing effective printers to consumers and small businesses around the world. The build dimension of this printer (large) 46.8 x 51 x 55.8 cm with an average weight of 24.5kg. The print size is approximately (20x20x20cm) which is 20 percent larger than what other 3D printers in its class can print. This is a plug and plays printer since it requires no assembly or equipment making it one of the few genuine plug-and-play 3D printers available to consumers. User-Friendly Filament with easy-to-install filament cartridges users can easily refill the printer or switch colors.

It has some automatic software upgrade from the manufacturer and this makes it easy to print since there is an open source free database, it has a printing speed of 150mm/sec with a resolution of approximately 1.5. This makes it produce fairly good prints as compared to other types of printers

How is a function is by either Access the XYZ cloud to find a design or upload a .stl or XYZ file of your favorite design then using the control panel which allows you to drag and drop files right onto the virtual build space After choosing your design, material, and color -- it's time to print.
XYZprinting da Vinci Jr uses Mainboard for da Vinci 1.1 plus with wi-fi. The software they are using is designed by XYZprinting Company.

Figure 3: XYZ Printing da Vinci Jr

2.1.3. Uprint SE plus

Sprint [6] uses a higher technology for printing than previous two printers. It brings models into reality by use of print support which wasn't found in the above two printers. The printer has a build size of 203 x 203 x 152 mm bed size with the overall size of 635 (w) x 660 (d) x 940 (h) mm and a weight 94kg. It comes with specific material to use from the manufacturer of a variety of colors. The Sprint has a resolution of 10microns. This means that the prints are good quality than the other two printers described above. This is the highest resolution. Inside the 3D printer, plastic filament travels through a tube to the print head, where it's heated to a semi-liquid state and extruded with precision. An optional second material bay provides twice the uninterrupted print capacity. Modeling bases provide a smooth surface on which your models grow. Once printing is done, you simply take the recyclable base out of your 3D printer and snap off the model.

Figure 4: Uprint SE plus

2.1.4. Generic 3d printers

This is open source printer (printers that are open to the public for building and prototyping collaboration) [8]-[12] also known as DIY printers that are they are left to the public to develop. They work similar to other printers only that most of them if not all, have been working to improve the printing resolution, they also brought about to reduce the cost of the printer and as well the printing of models
Most range about 100 to 150microns of resolution. Their size range between 46.8 x 51 x 55.8 cm and 50 cm x55cm x 60cm higher or below. Control board in use for this DIY printers include Mightyboard, Duet 2 with Wi-Fi, MKS Sbase, ANET MainBoard 3D printer controller Arduino board plus the Shield.The main Firmware in use by this printer is open source which includes Marlin software, Replicator-0040-installer and others which different companies are making the open source. Some of the generic 3D printers available include:

MakiBox 3D printer

Solidoodle 3D Printer

Printrbot Jr. (v2) 3D printer

Raise3D N2 Plus

XL 3D Printer Assembled

Z Corporation 3D Printing Technologies

Original Prusa i3 MK3

2.2 Merits and demerits of using 3D printers

Customization of products is a major advantage in 3D printing in that with just a raw material a blueprint and a 3d printer one is able to make any shape of any kind simple or complex it is. This is majorly demonstrated by car industries where complex replacement parts are able to be manufactured at fast hand and be replaced [12]

Constant prototyping and increased productivity for variety of products for real objects or for a small scale version of real objects in less time than using conventional method. This helps the designer to improve on the prototypes for a line of production. Through this, a producer or a manufacturer is able to improve on the quality of products for final manufacturing.

Affordability, the initial cost of setting up a 3D printer facility is initially very high, however it is much cheaper compared to labor cost and manufacturing cost of producing or manufacturing products using 3D printing technology equal for a small scale manufacturing.

Storage is much save in that product is printed when needed as compared to traditional method where products had to be manufactured and stored as they wait to be used. This would lead to wastage or damage of product and rendered useless.

There many other advantage associated with printing such as in medicine[13] where organs are being replicated, increased in job opportunities in that people use this technology for self-sustainability amongst others.

Limited raw materials, Traditional manufacturing of products has an enormous range of raw materials that can be used. Presently 3d printers can work up to approximately 100 different raw materials and creating products that uses more raw materials are still under development.

Limited size of objects printed with 3d printers is currently limited since there is no manufactured printer able to print size near to a wall of a house or, in the near future however large items such as architectural structures can be created using 3d printing.

Violation of copyrights is the biggest disadvantage of 3d printing is. Anyone who is with a blueprint will be able to counterfeit any products easily. It will become more common and tracing the source of the counterfeited items will be impossible or nearly impossible. Many copyright holders will have a hard time protecting their rights and businesses producing unique products will be at a disadvantage.

2.3 Part description

Working on the printer it needs to be understood that it's majorly divided into three major parts:

1. Electronics:

This involves the circuit that controls the whole 3D printer. In this case, what is going to be used is as below:

Arduino 2560, with RAMPS (motor drivers), direct drive extruder, and stepper motors, their interfacing with drivers and power supply (SMPS). Stepper motors are needed to be precisely interfaced with Arduino 2560, with no delay between any of the 5 motors to prevent misalignment

Electronics that include for the extruder are as follows:

1 x 100k Semitec NTC thermistor, 12v 40W heater cartridge, 1 1x12v 30x30x10mm fan, 1xhigh temperature fiberglass wire for thermistor (150mm) 2x0.75mm ferrules- for solder free wire joins

Each of this electronics have very essential function in the functions of the build of the 3D printer movement during the printing process.

2. Software:

A program needs to be written for that sits on the Arduino, the brain of the printer that enables the interpretation of CAD design tools and slicer tool. 3D object designing tool is open source software and needs no special license for its use and distribution. This CAD file is not machine readable and thus needs an intermediate software, slicer. This intermediate software deals with extruder heating, layer thickness, and calculates coordinates in three axes for the motor ultimately creates a '.stl' file, which is machine readable by Arduino

3. Mechanics:

This is the mechanical parts of it. Majorly involves building the part that can hold the electronics either by metallic or chassis designed. This also involves integrating guide bars both in x y and z directions. The majority of the project involves the mechanical parts designed for the metallic bars and with the number of guide bars and having threaded rods, bushing for the motion along any single axis a belt and a pulley mechanism for controlling a position of the extruder and bed in both x and y directions. Other complementary components include washer's nuts and screws among others.

2.3.1 What to look for in a 3D printer

Apart from the normal appearance, physical appearance of the machine, electronics the user or the consumer needs to know what really to look for when a 3Dprinter. The outside appearance doesn't determine how the machine will work or doesn't determine how the model appearance will appear. Some maybe from the software they are using to design or for slicing the material for example repetier-host which you're able to set the printers hating of the material and be able to integrate with the software feed to the machine and give out a molten.

Printers speed, this determines how fast a model is printed. This is done through the software under setting. Essentially the lager the object, the more complex its form and the greater the 3d resolution the longer it will take to create your 3D printed model. Additional to the impact of the objects characteristics on the print speed, print speed is also determined by the mechanics of the 3D printer itself. The print head or the extruder exists in two moving states one when it is actually printing and one when it d moving to a new states, one when it's actually printing and one when its moving to a new area of printing. The speed is defined in mm/sec and when comparing 3dprinters this is a major part to look for and from which level does it go at highest speed.

The quality of the end product[14] is determined largely to a large extend by the printers resolution. 3d printer has two measures of resolutions. In the horizontal plane, along the x y axis, or sometimes called the features resolution determines the level of detail that your finished object will have. The vertical resolution, the z axis can have a big impact of the smoothness of the finished object, the lower the resolution the bigger the steps or the rougher the surface will feel. The range of resolution is around 100microns (0.01cm) or 200microns (0.02cm). It's of high importance to bear in mind that the greater the resolution the more layer are deposited and the longer the print time. Also its god to know that the nozzle size also determines resolution, how thin a bead of plastic one can extrude. Thus printers with good resolution definitely gives good products and this is majorly one factor that determines it.

The maximum size that a 3D printer can build is determined by its build area. For instance uprint 3d printer has a build volume of 20.3cm x 15.2cm x15.2 cm. this dimensions refer to X, Y and Z planes of the build area. 3d printer with large print bed cost expensively. 3d printed parts are often build from different smaller parts so even if the final product is large the individual part may be relatively be small and since large objects take longer time to print. Also when it comes to printing and when considering bigger print bed, we consider the type of material that will be used and how long does it take to heat the bed. And this is added to the print time of the object when it comes to printing.

The material used or "ink", comparing it to a normal paper printer, for a 3dprinter is called the filament. The filament passes through an extruder where it reaches a temperatures that melt the filament.as the melted filament is laid down on top of itself it builds up a 3d object. For more multiple extrusion, multiple extruder 3d printer machines are available if one is printing a complex design involving multiple colors. This has its own advantages in that different materials can be used and the print time can be reduced.

All the above requires learning to be able to calibrate and to be able to print an object. It doesn't mean that that building a3d printer is final, it requires maintenance to determine whether the above are maintained at a constant operation and this is where learning of the calibration of the machines comes in. However, most companies make sure this is the area where the user never gets in and when needed to calibrate the company is consulted.

2.4 Inferences

Table 2 showing some of the findings based on the research done.

Name	Print quality	Print time	Efficient	Cost in $	Availability	Downtime	User Friendliness	material	Material availability
Original Prusa i3 MK3	50% perfect	-	70	1208	Not Available	Less	Easy to use	PLA ABS	Available
MakerBot Replicator 2	50% perfect	1hr 40 min	60	2199	Not available	less	Easy to use	PLA ABS	Available
Solidoodle	50% perfect	-	60	300-500	Not available	high	complex		Available
XYZprinting da Vinci jr	50% perfect		60	300-400	Not available	high	complex	ABS	Available
Zortrax M300	80% perfect	-	70	2990	Not available	high	Complex		Not available
rize one	Almost 100%	-	90	26000	Not available	high	Complex to use		Not available
MakiBox	40% perfect	-	30	300	Not available	less	Easy to use	PLA abs	available
Uprint SE plus	90%	50 min	90	22000	Not available	High	complex	PLA	Not available

Efficiency is given in terms of percentage which describes the work output the machine gives the quality of the print. A good number of printers are efficient and this means high cost of 3D printer that is the higher the efficiency the higher the cost. An example is the Uprint SE plus and Raze one, this two machines are efficient giving an average of 90% efficiency this meaning that the print quality is good. This applies only on high end printers, looking at low end printer which are generic, we find that the print efficient is much less ranging from 50% to 70% efficiency which means that their prints are fairly good[14].

Downtime describes the time of failure and the time of operation. This includes the time of repair when the 3D printer breaks down, getting the materials for printing as well as getting the spare parts for the printer, are they locally available or you have to outsource for the from the producing company. Some of this was observed in Uprint SE plus and raze one which you have to buy most parts from their company as well as printing filament.

Availability, in this case, has been used to describe if the printer is available to the local market. This depends on the technology of the printer and the complexity. This will highly determine the availability of it. For instance printer that require a specified printing material would not be available easily. The users would not see the need to use it as long as there is a complex nature involved.

Print quality, this describes the smoothness or the appearance of the printout compared to the original

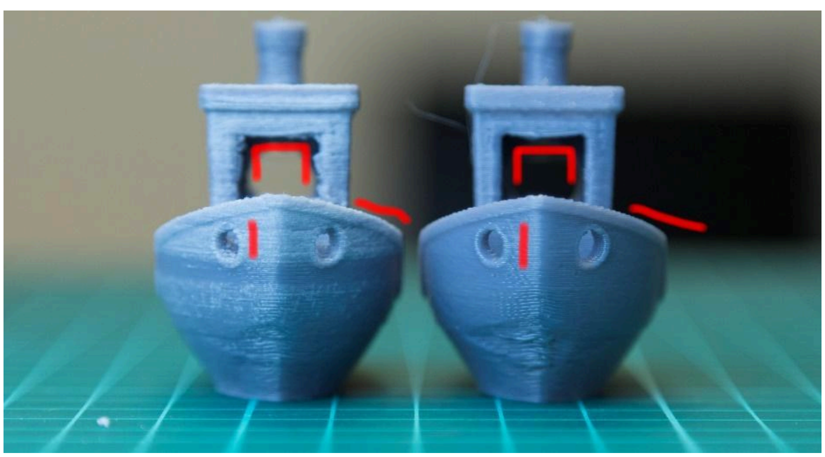


Figure 5: Comparison of a good print and a bad print

This is majorly determined by the resolution of the machine. Depending on the printer build on the x, y and z movement step movement on either direction. The step movement hence determines the resolution of the printing and how fine the object will appear [15].

Print time ,time is taken to complete printing of an object(same load), (NB: it was hard to know specific timing for each machine because of availability) some printers use support materials thus making them take more printing time for a small object also, the time is taken for heating also adds up to the print time. Depending on the complexity of the build and technology used by the printer some may print very fast for similar object. For do it yourself (DIY) printers speed can vary and this is highly dependent on the integration of the components of different printers

The key point of the hardware specification includes filament material (plastic, metal, ceramic, among others) durability size of the build peripheral technologies and ease of use. Do the user understand the design requirement to address any of the hardware specs? How versant is the customer to the design so that they can to solve the downtime of the machine, how complex is it? This will determine how well the end user will end using the machine. If the user doesn't understand the machine and how to use it there is no way they are going to buy it or even get interested to using it.

Consumer 3D printer currently ranges from \$300 - \$3000 and in the business space printers cost of one printer range from \$500-\$80000. If printers are often used to facilitate the research and development process, how much users are willing to pay for these technologies? [16](Prices are indicated in US-dollars)

Most user opt to buy low end printers that are easily accessible to the market and that are efficient to them according to the use. Mostly, most user look at the output (end product) and the features of the printers. Entry level printers [15] costing as low as \$300 or less to \$500 may features only to print small objects only. They ae often noisy and slow. On the middle level printers, which range as from \$400 to \$1500 or above. In this category they are better faster and more flexible and the print quality are better as compared to the entry level printers. They are easily upgradable. On high end printer, costing as from \$1500 to \$3000 or above. This is where professional printers fall which can the industry printer

3D printers come in different sizes and categories according to features, quality and prices. Although there expensive machine there is also affordable ones and as technology advances printers are experiencing a growth in popularity as more and more usage of it continues. Hence it is found that there is need to build a 3D printer that is cost friendly, with better resolution and that has fairly good speed for printing. This is achieved using J-Head V6 Bowden hot end 0.4mm nozzle for 1.75MM filament as an extruder to arrive at this goal of rapid prototyping.

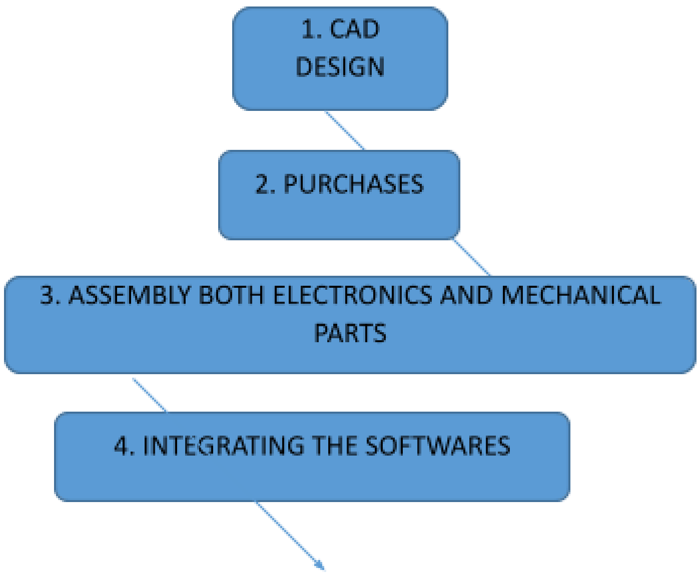
CHAPTER 3

METHODOLOGY

From the previous study done, in this chapter we are going to describe ways used to build a 3D printer that archives and solves the following problems as seen from the study.

1. Resolution of the machine
2. Print speed
3. Cost

Thus proceeding section of this document seeks to describe and definitively expounds on the materials used, procedures, designs and relevant mathematical modelling equations that were used in the experimental analysis after the build and finally arrive at the final product. The following is a summary of the approach



Chat showing tasks to be executed

1. Designing 3D printer in CAD for simulation purposes and identification of parts and obtaining the list of components required
2. Obtaining the mechanical parts and electronics for assembly and building of budget for the electronics and mechanical parts
3. Assembly of the machine as per the design drawn on the CAD
4. Flashing of the machine with firmware.
5. Calibrating of the machine

3.1 Material selection

The following section gives details of materials to be used to obtain relevant experimental results for the analysis and discussion

3.2.1 Hardware requirement:

<u>a) Electrical parts</u>

i)Arduino MEGA 2560 Board

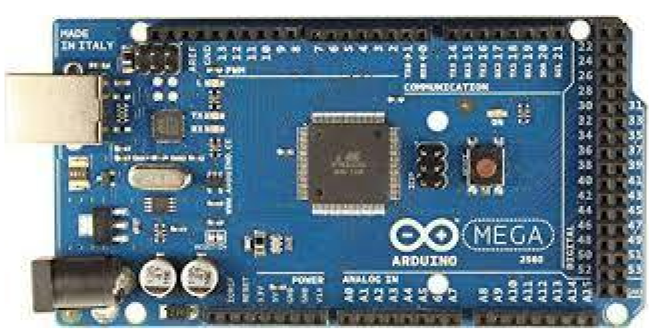


Figure 6: Arduino layout

The board layout for this 3D printer is based on Arduino. This is an electronics platforms which is open source for prototyping. To accomplish all this, the platforms has on one hand an Integrated Development Environment (IDE) that allows Arduino programming. Moreover, on hardware it consist of two main, a microcontroller Atmel which makes it possible for reading all sensors, that is , it allows communication to other devices; and a USB-serial converter which converts communication protocol to another therefore facilitating the programming of the microcontroller.

ii) RAMPS 1.4 control board (motor drivers)

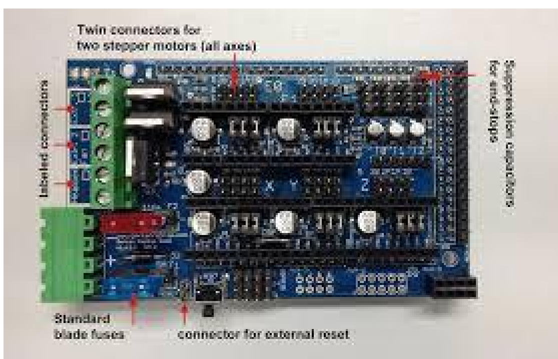


Figure 7: RAMPS 1.4

This is a shield designed for the majorly controlling external components and only works when connected to its mother board Arduino mega 2560. Owing to its stability in operation and great compatibility with most 3D printers. Some of the features it has include the following which makes it compatible with printing:

I. Standard interfaces (as that of extruder)
II. Reserved GCI like I2C and RS232
III. MOSFET 3 MOSFET are applied to the heater/ fan and thermistor circuit.
IV. Adding another 5A to protect the component parts.
V. An 11A fuse is added to the hotbed
VI. Support 5 stepper drive board
VII. The adoption Pin Header as pololu makes it more convenient to repair or change.
VIII. I2C and SPI are reserved for expanding
IX. All the MOSFET can be controlled by PWM
X. Use the interface of servo motor to adjust the level of printing platform automatically.

XI. Adding a SD module for SD ramps module.
XII. LED can indicate the status of the heater (the open and close of MOS).
XIII. 2 stepper motor for Z axis in parallel.

iii) Motor drivers A4988

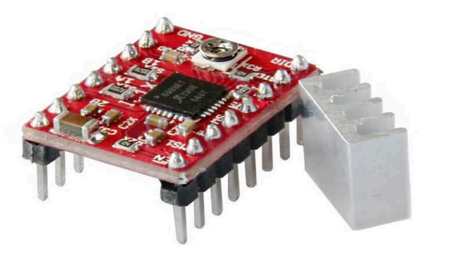


Figure 8: Motor Driver

The A4988 is a micro stepping driver that controls the bipolar stepper motor which has built in translator for easy operation of the stepper motor. It provides different steps resolution, full-step, half-step, quarter-step, eight-step and sixteenth-step. Its temperature can be adjusted using potentiometer thus proving an over-temperature regulation. It logic voltage is from 3volts to 5.5volts and the maximum current provided is 2A.

iv) Stepper motors NEMA 17

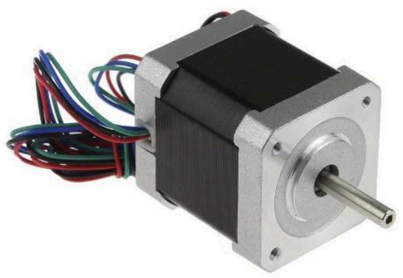


Figure 9: stepper motor Nema17

This is a dc motor that moves in discrete steps. They have multiple coils that are organized in groups called phases which rotates one step at a time. With a computer controlled stepping you achieve very precise positioning and speed control. For this reason stepper motors are the motor of choice for many precision motion control applications. Some of the features that make it useful majorly is the being able to move in steps and the fact that it's available in the market at a cheaper price. The required number for the buildup of the 3D printer is 5 units of Nema17 of same specification.

v) 24V, 13A power supply

To enable smooth movement and precision and to enable heating of extruder and hot bed, a 24volt 13A power supply is need. Out of this, the shield is able to distribute the power accordingly to different devices accordingly. When choosing a power supply specifications matters, and it's good to understand them and don't use any type, printer power supply usually has the following specifications:

- The **rated voltage(s)** of a PSU indicates what voltages it will accept out of the wall. In most cases, this can be changed using a switch on the side of the PSU. As such, they can work on both 110V @ 60Hz and 240V @ 50Hz AC.
- The **output voltage** is what comes out the other end: the voltage of DC current that the PSU can provide. This will vary from supply to supply, but each unit will only support one particular voltage, for example 12V. This is important because each component on your printer is rated for a specific voltage. If you get it wrong, things won't work.
- The **output current**, or output amperage, is the highest number of Amps that the supply can provide at any given time. This number will affect how many heaters your printer can have. It's most often seen as a limit to how hot a heated bed can get.

- The **total wattage** of a PSU is how much power (energy per unit time) it can provide. Mathematically, it is the product of the output voltage and the output current. For example, a 12V supply with a 30A maximum current will be able to provide 360 Watts (12 x 30 = 360)

Figure 10: power supply

vi) Intelligent LCD 12864 display

Figure 11: LCD 12864 display

Some of the features that make it more useful include the following:

1. Large screen LCD12864 Controller

2. Comes with the encoder, can realize the parameter adjustment, and the document choice printing!
3. Ramps plug and play, but need to modify the firmware to support.

This enable easy control of the features such as testing stepper motor movements and also testing the heating element of the bed. It offers control element of different software installed in the printer more visually.

vii) Heated Bed

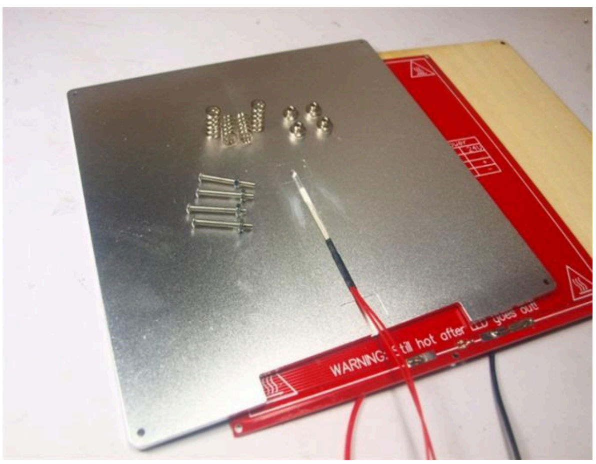


Figure 12: Print bed

This PCB consist of printed circuit that helps rapid distribution of heat and uniformity if the temperature. It's capable of maintain the temperature form 100 to about 130 degrees. This temperature is adjusted depending with the type of material used for printing. Some of usable properties of this bed include

Total dimensions 214x 214mm, Heat conductive dimensions 200x200mm, Laminate FR4 1.6+-0.15mm ,2 layer, 35µm copper, Red Soldermask - both sides, White Silkscreen - both sides , Power Input: 12V or 24v,Copper board holes, Resistance between 1.0-1.2 Ω (12V) or 3-3.4Ω (24V) EPCOS 100k thermistor hole, Functioning current PLA 8-9A, ABS 10-12A

viii) End stops

Figure 13: End stop

This is an essential part when it comes to printing, this enables to determine the position of the coordinate origins. It's essential when it comes to setting the machine to an origin position and homing the machine before starting to print.

The end stop used is mechanical one because they are easily available and they have to states corresponding to high and ow levels (5v and 0v)

ix) Electrical heavy wires 14 Gauge

When it comes to wiring of the printer, determining types of wires to use in different parts is essential. For heating bed the wires would be different cause it needs more currents or rather more current is drawn for heating either the extruder or the bed.

x) Extruder electronics

Electronics that compound the extruder include

1 x 100K Semitec NTC thermistor

12v 40W Heater Cartridge

1 x 12v 30x30x10mm fan

1 x High Temperature Fiberglass Wire - for Thermistor (150mm)

0.75mm Ferrules - for Solder-Free Wire Joins

Each electronics has its function for the printing process for heating and cooling of the same extruder and material passing through to the printing bed.

Figure 14: Extruder construction

<u>b) Mechanical parts</u>

This comprises of the place where the electronics will it and where they will be placed to perform there functionality. This external body that will be made from Square Hollow Section, 3/4" Square tube 1.5mm thick – to be cut and welded as shown in the design.

3D printed parts as shown in the CAD design Fastener – M3 to M8 screws, nuts, and washers of 10mm, 20mm 30mm, and 40mm this helps to attach the electronics in this design.

625zz bearing and 608zz bearing this will help in the movement of the bed and the extruder on the x direction, some of the mechanical parts include the following:

i) Frame

Figure 15: Frame

ii) X and Y rails

Each directional rail(x and y) has two of rodes.

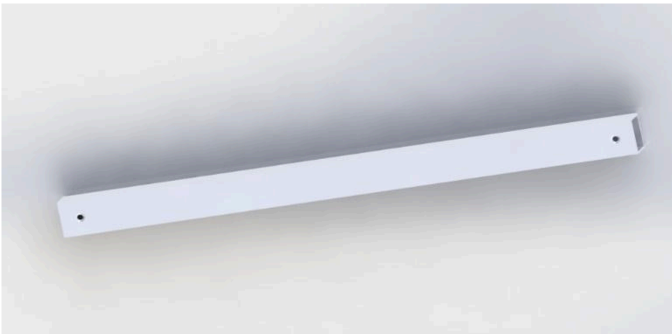


Figure 16: Rails

iii) Print bed plate

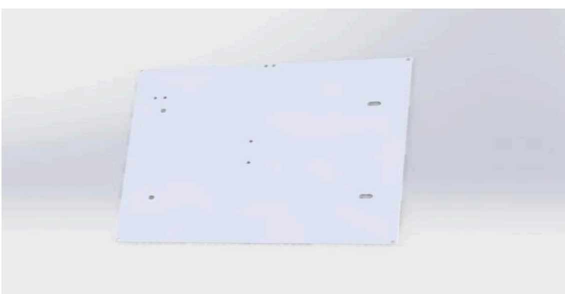


Figure 17: bed plate

iv) Printed plastic parts

This includes the parts that are used to attach everything together as per the design shown in the final product. Some of the printed parts includes the mounts used to hold electronics motors and the rails on the printer. Some are also used to hold the power supply in position.

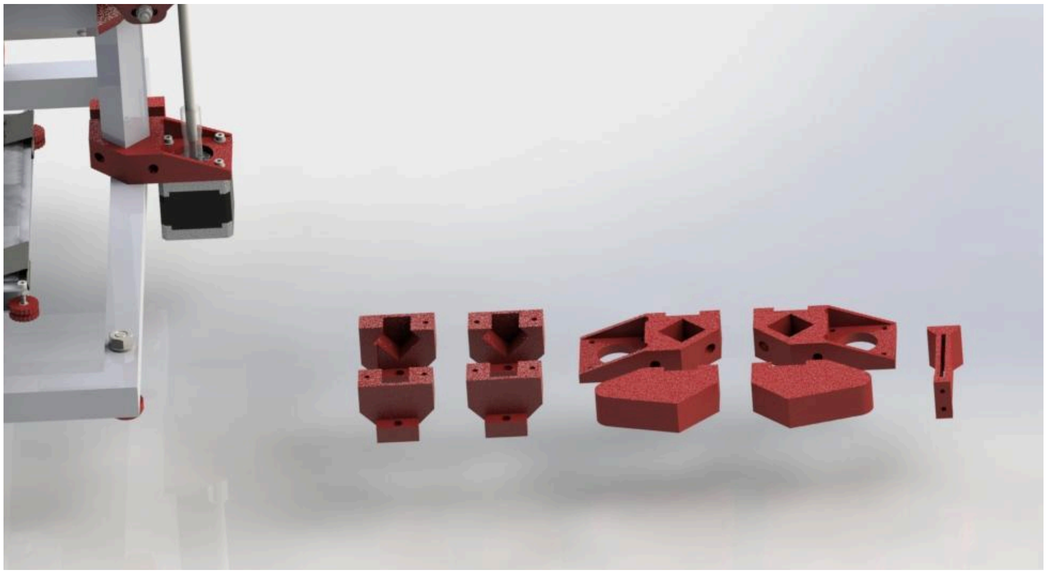


Figure 18: plastic parts

3.2 Budget

3D Printer

ELECTRONICS		Quantity	Price	Availability
	Arduino Mega with Ramps 1.4	1		
3mm	LED	1		
1K	Resistor	1		
12V <13A	Power Supply	1		
	Reprap discount Full Graphic Smart Controller	1		
	Wire			
18 awg	Heavy Wires	2		
	Heated Bed	1		
	Thermistor	1		
	Kapton tape	1		
	EndStops	3		
	Nema 17 Stepper Motors	5		
	GT2 Pulleys	2		
	625zz Bearings	28		
	608zz Bearing	3		
40mm	Fans	2		

FASTENERS						
1.5mm thick	3/4" Square tube					
	M3 Socket Cap Screw 10mm Long	18				
	M3 Socket Cap Screw 12mm Long	4				
	M3 Socket Cap Screw 16mm Long	10				
	M3 Socket Cap Screw20mm Long	6				
	M3 Socket Cap Screw 25mm Long	16				
	M3 Socket Cap Screw 30mm Long	15				
	M3 Socket Cap Screw 35mm Long	22				
	M3 Socket Cap Screw 40mm Long	9				
	M3 Socket Cap Screw 50mm Long	1				
	M3 x 8mm Set Screw or cap screw					
	M3 x 9mm Set Screw or cap screw					
	M3 Nuts	70				
	M3 Washers	73				
	M4 Nut	2				
	M5 Nuts	52				
	M5 Hex Bolt 25mm Long	1				
	M5 Hex Bolt 30mm long (Fully Threaded)	6				
	M5 Hex Bolt 35mm long (Fully Threaded	2				
	M5 Hex Bolt 40mm long (Fully Threaded	4				
	M5 Washer	29				
	M6 Nuts	2				
	M8 Hex Bolt 50mm long	4				
	M8 Nuts	8				
	M8 Nylock Nut	1				
	M8 Washers	12				
	M8 Dowel Pin	1				
	M8 Hex Bolt 45mm Long	1				
	M6 or M5 Threaded Rod	2				
	Hose Clamps	4				
	Sheet Metal Screw	4				
	Vinyl Tubing (35mm long)	2				
	Extruder Spring Guide	1				
	Springs	2				
	Zip ties					

Table 3 excel sheet showing item, quantity of items and prices of the item required.

3.3 Procedure

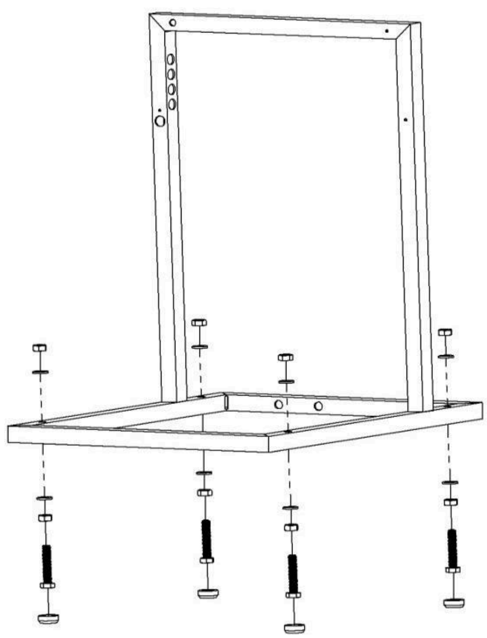
This section introduces the guide to building/Assembling of full operational 3D printer. The end goal of this section is to build and integrate the choose components both electronics and mechanical parts to come up with the finished product.

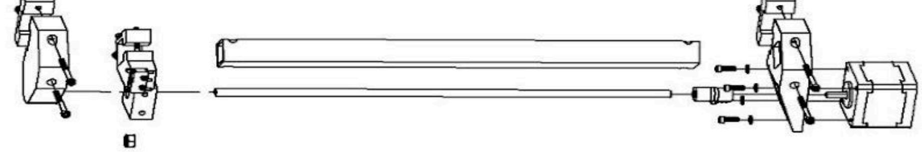
3.3.1 Frames

This forms part of which the electronics will be held. The positioning of each would highly affect the precision of the machine

a) assembly of the frame

Using the designed made from CAD design the following should was made. It was followed by smoothening and calibration. Reason being that the frame needs to be at 90 degrees from the ground to avoid miss alignment during printing. And also to correct any imperfection in geometry during welding process.





b) x and y and z frame assembly

i) Z axis assembly

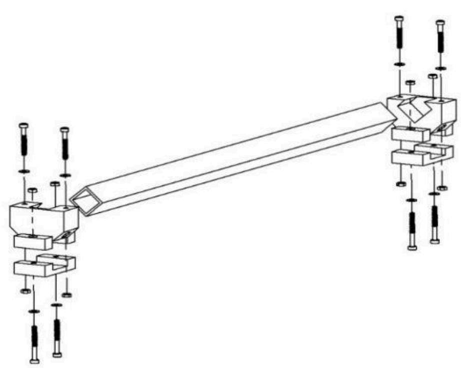
Including the stepper motor in the assembly the following steps were followed.

Steps:

1) Check to make sure the Z Nut Mounts fit into the X Ends. This will save time by ensuring the correct fit before things are assembled.
2) Push the M6 Nuts into the Z Nut Mounts.
3) Using 4 M3 Socket Cap Screws 10mm Long attach the Nema 17 Stepper Motors onto the Z Motor Mounts. Make sure that the wires are facing in towards the printer.
4) Thread the Threaded Rods into the Vinyl Tubing almost half way.
5) Push the Vinyl Tubing on the end of the Threaded Rods onto the shafts of the Nema 17 Stepper Motors.
6) Secure the Vinyl Tubing to the threaded Rods and the shafts of the NEMA 17 Stepper Motors with hose clamps.
7) Screw the Z Nut Mounts onto the Threaded Rods until they are about half way down.
8) Place the Z Rails into the sockets in the Z Motor Mounts.
9) Place the Z End stop Mount onto the right Z Rail with the orientation shown in the drawing.
10) The Z Axis is now ready to attach to the frame using the 8 M3 Socket Cap Screw 35mm Long. Note that the bolts enter from the front side of the Motor Mounts. On the Rail mounts they enter from the back side and the nuts drop into nut traps.

This was done as it is being connected to the overall frame.

ii) Y axis assembly

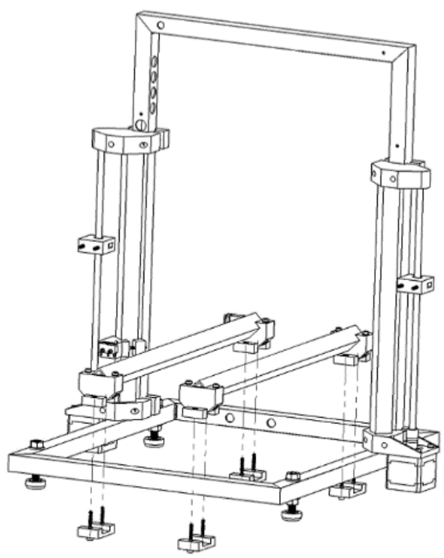


Using Y rails, screw and nuts and Y rail printed mounts the following steps were followed to attach the together.

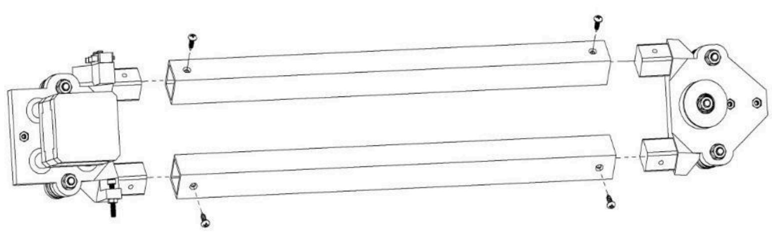
Steps:

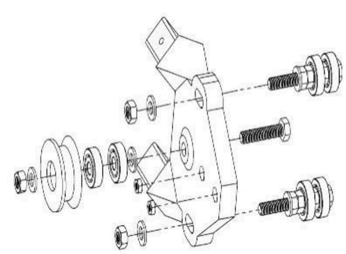
1) Press M3 Nuts into the nut traps on all of the Y Rail Mounts.
2) Tighten all of the 25 mm M3 Screws into the holes in the Y Rail Mounts. These help to keep the Y Rail Mounts from cracking.
3) Using the Plastic Screws, attach the End stop to the Y Rail Mount Left Back.
4) Press the Y Rails into the sockets in the Y Rail Mounts.
5) The Y Rails are now ready to mount onto the Frame.

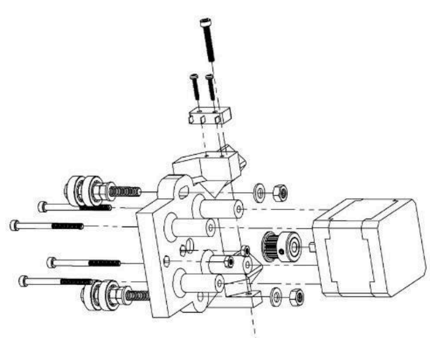
The y rails were attached to the frame to appear as shown below.



iii) X axis assembly





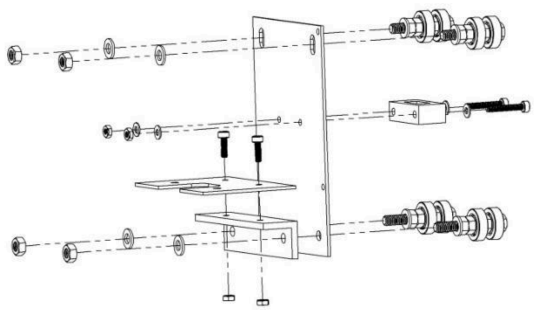


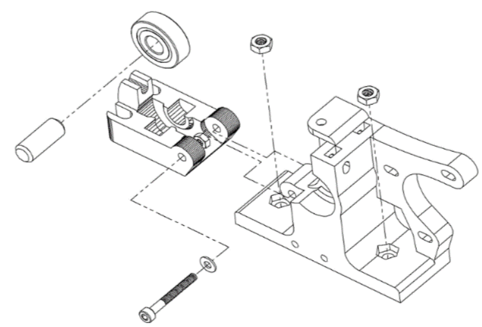
This involved taking calibration of the weights that will be carried by x frames. This involves the extruder electronics. The lighter the better and more speed of the movement. The following steps were followed to archiving this,

1) Remove all burrs from the inside of the X Rails. Don’t forget the edge of the drill holes inside the square tubing. Then test fit the X Rails into the sockets. If too tight, file the sockets a bit and try again. Try to do as little filing as possible and keep the fit tight but removable. File only on the back faces of the plugs to help keep the bars parallel.
2) Push the X Rails onto the X Ends until they reach the limit. Make sure the holes are lined up.
3) Fix the rails to each X End with a Sheet Metal Screw. Tight, but not so tight as to strip the plastic.

This was done after mounting the stepper motor on the X end motor side and as well as the idler side of the x axis.

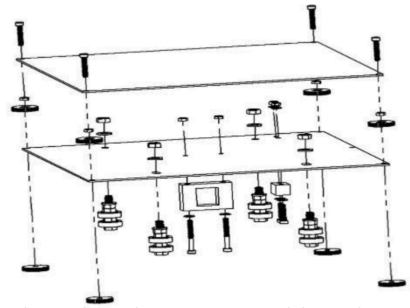
b) Assembly of the x carriage and extruder





The plate was cut and the other bearing attached to it as shown in the diagram. The extruder motor was attached to the extruder printed parts and this was to allow the movement of the filament. This is the most essential part in terms of printing. Wrong calibration of this part will make the prints have an error.

d) Assembly of bed carriage



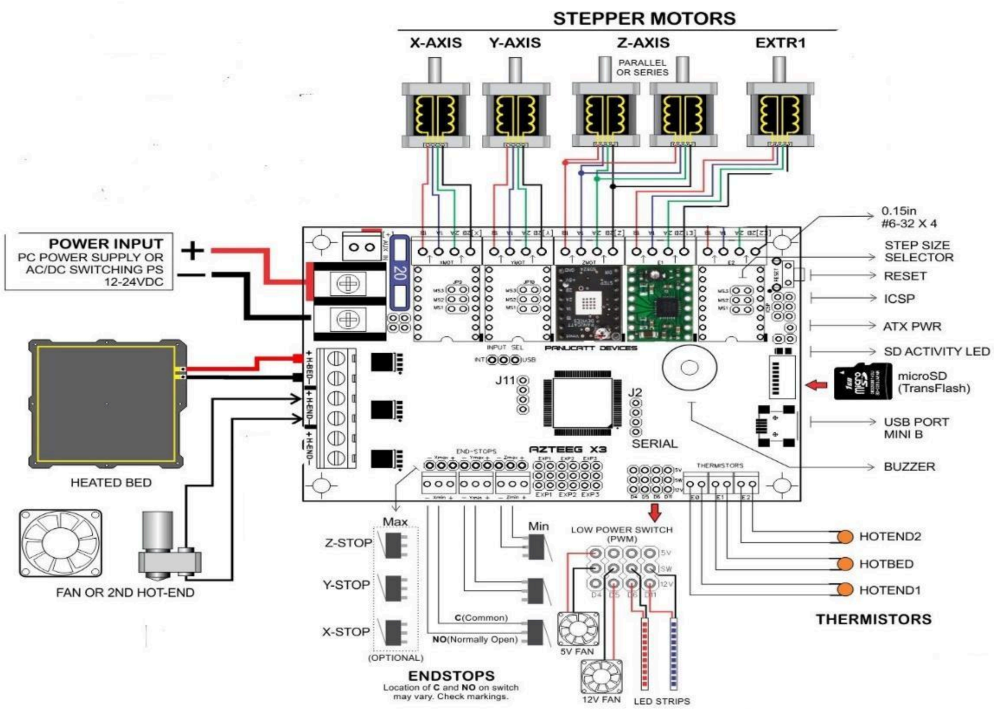
This is part the is used to carry the printed parts, to archieve its stability and precision the following steps were followed.

1) Mount the Y Belt Anchor using the two 30mm long socket cap screws and nuts. Don't worry about washers. There isn't enough space.
2) Mount the Y End stop Block with the two M3 Socket Cap Screw 16mm Long. Use washers on both sides.
3) Attach all 4 Bearing Stack 625zz 30mm Bolt. Tighten the two that are in the holes with a wrench and leave the other two finger tight. They will be adjusted later.
4) Put all 4 M3 Socket Cap Screw 20mm Long through the holes in the corners of the Print Bed (not print bed support. Secure each of them with an M3 Nut (no Thumb Nut). Tighten them well so that the bolts are held fast.
5) Put an M3 Thumbnut on each of the 4 M3 Socket Cap Screw 20mm Long. The nut should face the bottom of the Print Bed.

This was attached to the printers frame on the y rails to accomplish the whole y axis and carriage set up.

3.3.2 Electronic

The electronics were connected as shown in the following diagram.



All electronics were tested before connection through the following steps

1. Visual investigation was done to the circuit. This helps to investigate, get good look at the surrounding of the circuit and more so it helps it helps determine other tests that would be performed
2. The voltage measurement at each point is key. Heated bed requires 12voltage to get it hot as well as the extruder hot end. Fun for cooling it requires 5 volts only. This means at each point of this connection needs to be verifies before connecting to the main board. This enable to determine which part I not working and which part require more attention and close monitoring. This goes hand in hand with the current measurement in that incase of part like stepper motor which requires adjusting of the current going through the stepper driver.
3. Testing the improper neutral-ground bond.
4. Testing the functionality of each part before connecting.(this was done using the individual functions written in Arduino IDE)

After all tests were done the electronics were attached to the frame where routing of the cables was done accordingly and well as determining where all tis electronics will be located.

3.3.4 Calibrating and trouble shooting

References

[1] "Introduction to 3D Printing," Intractable, [Online]. Available: http://www.instructables.com/id/3D-Printing-1/.

[2] "Infographic: A brief History of 3D Printing," Troweprice, [Online]. Available: http://individual.troweprice.com/public/Retail/Planning-&-Research/Connections/3D-Printing/Infographic.

[3] "Makerbot replicator guide book" available: https://drive.google.com/drive/u/0/folders/1-9FbCo330TZgs0GBZqBq91P_kLsKcGEm?ogsrc=32
http://www.geeetech.com/wiki/images/8/8a/ReplicatorG-0040-Installer.zip
http://www.geeetech.com/wiki/images/9/99/MightyBoardFirmware-master.zip

[4] "Product Detail,"MakiBox, [Online]. Available: https://store.makibox.com/#/product-detail?type=1&&optio n=31.

[5]"XYZprinting da vinci Jr" XYZprinting, [Online]. Available: http://www.xyzprinting.com/public/CES/linkto/XYZprinting%20CES%20Media%20Deck_Jan04_2014_pptx.pdf

[6] "Uprint SE Plus," [Online]. Available: Uprint"http://usglobalimages.stratasys.com/Main/Files/Machine_Spec_Sheets/PSS_FDM_uPrintSE.pdf

[7] "Printrbot Jr. (v2)," Printrbot, [Online]. Available: http://printrbot.com/shop/printrbor-jr-v2/.

[8] "Litto 3D Printer," Tinkerine Studio, [Online]. Available: http://www.tinkerines.com/store/3d-printers/litto/.

[9] "Rapid Mega," makemendel, [Online]. Available: http://makemendel.com/3d-printer/rapidbot-mega.

[10] "XL 3D Printer Assembled," Airwolf3D, [Online]. Available: http://airwolf3d.com/store/products/buy-a-3d-printer-xl/.

[11] "Z Corporation 3D Printing Technologies," Z Corporation, 2005. [Online]. Available: http://www.zcorp.com/documents/108_3D%20Printing%20 White%20Paper%20FINAL.pdf.

[12] "Solidoodle 3D Printer, 2nd Generation," Solidoodle, [Online]. Available: http://store.solidoodle.com/index.php?route=product/product&product_id=56

[13] inkton, "3d Printing: Know its Advantages and Disadvantages," *Ink Toner Store Blog*, 18-Feb-2016. [Online]. Available: https://blog.inktonerstore.com/3d-printing-know-its-advantages-and-disadvantages/. [Accessed: 02-Feb-2019].

[14] "A 3D Bioprinter Makes a Spinal Cord Implant in 1.6 Seconds - IEEE Spectrum." [Online]. Available: https://spectrum.ieee.org/the-human-os/biomedical/devices/this-3d-bioprinter-makes-a-spinal-cord-implant-in-16-seconds. [Accessed: 02-Feb-2019].

[14] "What to look for when buying a 3D printer - iDig3DPrinting - Your UK 3D printing store for 3D printers & filament." [Online]. Available: https://www.idig3dprinting.co.uk/news/how-to-guides/buying-3d-printers/. [Accessed: 04-Feb-2019].

[14] "Comprehensive study of 3D technology" available:https://www.researchgate.net/publication/310961474_A_Comprehensive_Study_on_3D_Printing_Technology

[15] "Advanced printing" available:

https://www.flashforge.com/wp-content/uploads/2017/08/FlashForge-Advanced-Printing.V.20170801.pdf

[16] “How much does a 3D printer cost” available: https://www.allthat3d.com/3d-printer-cost/