TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING

KATHMANDU ENGINEERING COLLEGE

DEPARTMENT OF ELECTRONICS AND

COMMUNICATION ENGINEERING

MAJOR PROJECT

ON

3D PRINTER
[Code no. EG777EX]

BY

BIBEK POUDEL	–	EXAM ROLL NO. 39614
BIBEK SHRESTHA	–	EXAM ROLL NO. 39615
BIJAYA KHADKA	–	EXAM ROLL NO. 39616
BIKASH ADHIKARI	–	EXAM ROLL NO. 39617

KATHMANDU, NEPAL

2073

TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING

KATHMANDU ENGINEERING COLLEGE

DEPARTMENT OF ELECTRONICS AND

COMMUNICATION ENGINEERING

3D PRINTER

[Code no. EG777EX]

FINAL REPORT SUBMITTED TO THE DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE BACHELOR OF ENGINEERING

BY

BIBEK POUDEL	–	EXAM ROLL NO. 39614
BIBEK SHRESTHA	–	EXAM ROLL NO. 39615
BIJAYA KHADKA	–	EXAM ROLL NO. 39616
BIKASH ADHIKARI	–	EXAM ROLL NO. 39617

KATHMANDU, NEPAL

2073

Abstract

The purpose of this project is to create a working prototype of Delta Rostock 3D printer. 3D printer is basically a Fused Depostion Modeling system which is one of the Additive Manufacturing Techniques. This report summarizes the documentation of project from plan, design, build, working and various component or material used. Also includes some backgroud theory, application along with the history of 3D printing Technology. Hardware, software , electronics and Print material are the building blocks of the printer. The 3D object is produced by melting the print material (PLA). The project was completed within 7 month, from February to August.

Acknowledgement

We are highly indebted to Department of Electronics and Communication Engineering, Kathmandu Engineering College for providing us such a great opportunity to undertake this project as a major project. We would like to express our deepest appreciation to the Head of Department of Electronics and Communication Engineering **Associate Prof. Er. Sagun Manandhar**.

We would like to express our sincere gratitude to our final year project supervisor, **Er. Suman Sharma**, whose contribution in stimulating suggestions and encouragement, helped us to coordinate our project. We are grateful to our project coordinator **Er. Nirajan Koirala** who never failed to offer his help and advice.

We would also like to take this opportunity to thank **Mr. Rajendra GC** who guided us in various stages of the project. We express our gratitude toward our families and colleagues for their kind co-operation and encouragement. Also we would like to acknowledge the effort of any party involved but were not specified.

Table of Content

List of Figures

List of Tables

List of Abbreviation

3D	3 Dimensional
ABS	Acrylonitrile Butadiene Styrene
ATX	Advanced Technology Extended
BPM	Ballistic Practice Manufacturing
CAD	Computer Aided Design
CNC	Computer Numeric Control
DIY	Do It Yourself
DMLS	Direct Metal Laser Sintering
FDM	Fused Deposition Modeling
FFF	Fused Filament Fabrication
GUI	Graphical User Interface
HDPE	High Density Polyethylene
IDE	Integrated Development Environment
LCD	Liquid Crystal Display
MDF	Medium density Fiber
NC	Normally Closed
NEMA	National Electrical Manufacturers Association
NO	Normally Open
PLA	Polylactic Acid
RepRap	Replicating Rapid Prototype
SD	Secure Digital
SLA	Stereolithography Apparatus
SLS	Selective Laser Sintering
STL	Stereolithography
TTL	Transistor-transistor Logic
UART	Universal Asynchronous Receiver/Transmitter
UV	Ultra Violet
Vref	Reference Voltage

Chapter 1
Introduction

1.1 Background

The activity or business of producing writing or images on paper or other material with the help of machine is printing. The earliest known form of woodblock printing came from China dating to before 220 A.D. Later developments in printing include the movable type, first developed by Bi Sheng. The printing press, a more efficient printing process for western languages with their more limited alphabets, was developed in the fifteenth century.

Modern printing is done typically with ink on paper using a printing press. It is also frequently done on metals, plastics, cloth and composite materials. On paper it is often carried out as a large-scale industrial process and is an essential part of publishing and transaction printing. 3D printing is a form of manufacturing technology where objects are created using three-dimensional files and 3D printers. The objects are created by laying down or building up layers of material.

3D printer is device used of creating three-dimensional solid object using computer aided design(CAD). 3D printers use a process called additive manufacturing to form physical objects layer by layer until the model is complete. This is different than subtractive manufacturing, in which a machine reshapes or removes material from a existing mold.

Since 3D printer create models from scratch, they are more efficient and produce less waste than the subtractive manufacturing devices. The process of printing a 3D model varies depending on the material used to create the object. For example: when building a plastic model, 3D printer may heat and fuse the layers of plastic together using a process called Fused Deposition Modeling(FDM). When creating a metallic object a 3D printer may use a process called direct metal laser sintering (DMLS). This method forms thin layer of metal from metallic powder using a high powered laser [1].

1.2 Problem Statement

3D Printing is relatively new technology. Many people are unaware about this technology due to lack of an outreach to the general public. 3D printing appeals a solution for various fields and processes. A viable area for implementing 3D printing is hardware prototyping.

Hardware prototyping is one of the tedious, time consuming,resource hungry field in developing new designs. Also hardware design is an iterative process. This could be easily solved using 3D printers which allow rapid prototyping saving developers valuable resource, time and cost.

Currently very few 3D printers can be purchased for domestic use but are not nearly as user friendly as they should be. Most of them are quite expensive, consume a lot of time and cost to maintain, and have limited building capabilities in terms of size and resolution.

1.3 Objective

The objectives of this project are

- To create a working prototype 3D printer implementing Delta design

1.4 Applications

3D Printer can find application in various fields, following are some of the applications of the 3D Printer [2].

- Rapid Prototyping
  Engineers, Architecture and Designers can visualize and test their designs with the help of 3D printers.
- Manufacturing Industries
  Manufacturing industry can use the 3D printers for manufacturing there products

in a much more cost effective manner. Use of 3D printers can also reduce the product from time increasing the efficiency of the industries.

- Prosthetics
  3D printer industry can be helpful for designing prosthetics for disable and amputees. Due to the light weight of the material, robust nature and ease in the development of the prosthetics, 3D printing industries can be really helpful, effective and efficient for building prosthetics.

- Replacement Organs
  Bio-printing has already been used in 3D printing technology to construct the human blood vessels and other internal organs. This can lead to development of internal replacement organs at lower cost which can efficiently function.

- Spare parts
  In many occasions, the spare parts of complicated machinery are not easily available and even if available they are costly. With the help of 3D printer, one could easily produce required spare parts saving the time and money.

- Aerospace and Aviation industries
  The transfer of heavy machinery parts from one place to another place in aerospace and aviation is time consuming, risky and expensive. Using a 3D printer only the design should be transferred and the parts can be manufactured at the place required.

1.5 Organization of Report

Chapter 1 Includes the basic theory and background of 3D printing technology along with the problem statements, objectives and applications of this project. Chapter 2 revolves around the history and evolution of 3D printing along with various practices and techniques used to achieved it. Chapter 3 consists of the detail specifications and description of delta rostock 3D printer and its parts/components. Chapter 4 is covers the methodology performed for completion of this project as well as the working mechanism of the 3D printer. Chapter 5 concludes the project along with its limitations and future enhancements.

Chapter 2
Literature Review

3D printing is an application of Additive manufacturing technology. 3D printing evolved with the development in rapid prototyping techniques i.e. fast manufacture of prototype hardwares. It originated in 1986 when Charles Hull issued a patent to develop a Stereolithography Apparatus(SLA). Stereolithography is based on photo polymerization, a process in which light is used to chain molecules together to form polymers. In 1989, Carl Deckard filed a patent for Selective Laser Sintering (SLS) rapid development process , it used a laser power source to sinter (forming a solid mass material by applying heat and/or pressure to bind materials without melting it to the point of liquefaction). In 1992, the first SLA machine was produced by 3D systems. The machine's process involved a UV laser solidifying photopolymer, a liquid with the viscosity and color of honey that makes 3D parts layer by layer. Although imperfect, the machine proved that highly complex parts can be manufactured overnight [3].

In 1989 Scott Crump filed a patent for Fused Deposition Modeling (FDM) or Fused Filament Fabrication (FFF) technique of Additive Manufacturing. In this technique a large thermoplastic coil made of 3D printing material is fed to a nozzle of the printer which deposits the material in layers of print, next layer is printed after previously printed layer is cooled .It is one of the most popular method and is often used by entry level machines .Many other techniques like Direct Metal Laser Sintering (DMLS), Selective Laser Melting (SLM), Ballistic Practice Manufacturing (BPM) and Laminated Object Manufacturing (LOM) were later developed but we will be using FDM technique because of its simple process, Low material costs and production speed [4].

In 1999, the first lab-grown organ was implanted in humans when the young patients underwent urinary bladder augmentation using a 3D synthetic scaffold coated with their own cells. The technology was developed by scientists at the Wake Forest Institute for Regenerative Medicine. It opened the door to developing other strategies for engineering organs, including printing them. Since the parts are made with the patient's own cells, there was little to no risk of rejection. In 2002 scientists engineered a miniature functional kidneys that was able to filter blood and produce diluted urine in an animal. The development led to research at the Wake Forest Institute for Regenerative Medicine that aimed to print organs and tissues using 3D printing technology.

In 2005, Dr. Adrian Bowyer at University of Bath founded RepRap (Replicating Rapid Prototype) , and open-source initiative to build a 3D printer that could print most of its own components. The vision of this project was to democratize manufacturing by cheaply distributing RepRap units to individuals everywhere enabling them to create everyday products on their own. In 2006, the first SLS (selective laser sintering) machine became viable. This type of machine uses a laser to fuse materials into 3D products. This breakthrough opens the door the mass customization and on-demand manufacturing of industrial parts, and later, prosthesis. That same year Object, a 3D printing systems and materials provider created a machine capable of printing in multiple materials, including elastomers and polymers. The machine permits a single part to be made with a variety of densities and material properties. In 2008, following its launch in 2005, RepRap Project releases Darwin, the first self-replicating printer that is able to print the majority of its own component, allowing users who already have one to make more printers for their friends. Shape-ways launches a private beta for a new co-creation service and community allowing artists, architects and designers to make their 3D designs as physical objects inexpensively. The same year first person walks on a 3D-printed prosthetic leg, with all parts knee, foot and sockets printed in the same complex structure without any assembly. The development guided the creation of Bespoke Innovations, a manufacturer of prosthetic devices which made customized coverings that surrounded prosthetic legs. In 2009, MakerBot Industries, an open-source hardware company for 3D printers, started selling DIY kits that allow buyers to make their own 3D printers and products.

Bioprinting innovator Organovo, relying on Dr. Gabor Forgacs's technology, used a 3D bioprinter to print the first blood vessel. In 2011, Engineers at the University of Southhampton designed and flew the world's first 3D-printed aircraft. This unmanned aircraft was built in several days for a budget of £5,000. 3D printing allowed the plane to be built with elliptical wings, a normally expensive feature that helped improved aerodynamic efficiency and minimise induced drag. Kor Ecologis unveiled Urbee, a sleek, environmentally friendly prototype car with a complete 3D-printed body at the TEDxWinnipeg conference in Canada. It was designed to be fuel efficient and inexpensive . In 2011 imaterialise became the first 3D printing service worldwide to offer 14k gold and sterling silver as materials, potentially opening a new and less expensive manufacturing option for jewellery designers. In 2012 Doctors and Engineers in the Netherlands used a 3D printer, made by the LayerWise company, to print a customised 3D prosthetic lower jaw, which is subsequently implanted into an 83-years old woman suffering from a chronic bone infection. This technology is currently being explored to promote the growth of new bone tissue [2].

After 2012, there has been an outgrowth in new companies and startups that provide inexpensive 3D printing machines for everyday use . Big companies like amazon and Google have started their own 3D printing departments. Since 2013, 3D printing has been in the mainstream media and received widespread consolidation to the extent that it has been termed as *"4th industrial revolution"* by the Economist magazine.

Chapter 3
Rostock Delta 3D printer

The Rostock Delta 3D printer falls in the category of a delta robot. The frame is made with three post forming a delta structure. Each post has two parallel rods totalling six rods connecting bottom and top bases. These rods provide the structure to the printer and also enclose the printing volume. Along the length of the rod, one carriage runs at each post. The posts hold linear bearing or bushing which are fitted to the carriage for linear motion. Each carriage houses two parallel arms with another end of the arm connected to the end-effector. The arms are connected to the carriage and the end-effeector via universal joint allowing the maximum motion tranfer. The end-effector houses the print-head. The movement takes place according to delta kinematics. The co-ordinated linear movement of three-carriages translates into the movement of end-effector [3].

Thus, the delta structure provides a way to translate one axis movement into three axes movement and achieves the objective of a 3D printer. The frame structure of the printer is shown in figure 3.1.

Figure 3.1: Rostock Delta 3D printer

3.1 Basic Dimension

The build volume of printer is 29.6 cm x 29.6 cm x 91 cm with a base of 29.6 cm x 29.6 cm and a height of 91 cm. The length of each arm measures to 39cm providing a printing base radius of 10cm. The ground offset of the end-effector at its maximum position is 25cm. Thus, the printer has an estimated print volume is $25x314.159cm^3$ with a base radius of 10cm and height of 25 cm.

The NEMA 17 stepper motor has 200 steps per revolution. This is not quite enough for the smooth operation of the printer. The steps limits the speed, movement and precision of the printer. Ramps board comes with microstepping functionality which increases the number of steps per revolution. The motor can thus rotated with full-step, $1/2$ step (half-step), $1/4^{th}$ step, $1/8^{th}$ step and $1/16^{th}$ step. Most of the reprap machines use the $1/16^{th}$ microstepping.

Thus,with $1/16$ microstepping, the steps per mm can be calculated as follow:

$$\frac{steps}{mm} = \frac{steps \cdot microstepping^{-1}}{beltpitch \cdot pulleytooth}$$

In our case, the belt pitch is 2mm and the pulleytooth counts to 20,so

$$\frac{steps}{mm} = \frac{200 \cdot \frac{1}{16}^{-1}}{2 \cdot 20} = 80\frac{steps}{mm}$$

Hence, the stepper motor takes 80steps to move 1mm with the motors rotating 3200 microsteps per revolution.

The length of the smooth rods for the frame is approximately 910mm, so the length of the timing belt loops is 1820mm long, with teeth at 2mm pitch, the pulleys have 20 teeth, with 5mm bore and 2mm pitch.

3.2 Delta design over other designs

Delta design of this printer offers far better solution for 3D printing for a number of reasons.

Firstly, the Delta arm design enabless much faster motion in the Z-axis. Other printer design uses threaded rod, thus limiting the rapid movement of the end-effector in the

Z-axis. In Delta design, the speed of movement in the Z-axis is same as in the X and Y axes, allowing a faster speed for the printer overall.

Unlike other 3D printers, delta 3D printer has fewer moving parts. Other designs mostly consists of moving print-base which results in damage,smearing of outputs whereas delta printer has stationary print-base and a moving print-head resulting in better output. Also the moving parts of the delta printer are far less than other designs and hence prevents the mecha nical wearing and tearing.

The Delta design enables the print-head to change direction in quick, smooth movements. This provides high quality and high efficiency on the printing with advantage of speed. Due to freedom of arm movement, it is easy to print circular shapes with this design, and scale parts in every direction.

One of the drawback of the Rostock's Delta design is that it is trickier to calibrate the firmware and to convert the movements into Gcode. In this regard, Cartesian system offers a simple solution as the corresponding mechanical movements can be replicated directly into Gcode [5].

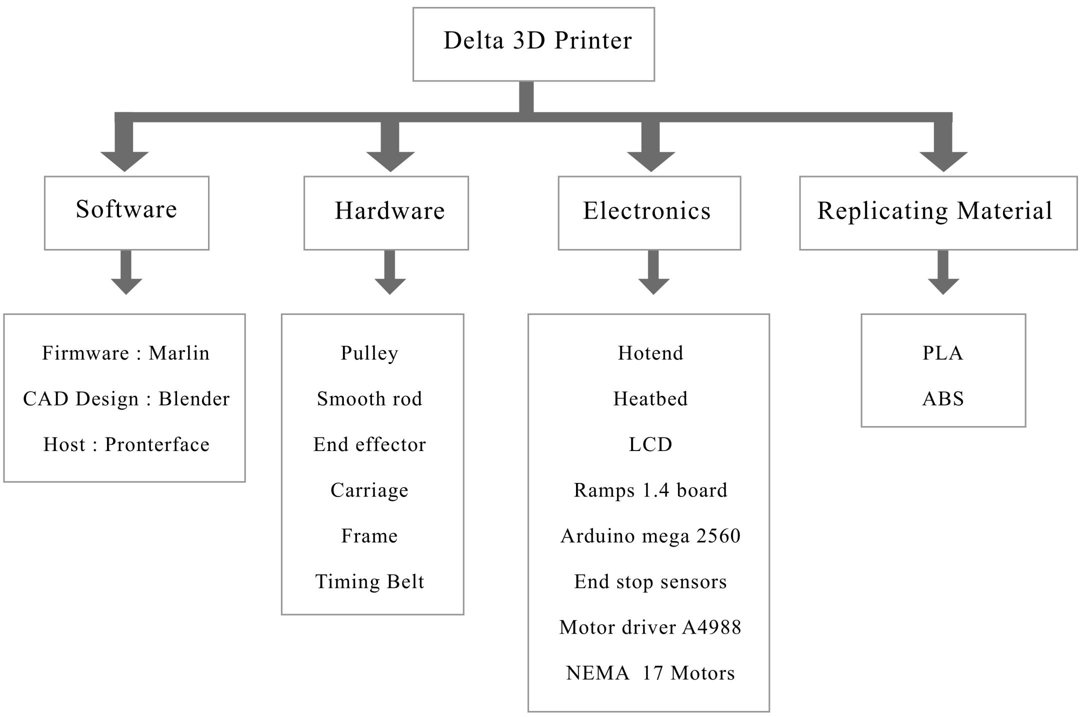

Figure 3.2: Building blocks

3.3 Hardware

The hardware provides structure and rigidity to the 3D printer. It also houses the printing volume. This design uses minimum hardware build volume with greater print volume. It consists of the frame and mechanical parts.

Six smooth rods (MK12), each of height 91cm are inserted into the hexagonal top and base to form delta structure. A carriage is attached to each pair of rods, which is connected to the end effector by two parallel arms. Length of each arm is 39cm. Linear movement of carriages are supported by two linear bearings or bushings in each pair of rod.

The top, base, carriage and end-effector of the printer are cut from MDF, whereas carriage-support and arms are of steel. The overall connection of above described components forms the frame structure of 3D printer as shown in figure [3.1].

The GT2 timing belt coupled with the carriage enable the vertical movement of the carriage allowing the delta movement of the arms. There is one GT2 pulley placed at top and bottom of the frame.

3.4 Electronics

The electronics allow the printer to operate, control the movements, store the firmware and translate the design inputs to the optput of the printer. The electronic block is given in following figure.

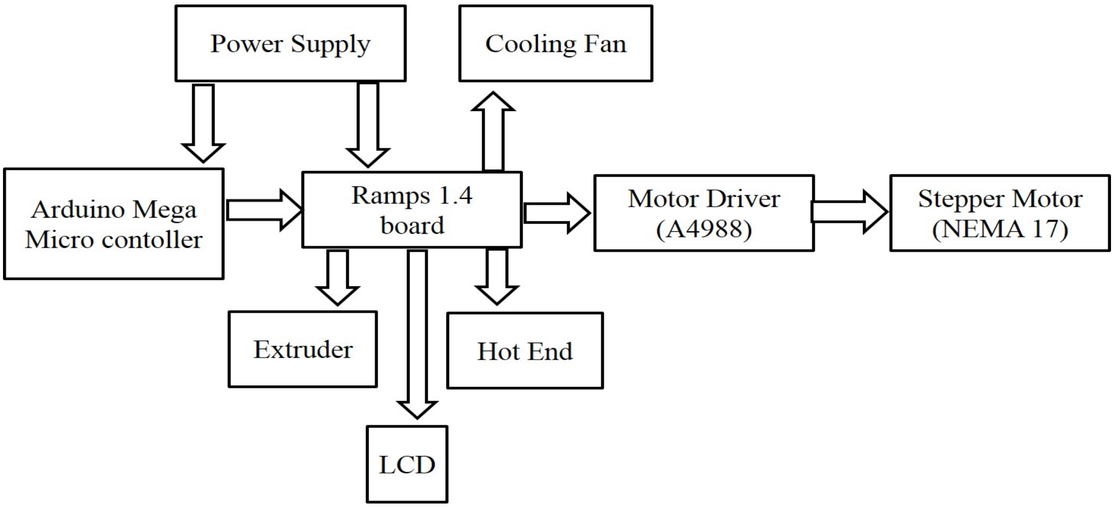

Figure 3.3: Electronics block

The circuit connection of the electronics is given in the following figure 3.4

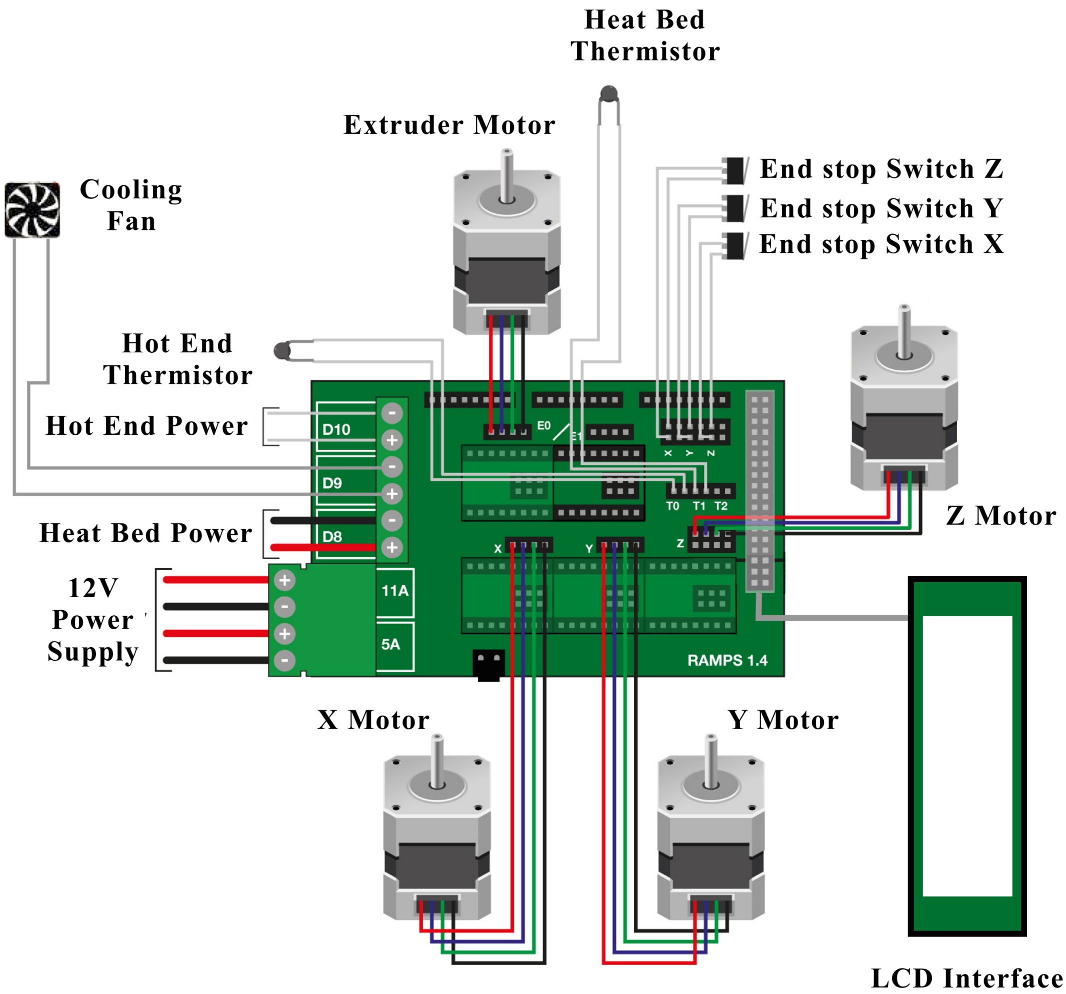

Figure 3.4: Overall circuit connection

3.4.1 ATX Power Supply

ATX is a motherboard configuration specification developed by Intel. The power supply unit used in ATX converts AC to low-voltage regulated DC power for the internal components of a computer. However, in this project ATX power supply unit has been used to supply the power to the 3D printer. It produces three main outputs, +3.3V, +5V and +12V. The +12 V supply is used to power Ramps 1.4 board and +5V is used to power the Arduino Mega and cooling fans.

3.4.2 Stepper Motor

The motors used in 3D printer are bipolar stepper motors, known as NEMA17 motors. These motors are often associated with the robotics industry. The stepper motor drivers feed the motors with power pulses and these pulses enable the motors to move through measured steps. The bipolar NEMA 17 motor is a powerful motor capable of producing a very high resolution rotation and is very suitable for applications that require high precision. The relevant technical specifications of the motor are given in following table.

Table 3.1: NEMA17 stepper motor specifications

[6]

Maximum Torque	4.8 Kg
Step angle	1.8°
Step error	5%
Rated voltage	2.8 V
Rated current per phase	1.68 A
Number of phases	2

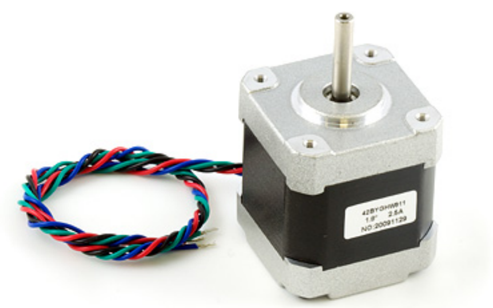

Figure 3.5: NEMA 17 Motor

3.4.3 Stepper Motor Driver

The stepper motor driver used in this printer is A4988.It is developed by pololu and is suitable for driving NEMA 17 motor. The relevant technical specifications are given in table [3.2].

Table 3.2: A4988 stepper motor driver specifications

Operating Voltage range	8 V to 35 V
Continuous current per phase	1 A (without need for heat sink)
maximum current per phase	2 A

The A4988 circuit for driving the stepper motors is given in figure

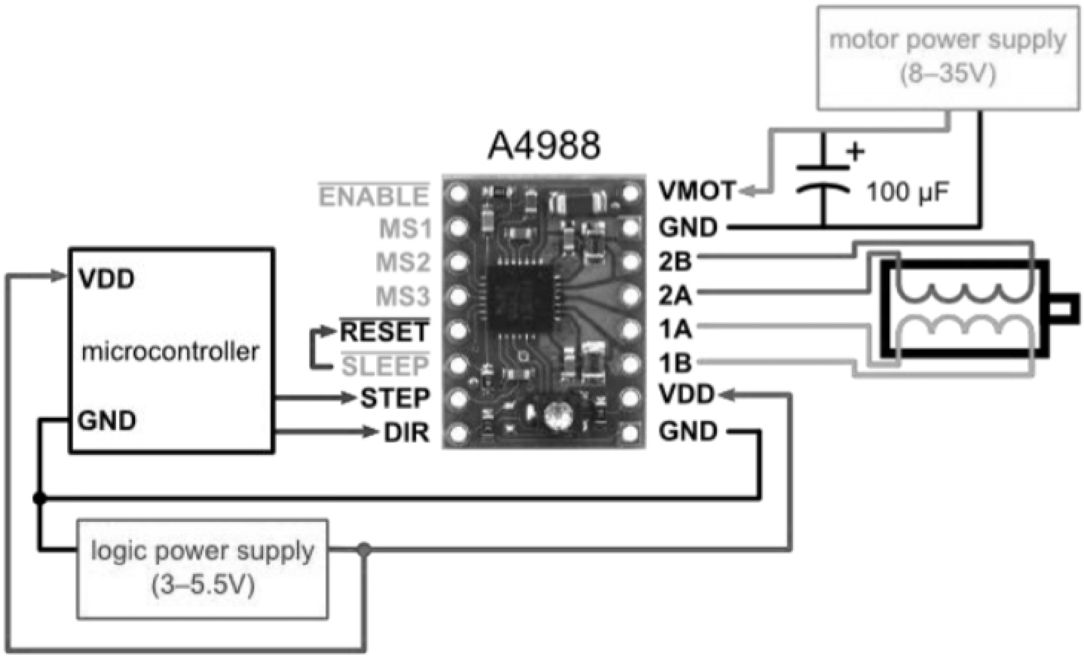

Figure 3.6: Stepper motor driving circuit

On the left side, the driver has 8 controls inputs, which it is described below:

- **ENABLE** : as the name suggests, enables the board but with negative logic, in other words, it must be logical LOW state.
- **RESET and SLEEP** : These should it be connected by board construction.
- **STEP** : Each pulse on this pin corresponds to one microstep.

- **DIR** : This marks the direction that the motor turns.
- **MS1-MS3** : as the logical value of these terminals, the motor will rotate at $1,1/2^{th}$, $1/4^{th}$, $1/8^{th}$ or $1/16^{th}$ step, as indicated in the following table.

Table 3.3: Microstepping of A4988

MS1	MS2	MS3	Microstep Resolution
Low	Low	Low	Full step
High	Low	Low	Half step
Low	High	Low	Quarter step
High	High	Low	Eighth step
High	High	High	sixteenth step

Some of the important features of A4988 motor driver are: micro-stepping, over current protection, over temperature protection and presence of adjustable current limiting potentiometer. A stepper motor always has a fixed number of steps. Microstepping is a way of increasing the number of steps by sending a sine/cosine waveform to the coils inside the stepper motor. Microstepping allows the shaft of the motor to move smoother and more accurately. When micro stepping is set to $1/16^{th}$ the smallest step that the shaft can move is:0.1125° which would otherwise be 1.8°. Hence number of steps is increased from 200 steps per revolution to 3200 microsteps per revolution.

The diver consists of a current limiting potentiometer whose value can change from 0 to 1.5. The empirical formula relating the potentiometer value and current to the motor is given as:

$$I(max) = \frac{Vref}{0.4}$$

where $Vref$ is measured between the potentiometer and ground

3.4.4 RAMPS 1.4

RAMPS 1.4 is a shield for the Arduino Mega 2560 board. It supports a maximum of five Stepper motor drivers A4988 thus, can control up to 5 stepper motors with $1/16^{th}$ stepping precision. It can also be interfaced with a hotend, a heatbed, a fan, a LCD controller, power supply, up to three thermistors, and up to six end stoppers. It is provided with additional auxillary ports which allows the addition of the functionality to the 3D printer.

Some important connections are:

- Fan (polarity sensitive) -D9
- Extruder 1 heater (polarity insensitive) - D10
- Heatbed Heater (polarity insensitive) - D8
- Stepper motor drivers
- Arduino ATMEGA 2560, Power supply (12 V),
- Temperature sensors
- LCD Display

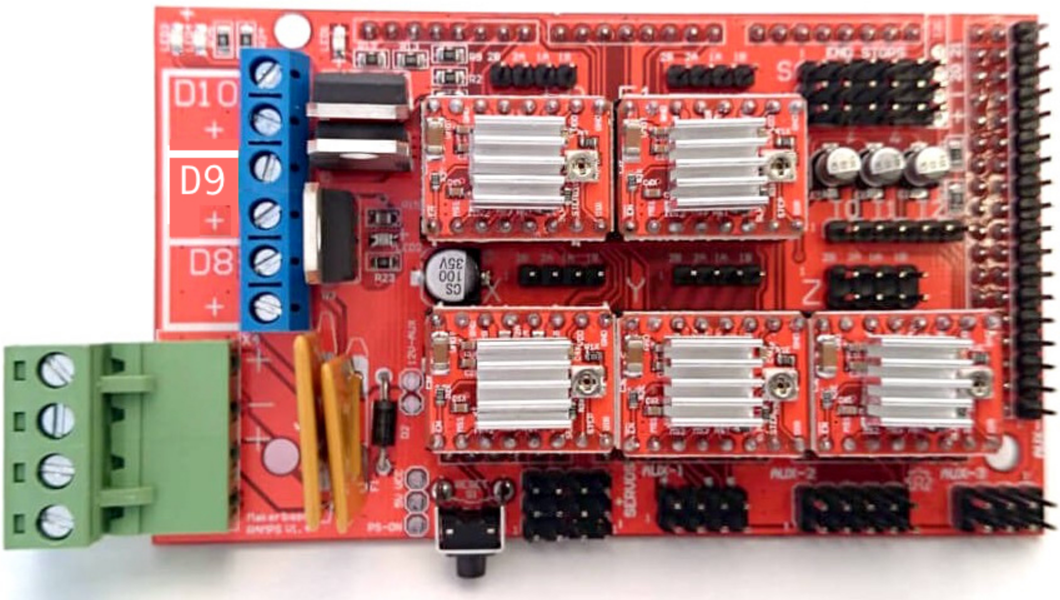

Figure 3.7: Ramps 1.4

3.5 Arduino Mega

Arduino is an open-source physical computing platform based on a simple i/o board and a development environment that implements the Processing/Wiring language. Arduino can be used to develop stand-alone interactive objects or can be connected to software on your computer. The open source Arduino IDE can be easily downloaded for any operating system. The Arduino Mega 2560 is a micro-controller board containing the ATmega2560 microcontroller. It is compatible with the Ramps 1.4 board which allows for interfacing and control of the NEMA-17 stepper motors. The pin configuration diagram is shown in figure.

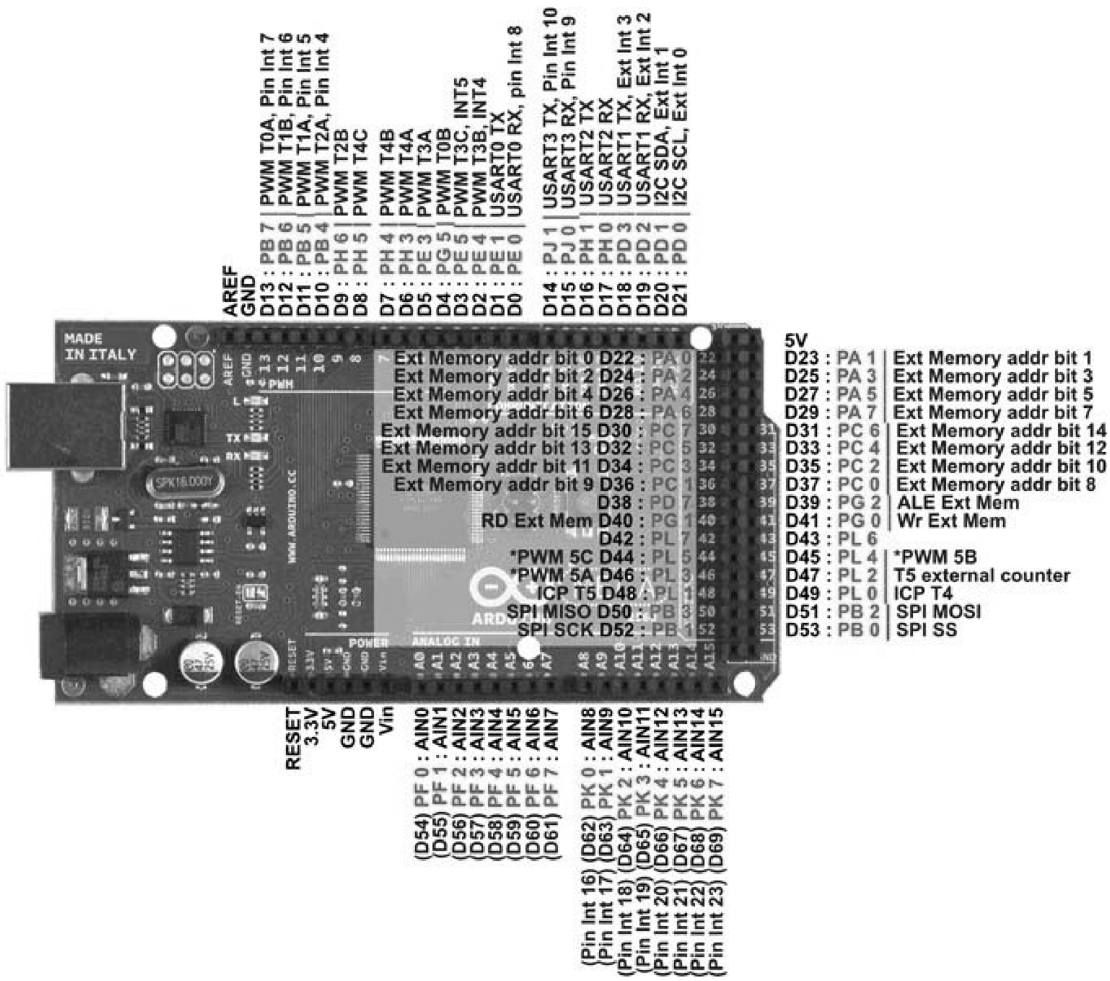

Figure 3.8: ArduinoMega pin configuration

Some of the relevant technical specifications of the Arduino Mega 2560 are given in the table.

Table 3.4: ArduinoMega2560 specifications

Base Microcontroller	AtMega 2560
Operating frequency / Clock Speed	16 Mhz
Input Voltage	5 - 12 V
Analog input pins	16
Digital I/O pins	54
Flash Memory	256 Kb

3.5.1 End Stop sensors

End stop sensors also known as the mechanical crash sensors are simple switch providing signal to the microcontroller when triggered. These are used to provide a reference point such that printer knows the location of the print-head. These are used for homing direction. Six end stop sensors can be interfaced with the Ramps 1.4 shield each for the minimum and maximum position of the X, Y and Z axes. In delta structure, three suffice as the rest is provided within the firmware. In the printer, these end-stops are located at the top of the triangular frame. The arms will not be able to travel any higher beyond these points. Mechanical end-stops are used, as they offer a simpler cheaper solution than the alternative; optical-end stops,hall-effect sensors.

The end-stop has three pins, Normally Closed (NC), Normally Open (NO) and Common (C). The NC and NO pins are set to ground, and the C pin is wired to the Signal port on the controller. When the button is triggered the end-stop will send a signal to the controller to let it know that that axis has reached its home position.

3.5.2 LCD module

The LCD Module used in this project is a smart controller developed by RepRap . It features a SD-Card reader, a rotary encoder and a 20 Character x 4 Line LCD display . It is connected to the Ramps 1.4 board using smart adapter which is basically a custom designed connection configuration compatible with the Ramps 1.4 board. The LCD module removes the necessity for a PC every time a print is performed . The rotatory encoder enables all actions like calibration, axes movements by appropriate adjustments to its knob . The process of printing an object is simplified to fewer steps by the use of this module ; A g-code design is stored on the SD card and the print is performed directly.

3.5.3 Extruder and Hotend

The extruder is one of the essential part of the 3D Printer. Its work is to control the flow of the filament into the hotend. It basically takes in the filament of replicating material or printing material and passes it through a heated channel and squeezes it out through nozzle of the hotend. The melted polymer is dropped onto the surface in layers and hardens as soon as it rests on the surface, then, the height of the extruder is incremented and another layer is set on top of the previous layer.

The extruder needs to be strong enough to pull the plastic through and feed it through the other end, at the nozzle. It needs to be able to withstand high temperatures, and easy to control precisely. It is also vitally important that it is possible to reload it, if, or when, it has been interrupted mid-build, and, it needs to be reliable.

When the extruder completes a layer or a line and needs to stop and move to another location, the extruder actually needs to stop projecting molten plastic, retract the plastic a small amount, and then, move and recommence projecting. For this reason, the extruder needs to be able to decelerate quickly and sufficiently and reaccelerate quickly again.

The type of polymer used will be PLA or ABS of diameter 1.7mm or 3 mm.

An extruder consists of a cold end and a hot end. The hot end is where the filament is heated and melted. The hot end can reach temperatures of approximately $240°C$. The hot end specifically refers to the part that is the tip of the extruder, this is the hottest part of the overall device, and where the melted plastic comes out. The cold end, then, is made from thermoplastics and it therefore, needs to be kept cool or these thermoplastic components will melt. It is here that the plastic is pushed by the gears.

In recent 3D printing extruder designs, the hot end and the cold end are separated. The reason for the separation is to keep the platform light, and therefore easier and quicker moving.

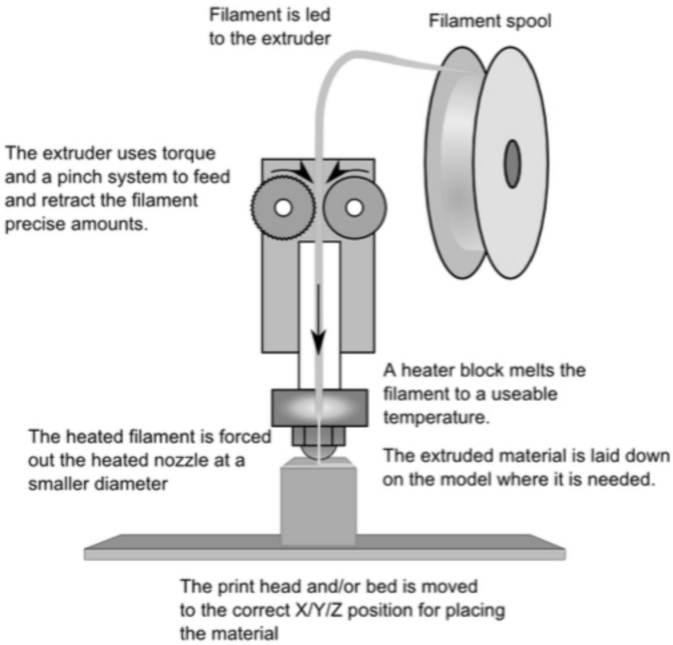

Figure 3.9: Extrusion process

3.6 Replication Material

Various thermoplastic materials can be used for the FDM/FFF 3D printer, examples include ABS, PLA, and HDPE.

PLA has a melting temperature of $173-178°C$ and a tensile modulus of 2.7-16 GPa. It can withstand temperatures of $110°C$. It is manufactured from a renewable resource, that is, corn, and is modified for use in injection moulding, thermoforming, and sheet extrusion. It holds its shape after it is formed, and is ideal for packaging. It can take 15 months to start decomposing. It is useful for its high stiffness, minimal warping, and it also possesses an attractive translucent color. It also has the advantage of being biodegradable and derived from plants. It has a melting point of $173-178°C$, and HDPE is a thermoplastic made from petroleum and has a melting temperature of $130°C$.

ABS is a common thormoplastic, amorphous substance and therefore, has no official melting point and is made from petroleum.$275°C$ is the accepted melting temperature for the purpose of 3D printing. It is very flexible and tough plastic. It is also more likely to warp than PLA, and a heat-bed will be required if ABS is used. It has a useful working temperature range of $-20to80°C$.

Figure 3.10: PLA spool

3.7 Software

For the Rostock 3D Printer, software is needed primarily to convert 3D drawings to Gcode, and firmware is required to translate Gcode into mechanical movement driving Ramps 1.4.

3.7.1 Design Software

The design software allows the user to create the model of the object to be created prior to the printing process. The user can locally install these software and create the designs by own with the help of these softwares. These allows the freedom for the user to have the design according to his specifications. These are really easy to use as they are user friendly and provide wide ranges of the tools for design process. Thus, created design with these software can be exported as *.stl* files. These files contain all the informations of the design allowing the conversion to the Gcode.Some of the softwares that are easily available are AutoCAD, SketchUp, Blender, etc.

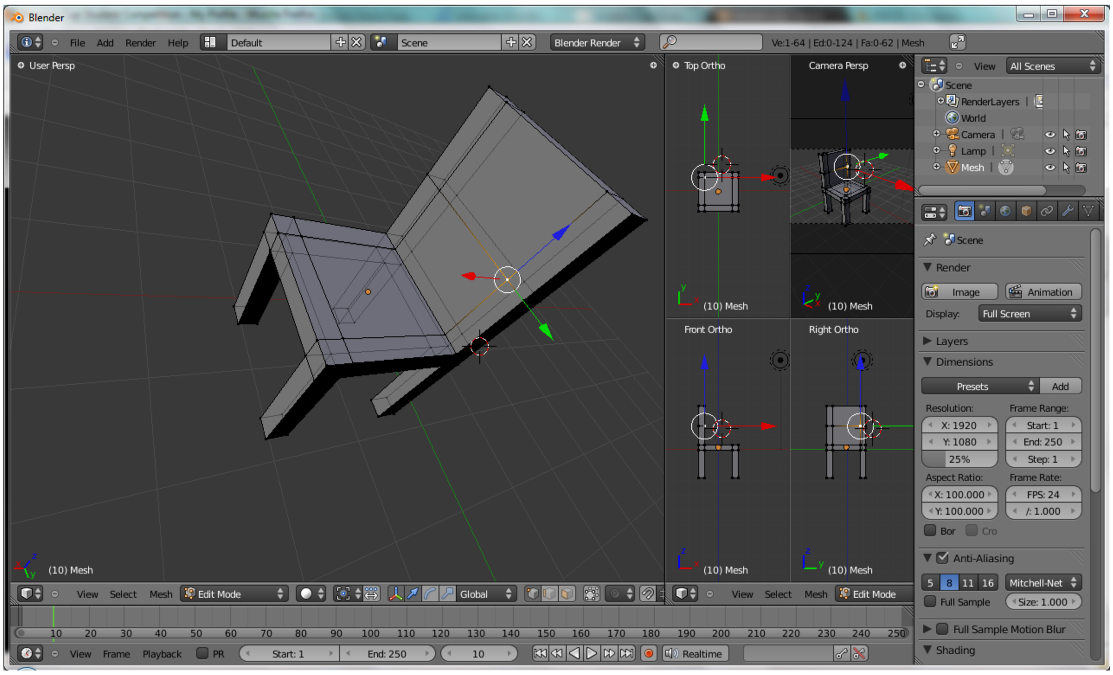

Figure 3.11: Design software: Blender

3.7.2 Host software

The host software allows communication to the printer electronics before and during the printing jobs. It allows the user to upload a .STL file and convert it to Gcode and monitors the printing process. Pronterface is a simple GUI software that permits the user to input Gcode instructions to the microcontroller. Cura or Slic3r are more intelligent host softwares that will take input 3D drawings (.stl files) and will geometrically breakdown the file into layers which are then converted into a series of paths in which the print-head should move. This information is sent to the microcontroller, via the firmware.

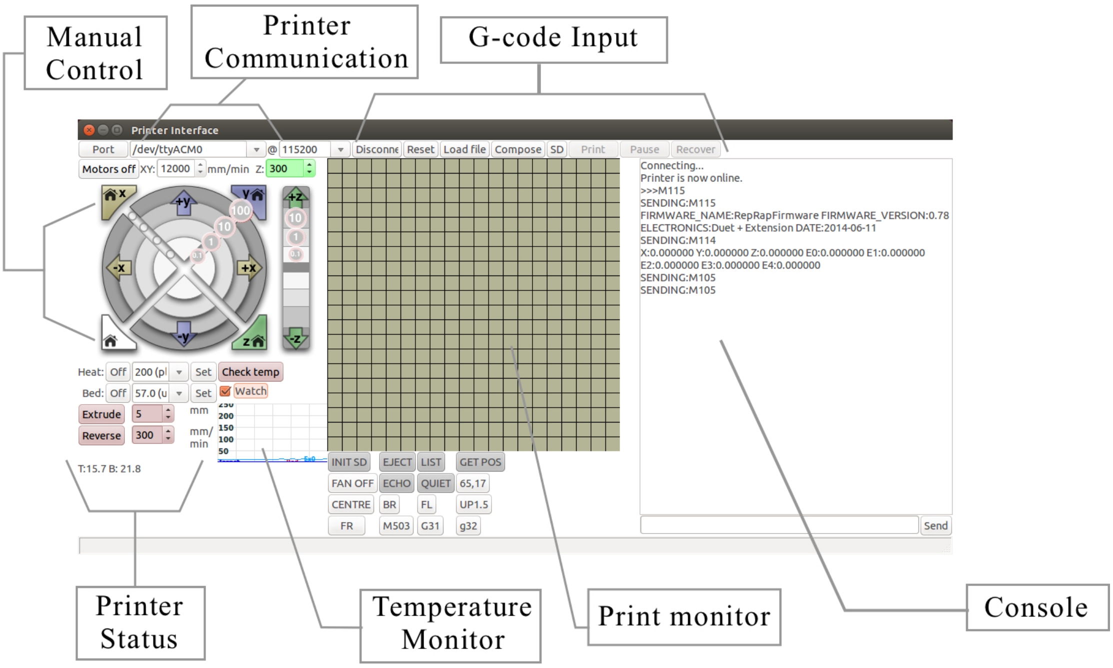

Figure 3.12: Host software:Pronterface

3.7.3 Firmware

The firmware is responsible for making the printer move according to the G-code commands. It will be able to calculate the distances each axis is allowed to move in order to reach the desired position. It is installed on the ATMega2560 microcontroller. It is what processes the Gcode instructions coming from the PC, and permits the arms to move from one coordinate to another. It also restricts the arms from crashing into its own unit, when properly calibrated.

The firmware used in Reprap machines includes Sprinter, Marlin and Teacup. The Arduino IDE is used for uploading the firmware to the ATMega chip. It is uploaded to the microcontroller using Arduino IDE[7].

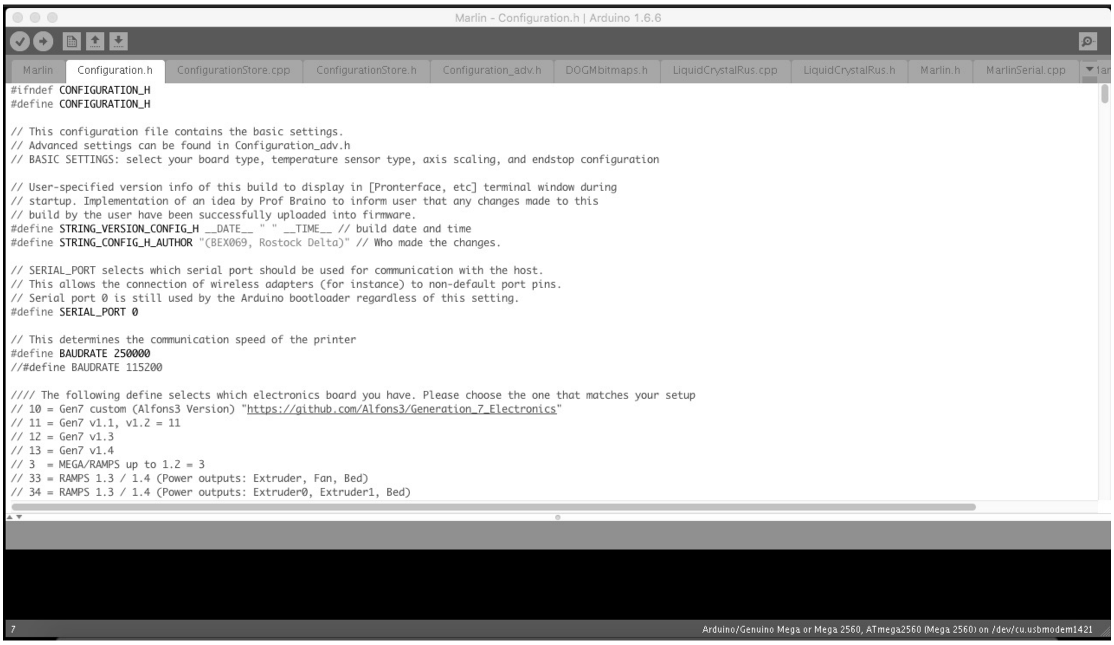

Figure 3.13: Marlin firmware

Chapter 4
Methodology

4.1 Project Overview

This project completed in different phases.Firstly, basic idea and thoery of 3D printing technique were studied. The parts and components were accordingly ordered and acquired. After that the mechanical design was drafted and implemented. After frame of the printer was built, electronics components and other hardware part were assembled. There were some glitches in the code and hardware which were debugged later on. Different phases of the project is shown in Figure 4.1

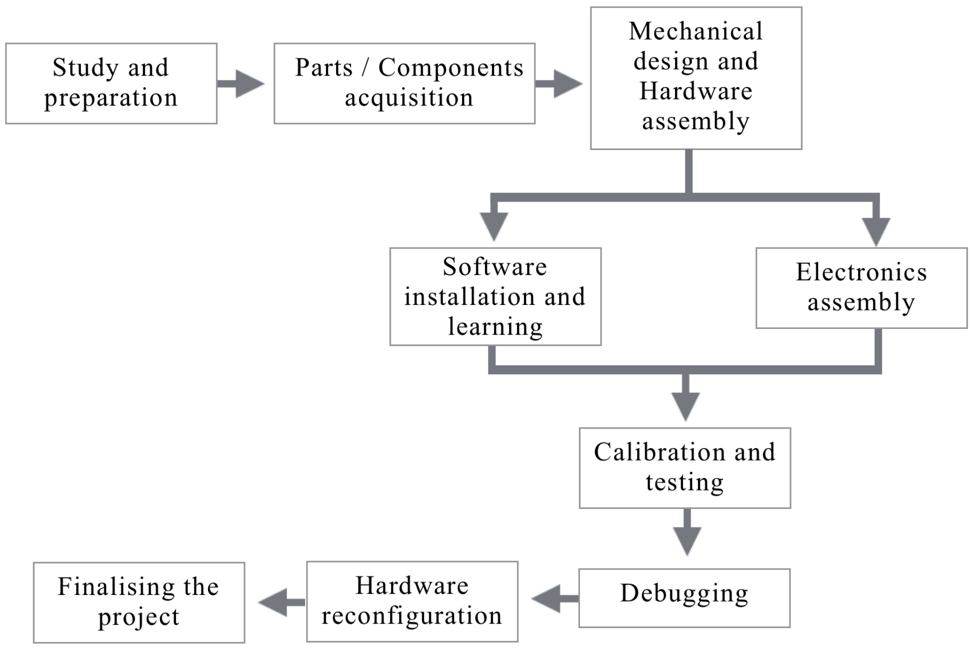

Figure 4.1: System Flow Diagram

4.1.1 Study and preparation

3D printing being relatively new technology, and is still in development phase. Various designs and printing materials are being under study. Thus, the information and resources available are also limited.

While developing a 3D printer, it was considered that the printer should be able to print a 3D object with the movement in all three axes. The simple solution to this was a 3D printer that has Cartesian movement coordinates, that is the printer has parts that are capable of moving in individual axis. With further study, a far better solution than the Cartesian printers came into light, the delta structured 3D printers. These printers were capable of 3D printing while having the actuator moving in only one axes, thus increasing speed, having small build-volume and larger print-volume. Hence, Rostock Delta 3D design was finalized as our 3D printer design.

All the parts that were required to build this printer were throughly studied. Further studies were made on the similar relevant projects. The resources on this design were gathered and analysed. The components it required, the types of hardwares and softwares as well as electronics were deeply studied before comensing on the project.

With thorough study, the list of components required was prepared and the informations on required components were gathered. It was vital to be able to use various tools and softwares, so information on those were also acquired.

4.1.2 Parts / components acquisition

After making essential study and preparation about the project, the parts were to be build and the electronics components and softwares needed were to be acquired. Majority of the hardware parts required to build the printer were acquired locally. Those parts that were not available in the local market, were imported.

Majority of the hardware were acquired locally while majority of the electronics were imported.

4.1.3 Mechanical design and Hardware assembly

The mechanical design were calculated and drafted on papers. When the satisfactory results were obtain, the design was implemented. The frames were cut out of plywood. The early design was crude with much reconsiderations to be made with regard of placing the components. Few tweaks were made in order to house the electronics components, motors and the pulleys.

All the hardwares were put together as in the figure 4.2

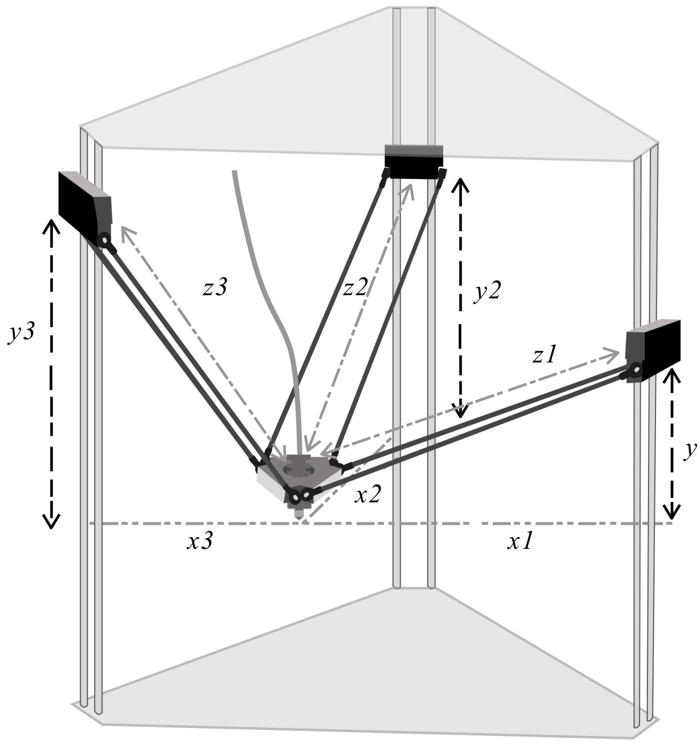

Figure 4.2: Hardware Assembly

4.1.4 Software installation and learning

Blender was installed as the design software on our computers and the basic design techniques were learned. The design were then exported in *.stl* file. Another software that was installed and learned was Slic3r, which provided layer to the design. Various parameters for the printing were learned to configure using this software. After setting proper parameters, the Gcodes were generated. Some of the basic Gcode commands were learned.

The Marlin firmware was acquired and configured to the settings required by our printer. The Marlin firmware was configured and uploaded to the microcontroller with the help of Arduino IDE.

4.1.5 Electronics assembly

After acquiring the electronics components, they were assembled. The Ramps 1.4 board was interfaced with the Arduino mega. Four A4988 stepper motor drivers were placed in the Ramps 1.4, three for axes movement and one for the Extruder. Nema 17 motors were placed on the frame housing and connected to the Ramps board. The End-stop sensors were connected to the X-max, Y-max and Z-max ports on the Ramps board. The hotend was connected to the D10 with its temperature sensor connected to respected temperature sensor of Ramps board. Similarly the heat-bed was connected to the D8 port. A LCD was interfaced in the Ramps board. Some fans were connected to provide the cooling. All this was powered through Ramps board powered using ATX power supply.

4.1.6 Calibration and testing

When all the harware and electronics were properly assembled, the printer was connected to the host software Pronterface. The printer was homed and manually controlled with the Pronterface. Few Gcodes were sent to test the response of the printer. After successfull calibration of the printer with Pronterface, a design was made and the generated Gcode was uploaded into the printer. The printer then automatically handled the print job. The hot-end reached proper heating temperature. The test was successful but had to be interrupted as the estimated print time was very long around 6 hours. So few adjustments were done while generating the Gcode and a faster print time was achieved.

4.1.7 Debugging

Although the printer ran smoothly, there were still some glitches. Also the LCD encoder was not working. So few adjustments were made in the firmware as well as the hardware. The electronics were properly connected and safely placed. The current to the motors were limited using the pot setting on the motor driver. Also due the motor jammed due to misalignment of the inner shaft, which was corrected by disassembling the motor and putting it back together.

4.1.8 Hardware reconfiguration

Few adjustments on the hardware were made after the calibration and testing. The stepper motor was constantly being out of place so it was fixed using zip ties. Also the carriages were tightly coupled with the bushing to ensure the levelled printing. The pulley and motor shaft were not of exactly coupled so it wobbled which is remedied with water-tape in between them.

4.1.9 Finalising the project

When the printer gave an satisfactory performance, all the electronics were placed and fixed. A finishing touch was provided to the printer.

4.2 System flow

The printing process goes through various phases. The figure 4.3 show a general process followed by a printing job.

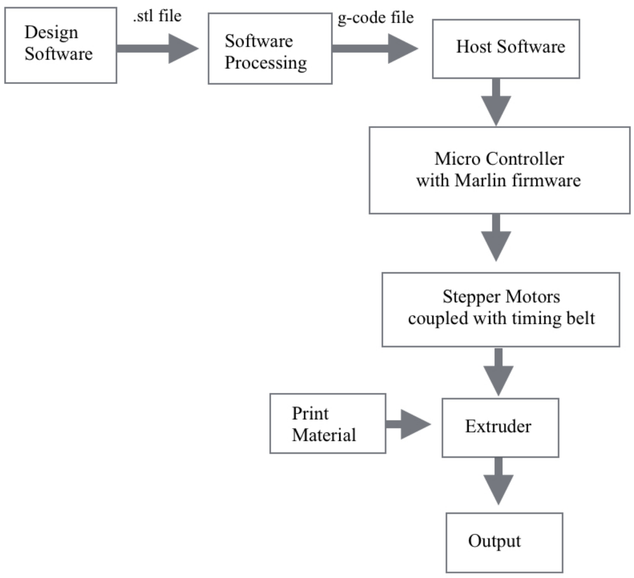

Figure 4.3: System Flow Diagram

4.2.1 Design Software

The object to printed has been first modeled in the design using various CAD tools like Belder , AutoCAD and Sketch App. Designs can vary from a simple cube to really complex ones. In this project Blender software has been primarily used for designing objects. The design has then been exported to a .stl (stereolithography) file which is later converted to resprective g-code.

4.2.2 Software Processing

In this project Slic3r software has been used to convert the *.stl* file design to Gcode. The software processing includes various parameters to be included in the Gcode. The specification of the motor, the nozzle size, the melting temperature of the printing material are to be included in the Gcode which is done using Slic3r. The parameters such as infill volume, number of solid layers and the layer width can also be defined. Similarly the infill types can also be choosen. This is critical to determine the print quality or the print speed of the printer.

4.2.3 Host Software

The g-code of the design can be readily printed using the printer, it requires a host software such as Cura and Pronterface. The Gcode file is uploaded to the host software. In this project Pronterface has been chosen as the host software because it provides features like real time control and monitoring of the printer and printing processes. The printing options includes the size of the object to be printed, the filling density, print quality, scaling of the model, the number of layers to be printed, the in-fill structure, etc. Host software convert the models into a series of digital cross-sections or layers, which the printer can use as a guide for printing the 3D shape. It also provide printer settings such as temperature control of the hotend and heatbed.

4.2.4 Microcontroller

Arduino Mega 2560 has been used to perform control function of this project. It has been first loaded with the Marlin firmware which contains various configuration files in which the setup of our printer has been defined. The configuration setup include length of parallel arms, offset values from center points defined in delta structure , expected print volume, thermal settings etc.

4.2.5 Stepper Motors and Driver

The stepper motors are responsible for the movement of the arms, the rotational movement of motor is converted to linear motion of the arms via timing belts and pulleys. The motors used in this device are bipolar stepper motors NEMA 17 it has been selected because it is a powerful motor, with the added advantage that it is capable of producing a very high resolution and is suitable for applications that require high precision. The stepper motor drivers feed the motors with power pulses and these pulses enable the motors to move through measured steps. Motor drivers A4988 made by Polulu has been chosen in this project because in addition to driving the motors they provide additional functionality of micro-stepping which helps the printer to be more precise.

4.2.6 Extruder

The printer requires a tool-head that extrudes the printing material. The working of the 3d Printer is same as the CNC machine, but instead, possesses an extruder instead of a cutter. The commands for this device are similar to the commands sent to a CNC machine. Extruder has been driven by the Pololu motor drivers A4988. It pinches the print mechanism to fetch the print material inside which is then heated to the point of semi-solidification and dispensed out of the nozzle.

4.2.7 Print material

In this project PLA is used as print material. It is the ink of the printer as the printed object is made of it. It can also be Polycarbonate or polymers like ABS Plus or may also be wax and ceramic. The materials available for 3D printing have come a long way since the early days of the technology. There is now a wide variety of different material types that are supplied in different states (powder, filament, pellets, granules, resin etc). Specific materials are now generally developed for specific platforms performing dedicated applications (an example would be the dental sector) with material properties that more precisely suit the application.

4.2.8 Output

The object is printed by extruding the semi-solidified printing material in layer by layer basis. The printer moves in the co-ordinated fashion to print out the material given as in the Gcode.

Thus the 3D print of the design of object is obtained following above design process..

4.3 System Model

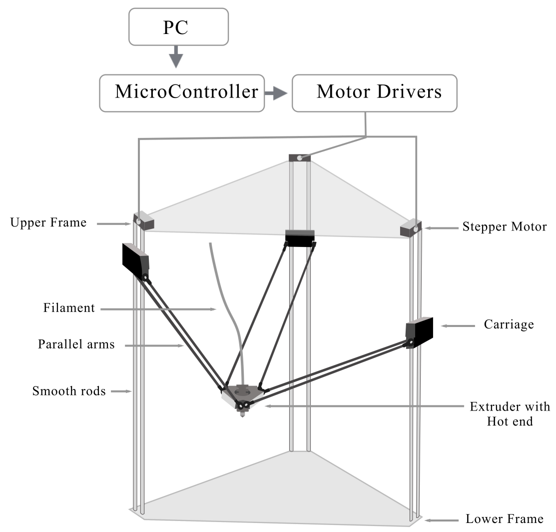

Figure 4.4: Model Diagram of 3D printer

The initial process of 3D printing a desired object is to make a design using computer software. The design is then exported in *.stl* file. The file is converted into Gcode. The Gcode is then uploaded to a host software. When the printer reads the designs in the form of Gcode. Motor drivers are sent appropriate signals by microcontroller and the movement of arms takes place according to the Gcode. The extruder controls the passage of the printing material filament which is melted by the hotend. Hence the layer by layer deposition of the material takes place in the printing base. The serial communication between host software and Arduino provides real time monitoring and control of the print that is being conducted.

A good output might takes hours to print, whereas speeding the printer might result in damaged output. So, a trade-off is made between the quality of the print and the speed. Optimum result can be obtained with proper calibration and design parameters.

4.4 Algorithm

The algorithm of printing an object with a 3D printer is as follows:

- Step 1 : Prepare the desired design in a CAD design software Blender.
- Step 2: Export the design as a .stl file .
- Step 3: Convert the .stl design to g-code using software like Slic3r .
- Step 4 : Export .gco or .gcode file from Slic3r.
- Step 5: Open host software Pronterface and connect the printer .
- Step 6: Upload the g-code file to host software like Pronterface .
- Step 7 : Print .
- Step 8: Obtain output.

Chapter 5
Epilogue

5.1 Problems Encountered and Solved

Some of the Problems faced during the project are:

1. **Use of Plywood as frame support material** Plywood was initially chosen as the support material for frame structure. As the work progressed it was found that plywood has lower density than required which brought problems like imperfections in drill holes and generally a frail structure. MDF was used which has properties high material density, sturdy and durable.

2. **Component failure** Components like the Arduino Mega board, A4988 Motor driver and Nema 17 Motor were found to be not working at various stages of the project. Some of them were faulty when provided to us and some were damaged during operation. They were tested for their and replaced as necessary.

3. **Motor and Driver testing** While running motor for operation many times some motors became unresponsive although the motor was smooth upon manual rotation, it was later found out that the problem was caused by motor driver failure. Care should be taken while installing motor driver chips. It is important to ensure the potentiometers are set to approximately 25% before applying power. Too much power if drawn from the motor will cause overheating so, use of heat sink is advised.

   Settings must be preconfigured in the marlin firmware (configuration.h and configuration adv.h files) before motors are run for the first time. X,Y and Z homing positions, arm length and printer floor height must be measured and updated in the firmware. To ensure that the motor driver is working properly the motor driver testing circuit must be implemented as presented in this report.

4. **Baud Rate** While preparing for the calibration, the connection between the host software and the Printer could not be established. With some careful study of

the firmware and the host software, it was found that the baud rate in the host software was differing from that of the baud rate defined in the firmware, which was 250000.

5. **Code alteration at different stages** The marlin firmware was uploaded to Arduino mega and program was run for the first time. Codes that were unnecessary to our current operation were bypassed. The code mainly included of LCD settings, Heat Bed and Hot end temperature sensor configuration and thermal settings. In the further stages of development all the necessary code was uncommented and reuploaded.

6. **Motor Jamming** Under high torque/load conditions there were numerous encounters of motors jamming and becoming stiff and unresponsive although the motor driver is working properly as verified from the driver test circuit. Upon examination by manual rotation it was found that there was some internal problem. The motor was opened and the underlying misalignment of the axis of rotor and stator was seen. The alignment was corrected, and mineral oil was applied to the contact points. In further operations the motor was not subjected to high levels of torque which might cause such misalignment.

5.2 Limitations of the project

This project can be improved with more time, resources and effort:

1. **Use of bushing instead of linear bearing** Linear bearing makes the smooth verticle movement of the carriage but due to the unavailability of the bearings bushings were used. Though the bushings provided a verticle movement it was not as smooth as it needed to be.

2. **Use of longer steel arms** The arms used were longer which decreased the printing volume of the printer. Also the arms were of steel which were heavier.

5.3 Conclusion

Based on the introduction, the main objective of this project has been the creation of a working prototype 3D printer with the implementation of the delta design. A working prototype of the 3D printer has been created. The delta design was implemented in this printer. The integration of the hardwares, electronics and the software, the printer can print objects when the geometric informations of the object is provided along with printing material.

5.4 Future enhancements

This 3D printer is still in the prototyping stage and has a lot of potential for future growth, the areas mainly include:

1. Extrusion of more than one material
2. An Unified software and User interface

Bibliography

[1] J. P. De Jong and E. De Bruijn, "Innovation lessons from 3-d printing," *MIT Sloan Management Review*, vol. 54, no. 2, p. 43, 2013.

[2] B. C. Gross, J. L. Erkal, S. Y. Lockwood, C. Chen, and D. M. Spence, "Evaluation of 3d printing and its potential impact on biotechnology and the chemical sciences," *Analytical chemistry*, vol. 86, no. 7, pp. 3240–3253, 2014.

[3] J. L. Irwin, J. Pearce, G. Anzolone, and D. Oppliger, "The reprap 3-d printer revolution in stem education," in *121st ASEE Annual Conference & Exposition*, 2014.

[4] H. Lipson and M. Kurman, *Fabricated: The new world of 3D printing*. John Wiley & Sons, 2013.

[5] R. Santos, J. James, T. Chris, S. Marshall, and P. Maalouf, "Deltronic solutions delta 3d printer," 2015.

[6] M. Haque, "Determination of nema design induction motor parameters from manufacturer data," *IEEE transactions on Energy conversion*, vol. 23, no. 4, pp. 997–1004, 2008.

[7] P. S. Heath, "3d printing; hardware and software for the consumer market," *International Journal of Students' Research in Technology & Management*, vol. 3, no. 8, pp. 440–444, 2015.

Appendix A

Component list

Table A.1: Component list

S.N.	SPECIFICATIONS	QUANTITY
Electronics		
1	Stepper motors (NEMA17)	4pcs
2	Ramps 1.4	1pc
3	A4988	4pcs
4	Arduino Mega2560	1pc
5	LCD 12864	1pc
6	Extruder MK8	1pc
7	Hot End(Bowden metal J-head)	1pc
8	Heat-bed	1pc
Mechanical		
9	M12 smooth rod	6 x 91cm
10	GT2 timing belt	3 x 6m
11	GT2 Pulley	6pcs

Appendix B

Gcodes and Mcodes

```
G0  Coordinated Movement X Y Z E
G1  same as G0
G2  CW ARC
G3 CCW ARC
G4 Dwell S<seconds> or P<milliseconds>
G28 Home all Axis
G90 Use Absolute Coordinates
G91 Use Relative Coordinates
G92 Set current position to cordinates given
M17 Enable/Power all stepper motors
M18 Disable all stepper motors; same as M84
M20 List SD card
M21 Init SD card
M22  Release SD card
M23  Select SD file (M23 filename.g)
M24  Start/resume SD print
M25 Pause SD print
M26  Set SD position in bytes (M26 S12345)
M27  Report SD print status
M28  Start SD write (M28 filename.g)
M29  Stop SD write
M30  Delete file from SD (M30 filename.g)
M31  Output time since last M109 or SD card start to serial
M42  Change pin status via gcode
M80  Turn on Power Supply
M81  Turn off Power Supply
M82  Set E codes absolute (default)
M83  Set E codes relative while in Absolute Coordinates (G90) mode
M84  Disable steppers until next move, or use S<seconds> to specify
    an inactivity timeout, after which the steppers will be
   disabled. S0 to disable the timeout.
M85  Set inactivity shutdown timer with parameter S<seconds>. To
   disable set zero (default)
M92  Set axis_steps_per_unit - same syntax as G92
M104  Set extruder target temp
M105  Read current temp
M106 Fan on
M107  Fan off
M109  Wait for extruder current temp to reach target temp.
M114  Display current position
M114  Output current position to serial port
```

```
M115  Capabilities string
M117  Display message
M119  Output Endstop status to serial port
M140  Set bed target temp
M190  Wait for bed current temp to reach target temp.
M200  Set filament diameter
M201  Set max acceleration in units/s^2 for print moves (M201 X1000
     Y1000)
M202  Set max acceleration in units/s^2 for travel moves (M202 X
   1000 Y1000) Unused in Marlin!!
M203  Set maximum feedrate that your machine can sustain (M203 X200
     Y200 Z300 E10000) in mm/sec
M204  Set default acceleration: S normal moves T filament only
   moves (M204 S3000 T7000) im mm/sec^2 also sets minimum segment
   time in ms (B20000) to prevent buffer underruns and M20 minimum
   feedrate
M205  Advanced settings: T=travel only, minimum travel speed S=
   while printing B=minimum segment time X= maximum xy jerk, Z=
   maximum Z jerk, E=maximum E jerk
M206  Set additional homeing offset
M220  S<factor in percent> set speed factor override percentage
M221  S<factor in percent> set extrude factor override percentage
M240  Trigger a camera to take a photograph
M301  Set PID parameters P I and D
M302  Allow cold extrudes
M303  PID relay autotune S<temperature> sets the target temperature
   . (default target temperature = 150C)
M400  Finish all moves
M500  Stores paramters in EEPROM
M501  Reads parameters from EEPROM (if you need reset them after
   you changed them temporarily).
M502  Reverts to the default "factory settings". You still need to
   store them in EEPROM afterwards if you want to.
M503  Print the current settings (from memory not from eeprom)
M999  Restart after being stopped by error
```

Appendix C

Schematics of Ramps 1.4

.