PROJECT REPORT

ON

"3D-PRINTER"

B.TECH- IV (ELECTRONICS & COMMUNICATION)

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CERTIFICATE

This is to certify that candidate **Mr. RATHAUR OMKAR SINGH, Mr. SHUBHAM GARG, Mr. ANURAG JAIN, and Mr. AKHIL GOYAL** bearing **Roll Nos: U11EC029, U11EC069, U11EC087, and U11EC119** of **B.TECH IV, 8TH Semester** has successfully and satisfactorily presented UG Project Preliminary & submitted the Report on the topic entitled "**3D-PRINTER**" for the partial fulfilment of the degree of Bachelor of Technology (B.Tech) in **May. 2015**.

Guide: ______________

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ACKNOWLEDGEMENT

It gives me great pleasure to present my seminar report on **“3D-PRINTER”**. No work, big or small, has ever been done without the contributions of others.

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Last but not the least I would like to thank lab assistant who allowed me to use the Desktop Computer to accumulate the resources and use the lab property in case of emergency.

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ABSTRACT

The population of the world would be raised around 8.9 to 10.9 billion till 2050 and it is predicted by frank appeal that the world would have customized lifestyles in 2050. Self-made, self-tailored design and customization would be the trend in the society. Mass producing companies and uniformity in the society would be lost. So, it requires the revolution in current 3D printing technology.

Current 3D printing technologies are no doubt very accurate but are very costly and bulky too. So, here we propose an affordable 3D printer which can be built under rupees 30,000. It has inherited the optimized and best mechanisms from the current technologies. This printer has great modularity and functionality so that any new feature can be added in future, moreover wide range of printing material and colours are available these days. Generally, ABS and PLA are used for the 3D printers due to their low melting point and high tensile strength. Currently we are using PLA polymer for printing the material because of various reasons discussed in this report.

Currently we are facing some challenges in printing objects which extends in x and y axes more than the dimensions of its base layer.

We are looking to use nylon as printing material, multiple colour printing items in future but it requires major changes in the process of extrusion which requires new mechanical design and high setup cost.

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Chapter 1: INTRODUCTION

3D printing is a form of additive manufacturing technology where a three dimensional object is created by laying down successive layers of material. It is also known as rapid prototyping, is a mechanized method whereby 3D objects are quickly made on a reasonably sized machine connected to a computer containing blueprints for the object. The 3D printing concept of custom manufacturing is exciting to nearly everyone. The technology for printing physical 3D objects from digital data was first developed by Charles Hull in 1984. He named the technique as Stereo lithography.

1.1 Literature Review

Now, we will discuss the current 3D printing technologies available in the market. We will each of them in detail.

1.1.1 Stereo lithography

Stereo lithography is an additive manufacturing or 3D printing technology used for producing models, prototypes, patterns, and production parts up one layer at a time by curing
a photo-reactive resin with a UV laser or another similar power source. It makes for great surface quality and build accuracy [1].

A moveable table, or elevator, is placed initially at a position just below the surface of a vat filled with liquid photopolymer resin. This material has the property that when light of the correct colour strikes it, it very quickly turns from a liquid into a solid. The most common photopolymer materials used require an ultraviolet light, but resins that work with visible light are also available. Most stereolithography systems are sealed to prevent the escape of vapour from the resin as indicated by the dashed line. The vapour is potentially harmful and there is also typically some odour associated with the resin.

A laser beam is moved over the surface of the liquid photopolymer to trace the geometry of the cross-section of the object. This causes the resin to harden in areas where the laser strikes.

The laser beam is moved in the *X*-*Y* directions by a scanner system.These are very fast and highly-controllable motors which drive mirrors that paint the laser beam over the surface.

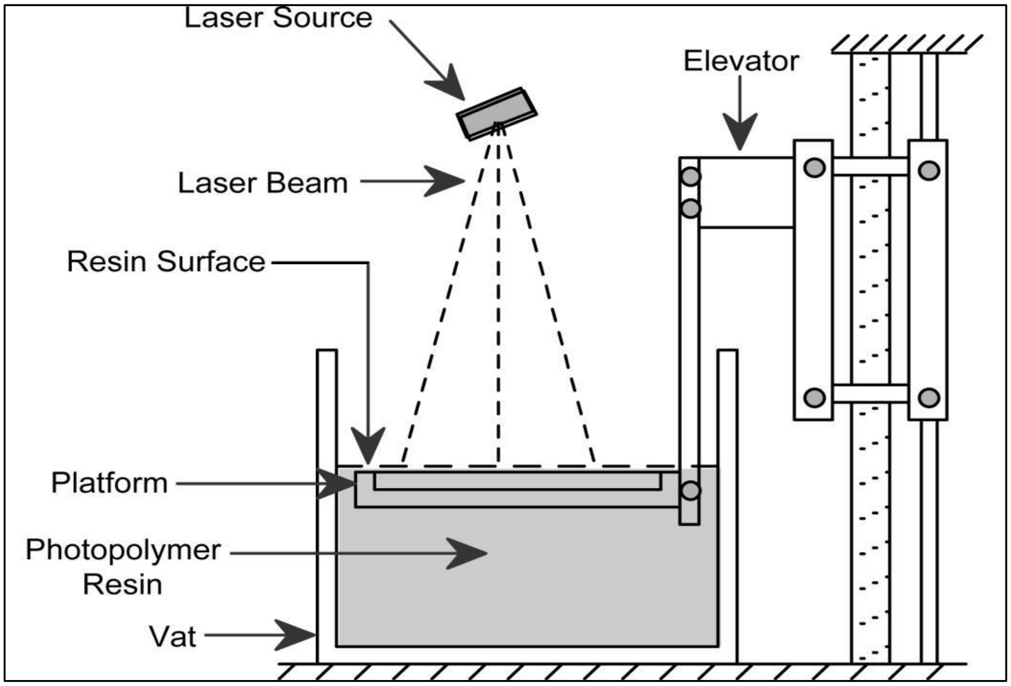

Figure -1.1: Layout of Stereo Lithography [1]

A laser isn't the only way to expose and harden a photopolymer. An increasingly popular way to do that is by using a conventional light source, such as an arc lamp, in conjunction with a liquid crystal display panel or a deformable mirror device (DMD). These so-called spatial light modulators expose an entire layer of photopolymer at one time.

The motors are guided by information from the CAD data that describes the cross section of the object that's being made. The exact pattern that the laser traces is a combination of this basic geometric information and added information from the machine's internal software that optimizes the accuracy of the fabricated object by compensating for errors, such as shrinkage. A great deal of work over the years has gone into optimizing this exposure technique [2].

After the layer is completely traced and for the most part hardened by the laser beam, the table is lowered into the vat by a distance equal to the thickness of one layer. To speed this process of recoating, early stereolithography systems drew a knife edge (E) over the surface to smooth it [3].

1.1.2 Fused deposition modelling

Fused deposition modelling (FDM) is an additive manufacturing technology commonly used for modelling, prototyping, and production applications. FDM works on an "additive" principle by laying down material in layers; a plastic filament or metal wire is molten, unwound from a coil and laid down in layers to produce a part. This is the most seen 3d printing method, as most inexpensive machines use this method. A plastic filament, approximately 1/16 inch in diameter, is unwound from a coil and supplies material to an extrusion nozzle. Some configurations of the machinery have used plastic pellets fed from a hopper rather than a filament. The nozzle is heated to melt the plastic and has a mechanism which allows the flow of the melted plastic to be controlled. The nozzle is mounted to a mechanical stage which can be moved in both horizontal and vertical directions. Some manufacturers take an opposite approach and move the table instead [4].

As the nozzle is moved over the table in the required geometry, it deposits a thin bead of extruded plastic to form each layer. The plastic cools and hardens immediately after being squirted from the nozzle and bonds to the layer below. In professional-level systems, to prevent warping of parts the entire mechanism is contained within a chamber which is held at a temperature just below the melting point of the plastic. Thus, only a small amount of additional thermal energy needs to be supplied by the extrusion nozzle to cause the plastic to melt. This provides much better control of the process. Basic machines may simply use a heated table [5].

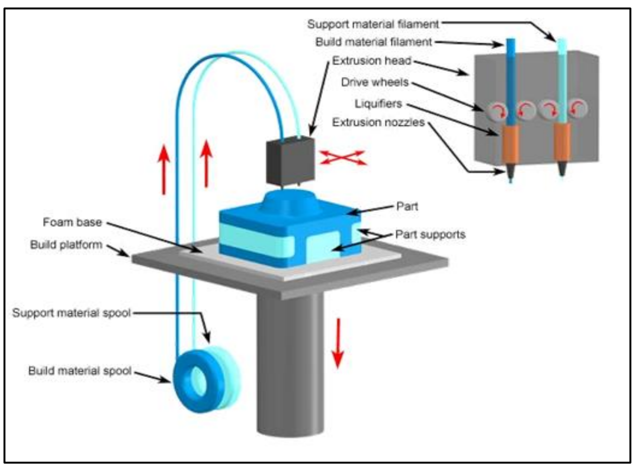

Figure 1.2: Model of Fused deposition modeling [4]

1.1.3 **Selective laser sintering** (SLS)

Selective Laser Sintering (SLS) is an additive manufacturing technique that uses a laser as the power source to sinter powdered material (typically metal), aiming the laser automatically at points in space defined by a 3D model, binding the material together to create a solid structure. When a layer is finished, the build platform moves down and an automated roller adds a new layer of material which is sintered to form the next cross section of the object. Repeating this process builds up the object one layer at a time. SLS includes sintering of both thermoplastic and metal powders. SLS is a relatively new technology that so far has mainly been used for rapid prototyping and for low-volume production of component parts. SLS is both a cost and time effective technology, making it ideal for prototyping and end use manufacturing [6].

In Selective Laser Sintering (SLS), a laser beam is traced over the surface of a tightly compacted powder made of thermoplastic material. The powder is usually spread by a counter-rotating roller over the surface of a build cylinder, although other methods are also used. A piston moves down one object layer thickness to accommodate the layer of powder.

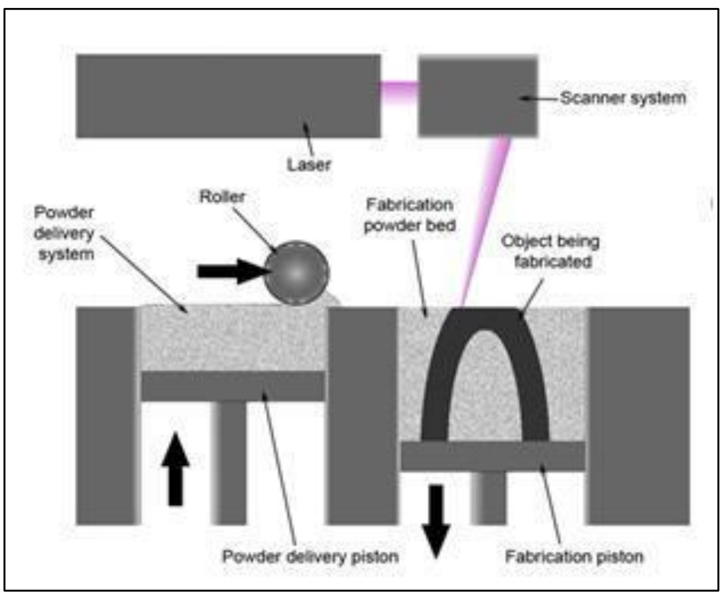

Figure 1.3: Design of Selective laser sintering [6]

The laser beam is moved in the *X*-*Y* directions by a scanner system. These are very fast and highly-controllable motors which drive mirrors that paint the laser beam over the surface of the compacted powder in the build chamber. The laser selectively fuses the powder in the form of the cross section of the object.

The laser used provides a concentrated infrared heating beam. The entire fabrication chamber is sealed and maintained at a temperature just below the melting point of the plastic powder. Thus, heat from the laser need only elevate the temperature slightly to cause sintering, greatly speeding the process. A nitrogen atmosphere is also maintained in the fabrication chamber which prevents the possibility of explosion in the handling of large quantities of powder.

After the object is fully formed, the piston is raised to elevate the object. Excess powder is simply brushed away and final manual finishing may be carried out. That's not the complete story, though. It may take a considerable time before the part cools down enough to be removed from the machine. Large parts with thin sections may require as much as two days of cooling [7].

1.2 Working Principle of 3D printer

3D Printers are the machines that produce physical 3D models from digital data by printing layer by layer. There can be two method of giving model to Printer. First is using a CAD program like AUTOCAD and other method is designed by us. In this we are planning to feed the point cloud data collected by the Xtion Pro live sensor and processing this with Intel Atom Processor Board and sending the command to the printer.

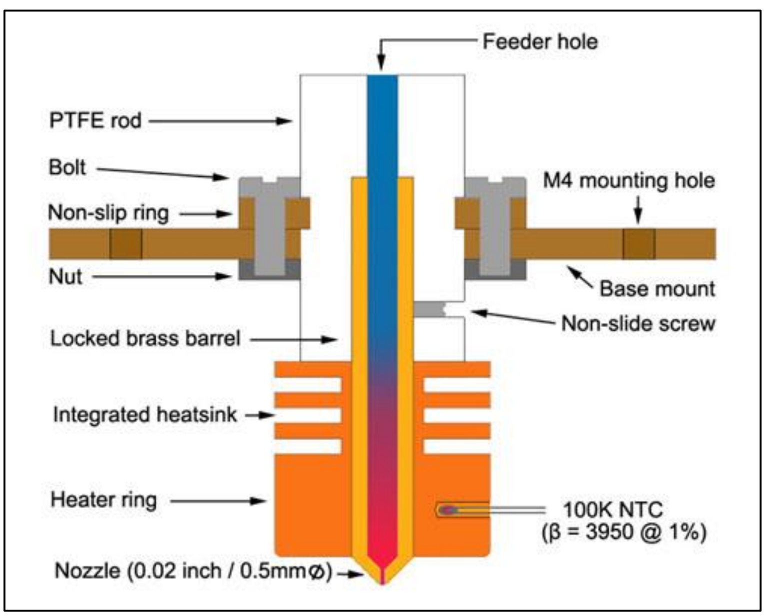

Figure 1.4: Current Prototype [7]

We have seen above the working of various different 3D printer technologies, what we have done is, we have taken the best out of all technologies. It consists of three axis X, Y and Z axis, in earlier technology laser was being used, but here we used a simple copper hot end for extruding the material from the nozzle (0.75mm). Hot end is heated continuously so that the plastic can melt and come out of the nozzle.

Three axis develops a cartesian coordinate system so that extruder can be moved anywhere in the region between 20x10x20 cuboid. Commands to the motors are given from the laptop in form of motor understandable language (G-Code). It is discussed in detail in chapter 4. Now, according to the G-code motors move to print the 3D-model.

1.3 Motivation

Fused Deposition Modeling 3D printer cost around $10K-100K and availability of color and material is also limited. No, doubt about Stereo lithography accuracy but it comes at very high cost parts. Complete printer comes at the cost of $800K. Moreover all this printers are not at all portable due their large sizes [8], [9].

So, we got idea of building up our own 3D printer under Rs. 30,000. Printer should have modularity, choice of material and low power consumption. This printer have modularity so that any new feature can be added in future, moreover wide range of printing material's color are available. Generally, ABS and PLA are used for the 3D printers due to their low melting point and high tensile strength.

1.4 Report Organization

We have already seen the highly accurate current technologies. In second chapter, we will deal with the mechanical design aspects. Apart from it we will comparison between different materials that can be used for printing. In Third chapter we will look towards the heart of 3D printer i.e. Electronics parts required for building this up. We will start from microcontroller and will end up with power supply.

In Fourth chapter we will look at the algorithms involved in printing along with the software (On

PC side) used for sending commands, making 3D model and generating G-Code for the 3D model. In fifth we will discuss about various features that we have added to this printer. Finally we have concluded and proposed future aspects for 3d printer.

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Chapter 2: Mechanical design and other aspects

2.1 Block Diagram of 3-D Printer:

This is complete block diagram of Desktop 3D printer which includes various interfaces such as Display unit, Stepper motor driver, temperature sensor (thermistor) and five stepper motor.

This chapter deals with various mechanical design of X-axis, Y-axis and Z-axis of 3D printer. It explains the extruder working, mechanism of motion for all the Axis.

Next chapter deals with electronics aspects of 3D printer which includes motor control of all the motors. It also deals with the Display Panel Unit.

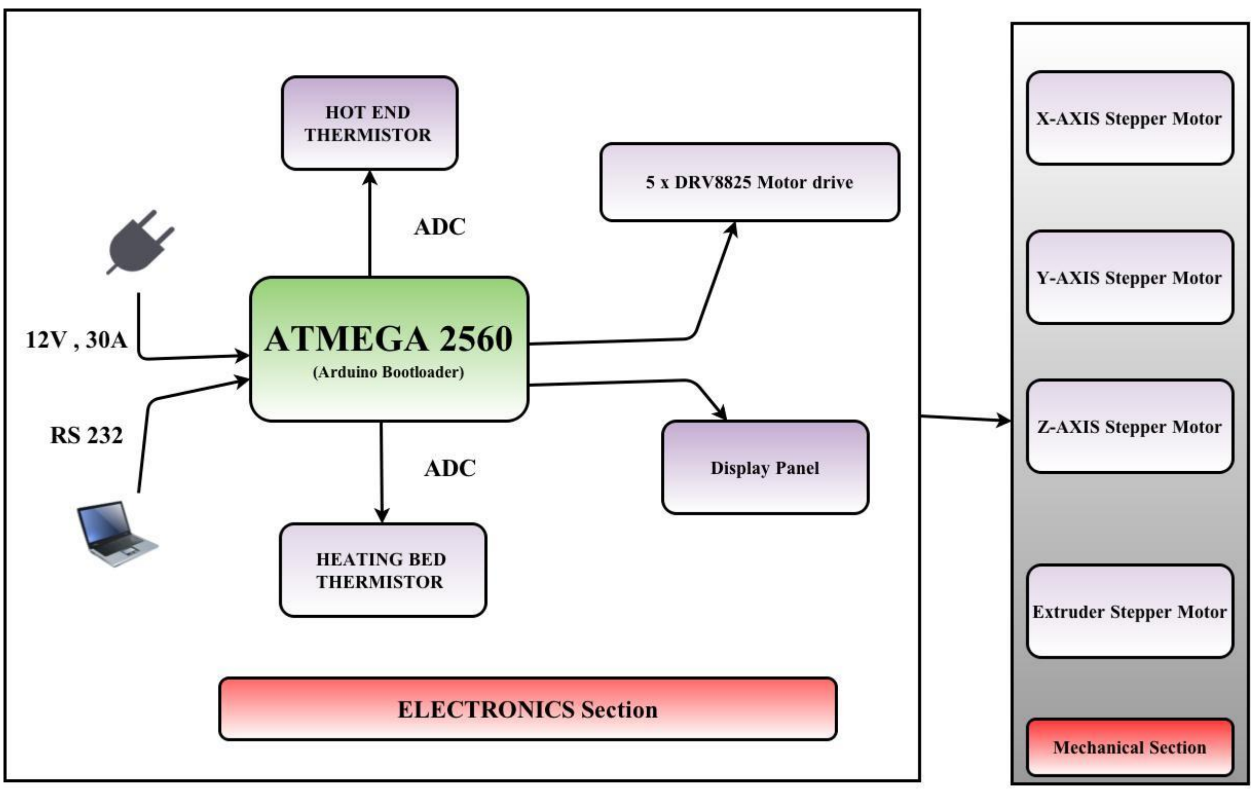


Figure 2.1: Block diagram of 3D printer

2.2 X, Y and Z axis

When it comes to the mechanical body, it can be generally broken down into two parts:

1. Movement along the X, Y and Z axes.
2. The print bed

When facing the front of a our prototype as shown in Fig 2.1, X axis movement is side to side, left to right movement, Y axis movement is forwards/backwards movement and Z axis movement is up and down along the vertical plane is shown in Fig2.2.

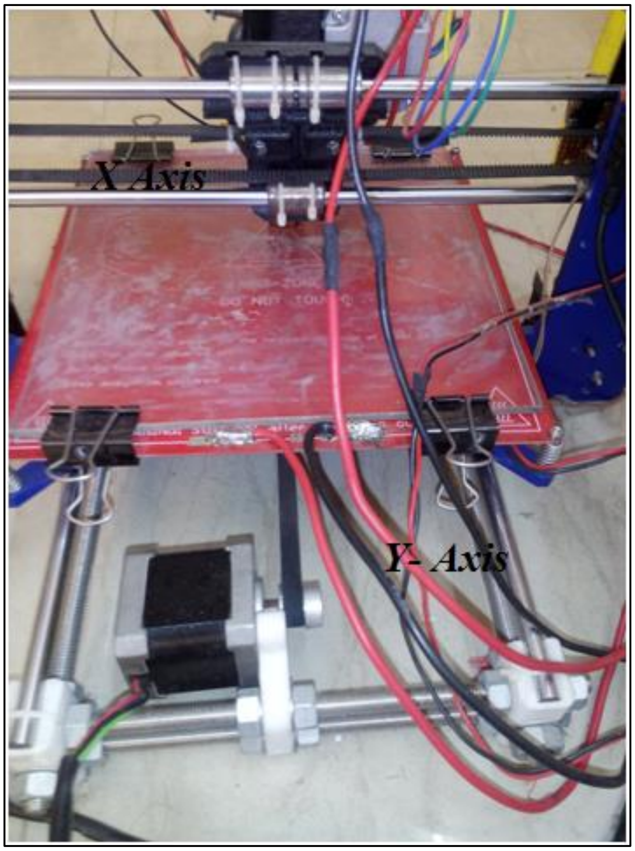


Figure 2.2: X-axis and Y-axis of 3D printer

Linear movement is generally accomplished using belt/pulley driven motion. Belts and pulleys are good for fast/lightweight movement and threaded rods are good for slow but forceful movement. We are using a combination of belts for X/Y axis movement and threaded rod for Z axis movement.

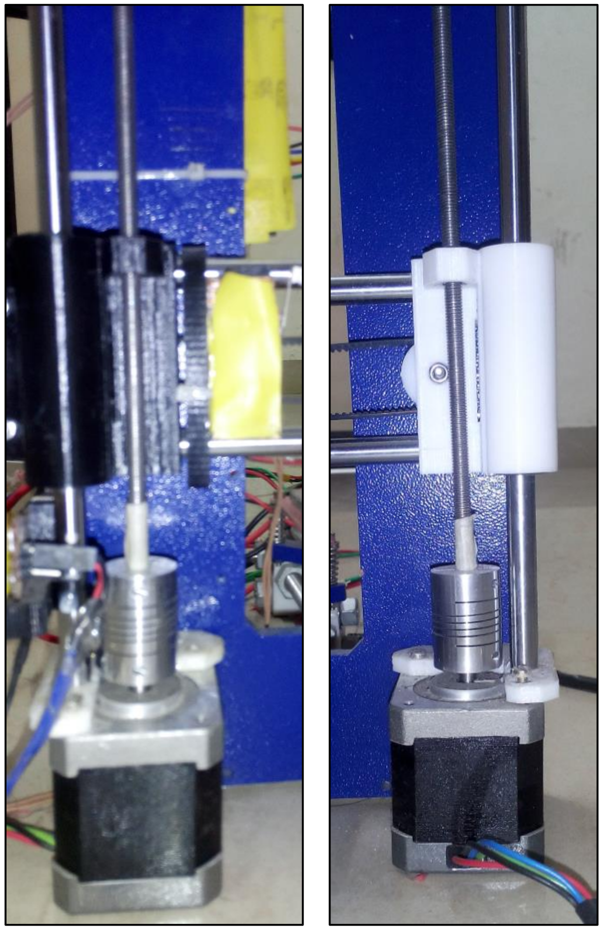


Figure 2.3: Z-axis of 3D printer

2.3 Heating Plate

A flat metal sheet is required as a build surface (with or without tape) and as a heat spreading device. Since most of the metal have high thermal conductance, a metal sheet will spread heat evenly. Metals can expand quite a bit when heated, so if the metal sheet is not allowed to expand on the heated bed, it can bow and damage the prints. Bowing can also occur if the edges of the metal sheet cool faster than the center, so sheets larger than the heater are not recommended. The thinner the sheet, the more prevalent the bowing can be.

The specific heat (this can be thought of as how fast a material heats up and cools) can be vary different for different metals. Aluminum, for example, has a low specific heat and will heat and cool very quickly. Steel and copper have a much higher specific heat and take a lot longer to heat up or cool down. There are advantages and disadvantages to high and low specific heats, so with various hit and trial we have decided to use the copper metal plate as heating bed. While it doesn't change the specific heat of the material itself, thicker sheets of metal will also hold their heat longer.

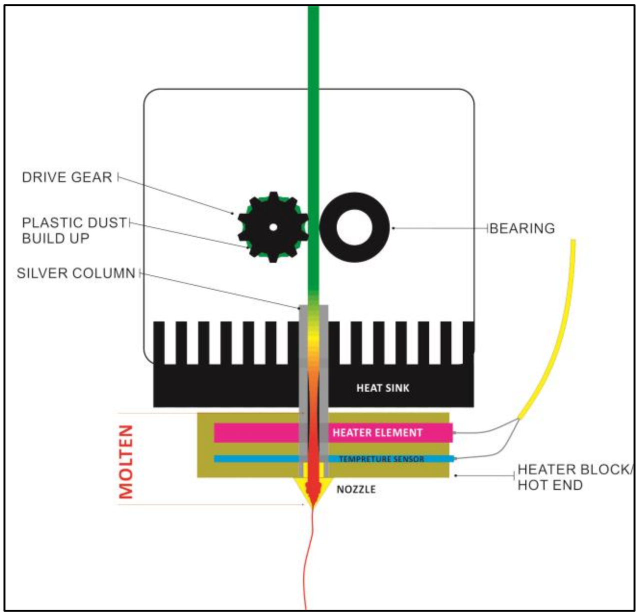
2.4 Extrusion

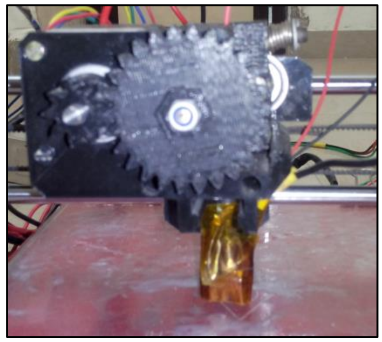
3D Printer extruder has the following components:

- Stepper Motor: Used to drive the plastic material into the hot end.
- Drive Gear: Bites into the plastic and pushes it down with some force into the hot end.
- Bearing and Cover: The bearing is to allow the filament to be passed through easily.
- Heat sink & fan: This keeps the top part of the silver column cool, to ensure the filament remains solid and rigid in order to push down onto the molten filament below.
- Silver Column: This is attached to the heat sink and guides the filament into the nozzle.
- Nozzle: Screwed into the Hot End / Extruder Block
- Heater Block/Hot End: Heated up to 195 degree Celsius and monitored by the temperature sensor (thermistor).

Theory of plastic extrusion 3D Printing:

1. The filament is pushed down by the drive gear, pushing the filament into the hot end.
2. Because the extruder gets very hot, the heat easily travels up the silver column and would soften the filament. However we don't want that to happen.
3. The fan blows cold air onto the heat sink, so the heat sink deflects the heat from the upper part of the silver column and the filament stays rigid.
4. The rigid filament pushes down on the molten filament and also creates a pressure or force on the molten filament, thus extruding it out of the tiny hole in the nozzle.
5. Without this pressure or force, we would not be able to print. The model or platform slightly blocks the nozzle during printing, thus a fair amount of force is required to extrude during printing and hence the filament is squished out flat onto the model or platform [10].





(a) (b)

Figure 2.4: (a) General Mechanism of Extrusion [11] (b) Extruder of our prototype

2.5 GT-2 Pulley and Belt

When it comes to accuracy, the most important part is belt/pulley combination. Current we are using the GT2 belt, along with a machined pulley that matches the exact bore size of Nema 17 stepper motors (normally it is 5mm) [11].

Timing Belt Specifications:

- Material: Neoprene, fiberglass reinforced
- Tooth profile: GT2
- Pitch: 2mm (0.08in)
- Number of grooves: 582 - Pitch length: 1164mm (45.83in)
- Belt width: 6mm (0.24in)

Timing Pulley Specifications:

- Material: Polycarbonate, fiberglass reinforced, brass insert
- Tooth profile: GT2
- Pitch: 2mm (0.08in)
- Number of grooves: 36

- Max. belt width: 6mm (0.24in)
- Bore diameter: 5mm (0.20in)

Figure 2.5: GT2 pulley and pulley[11]

2.6 Chemistry Related with 3D Printer

There are two printing materials available for 3d printers, we are going to discuss about both of them in brief here. Let us start with ABS material.

The printing temperature guideline for printing with ABS filament is approximately 235°C to 256°C. It is necessary to use a heated print bed when printing ABS. ABS has a tendency to warp, which makes it a difficult material to print without a heated print bed. Ideally we need to set print bed temperature at approximately 80° to 110 ° C. ABS will bend under too much heat, so after the first few layers, it's best to turn down the print bed temperature a bit. So, we have seen that ABS requires high temperature for both the heat (printing) bed and hot end. Hence, we have used PLA by compromising with some amount of tensile strength.

The printing temperature for printing with PLA filament is approximately 210°C. PLA has much less tendency to warp compared to ABS. Therefore it can be printed both with and without a heated print bed. But many times it becomes necessary to set print bed temperature to approximately 40° to 50° C. A good first layer adhesion is of the utmost importance in obtaining the best results for prints. There are several tricks to get the first layer of PLA print to stick better to the print bed of the 3D printer.

We tried following two ways during testing phase for better adhesion but failed, third way worked well.

- Kapton Tape: ABS print stick better to polyimide tape than to the print bed. So, we tried it using with PLA polymer but failed after 2~3 cm height of the printing material, the object detached from the heating bed.
- Blue Masking Tape: PLA prints usually stick really well to blue masking tape. But in our case blue masking tape was unable to stick the printing material properly, it was performing better at very high heating bed temperature but we want the working temperature of our printer to be low.
- And we tried something new, we mixed fevicol with water and made a layer of it on borosilicate, now the first layer is properly sticking to the borosilicate even for 15~20 cm of Z-axis. But still one problem is remaining to solve, after completion of the printing it is difficult to remove the printed material from the surface of borosilicate (It sticks so well). Right now we using water sprays for removing it from the surface. So, now it becomes necessary to add the fevicol and water mixture every 4~5 prints.

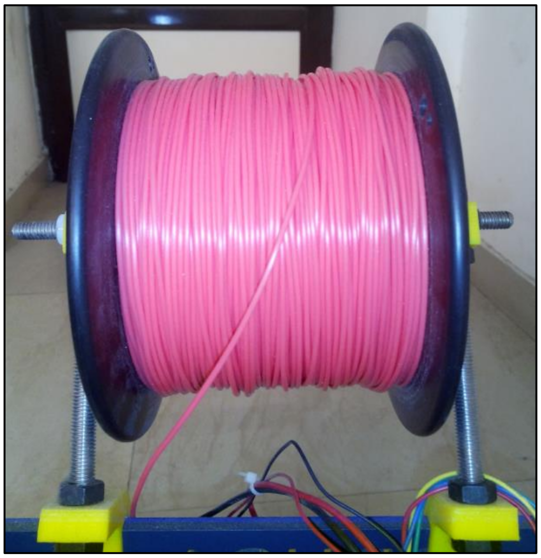


Figure 2.6: Arrangement of PLA ROLL on printer

2.7 <u>Calibration of Prototype:</u>

Calibration is the collection of mechanical "tweaking" processes needed to get exact, quality prints. Even if we have worked best as far as the electronics are concerned, calibration is still necessary to have well printed parts.

Without calibration, prints may not be of the correct dimensions, they may not stick to the build surface, and a variety of other not-so-wanted effects can occur.

Once we have built our prototype, calibration is the next big hurdle. Trying to print before calibration will likely result in a messy "blob" smeared over the printer bed.

Note that calibration is an ongoing process that needs to be performed throughout the life of the printer. There are almost always adjustments and tweaks that can be done to improve print quality.

We started working with each axis in turn. We started with the x axis end stop. Pronterface will send commands to move each of the axis in small increments in both directions.

We send command to move x-axis by 10mm, ideally it should move exactly 10mm but it move some less more than 10mm. Similarly the measurements can be done for y-axis.

Then we started testing our endstop whether they are working or not. We manually closed x axis endstop and other endstops and checked if motor were stopping or not.

Bed leveling was one more challenge in front of us. To level the print bed so that our objects will adhere to the surface. The result of this step has made the extruder nozzle the exact same height above the bed across the entire bed surface.

If bed remained unleveled plastic will adhere only to certain part of the bed but not everywhere. The extruder nozzle might "dig" into parts of the bed, pulling up or deforming the bed surface.

Importance: The first layer of the print is the foundation of all subsequent layers. A bad first layer could mean the part might peel off of the print bed during the print, "blobs" of plastic may form, causing problems in following layers, and a variety of other things.

The final result of the calibration has been added in the code using this three lines

```
#define DEFAULT_AXIS_STEPS_PER_UNIT   {160,160,8000,570}

#define DEFAULT_MAX_FEEDRATE  {500,500,2,25}

#define DEFAULT_MAX_ACCELERATION {180,180,10,200}
```

Chapter 3: Electronics of 3D printer

3.1**Arduino Mega 2560**

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started [12].

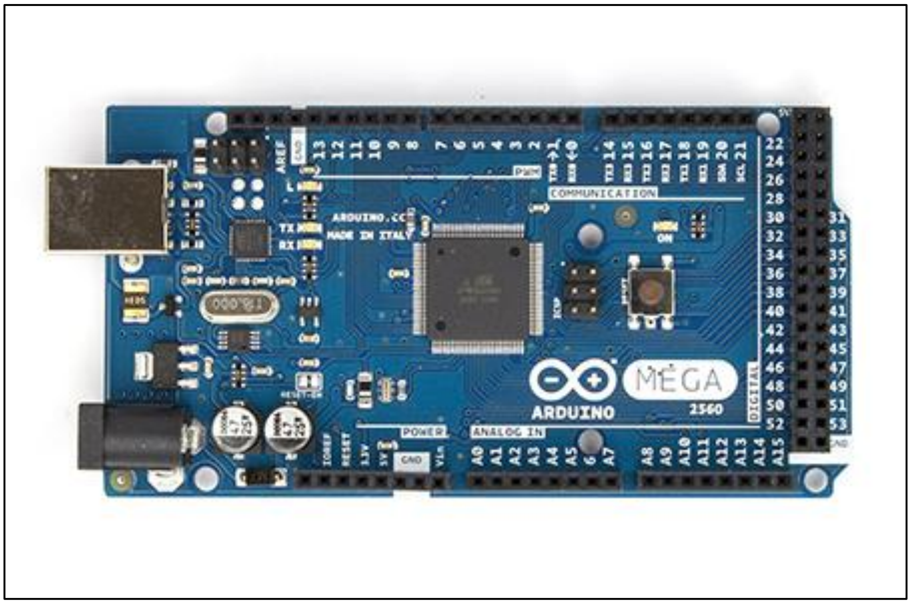


Figure 3.1: Arduino 2560 Mega

The stepper motors are connected directly to the motor driver. We can connect up to 5 stepper motors, 1 for each axis, except for the Z-axis, which allows two stepper motors to be connected.

Motor driver DRV8825 is receiving command from the Atmega2560 microcontroller.The thermistors are connected to the ADC pins for reading heated bed and extruder temperature.

Three End stops are connected directly to the interrupt pins of Atmega2560, so that as each can move in its limit. Currently our shield on the Arduino board is receiving the Command from the computer regarding the movement of the motors. We will be each and every in details in this chapter.

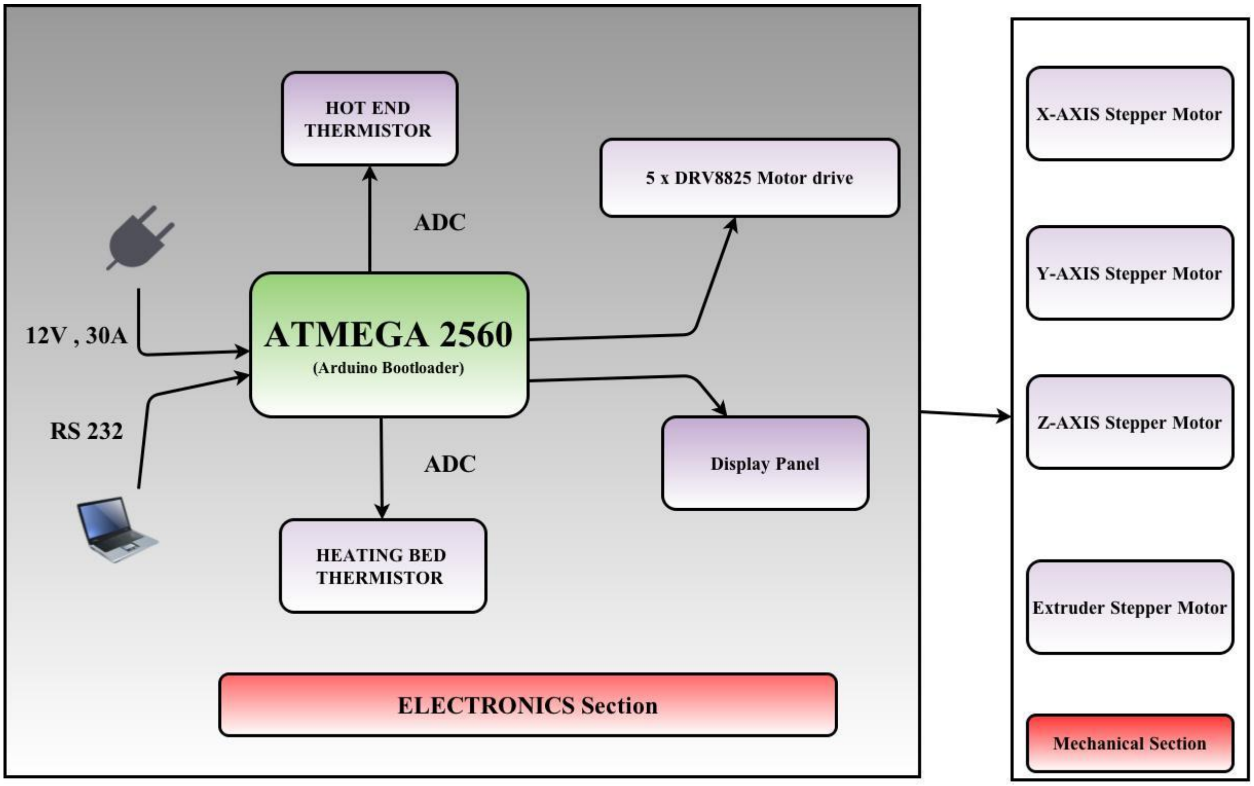


Figure 3.2: Block diagram of 3D printer

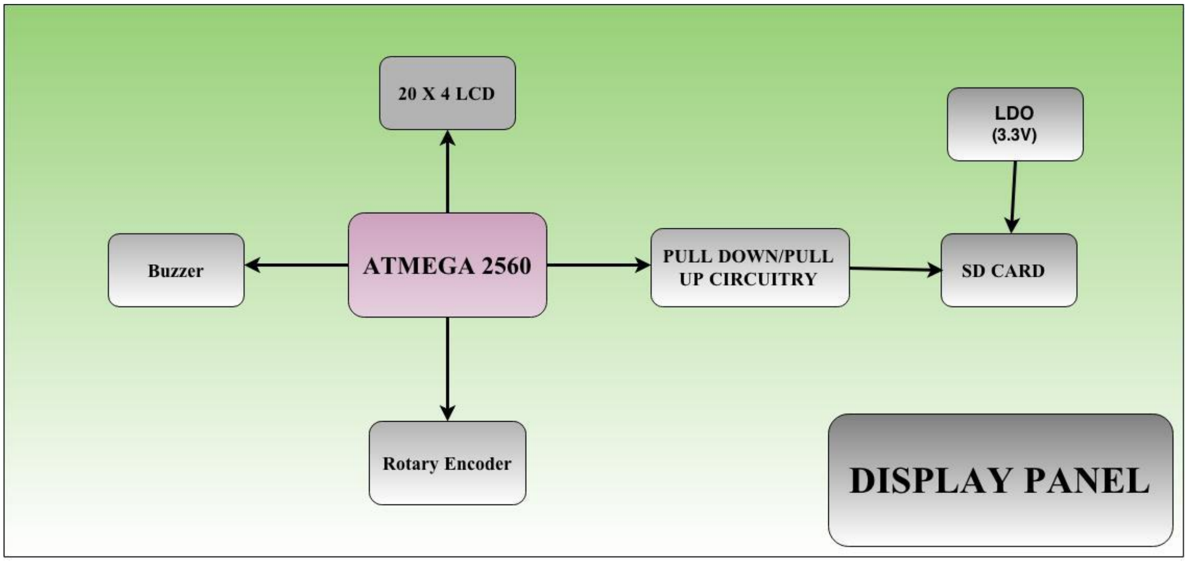


Figure 3.3: Block diagram of Display Panel

3.2 Stepper Motor

A stepper motor (or step motor) is a brushless DC electric motor that divides a full rotation into a number of equal steps. The motor's position can then be commanded to move and hold at one of these steps without any feedback sensor (an open-loop controller).

There are two basic winding arrangements for the electromagnetic coils in a two phase stepper motor: bipolar and unipolar.

3.2.1 Unipolar Motor

A unipolar stepper motor has one winding with center tap per phase. Each section of windings is switched on for each direction of magnetic field. Since in this arrangement a magnetic pole can be reversed without switching the direction of current, the commutation circuit can be made very simple (e.g., a single transistor) for each winding. Typically, given a phase, the center tap of each winding is made common: giving three leads per phase and six leads for a typical two phase motor. Often, these two phase commons are internally joined, so the motor has only five leads.A micro controller or stepper motor controller can be used to activate the drive transistors in the right order.

3.2.2 Bipolar Motor

Bipolar motors have a single winding per phase. The current in a winding needs to be reversed in order to reverse a magnetic pole, so the driving circuit must be more complicated, typically with an H-bridge arrangement. There are two leads per phase, none are common.Static friction effects using an H-bridge have been observed with certain drive topologies. Dithering the stepper signal at a higher frequency than the motor can respond to, will reduce this "static friction" effect.Because windings are better utilized, they are more powerful than a unipolar motor of the same weight. This is due to the physical space occupied by the windings. A unipolar motor has twice the amount of wire in the same space, but only half used at any point in time, hence is 50% efficient (or approximately 70% of the torque output available).

Due to above reasons we have used NEMA 17 bipolar motors. This 4-wire bipolar stepper has 1.8° per step for smooth motion and a nice holding torque. The motor was specified to have a max current of 2000mA so that it could be driven easily driven by DRV8825

Some technical specification of NEMA 17:

- 200 steps per revolution, 1.8 degrees
- Coil #1: Red & Yellow wire pair. Coil #2 Green & Brown/Gray wire pair.
- Bipolar stepper, requires 2 full H-bridges
- 4-wire, 12 inch leads
- 42mm/1.65" square body
- 31mm/1.22" square mounting holes, 3mm metric screws (M3)
- 5mm diameter drive shaft, 24mm long, with a machined flat
- 12V rated voltage at 2000mA max current
- 28 oz*in, 23 N*cm, 2 Kg*cm holding torque per phase
- 1.3 ohms per winding [13].

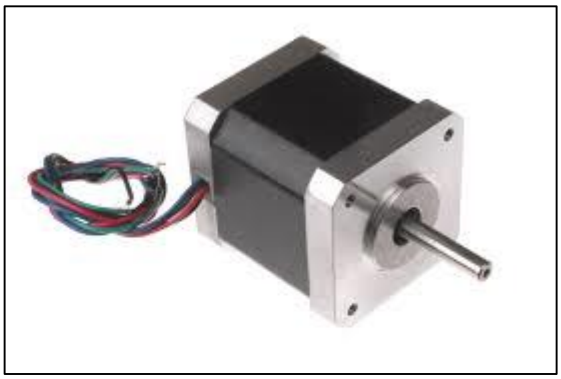


Figure 3.4: NEMA-17 Stepper motor

3.3 <u>DRV8825 motor driver</u>

The DRV8825 is an integrated motor driver solution for bipolar stepper motors. The device integrates two NMOSH-bridges, current sense, regulation circuitry, and a microstepping indexer. The DRV8825 can be powered with a supply voltage between 8.2 and 45 V and is capable of providing an output current up to 2.5 A full-scale. A simple STEP/DIR interface allows for easy interfacing to the controller circuit. The internal indexer is able to execute high-accuracy microstepping without requiring the processor to control the current level. The current regulation is highly configurable, with three decay modes of operation. Depending on the application requirements, the user can select fast, slow, and mixed decay. A low-power sleep mode is included which allows the system to save power when not driving the motor.

The current through the motor windings is regulated by a fixed-frequency PWM current regulation, or current chopping. When an H-bridge is enabled, current rises through the winding at a rate dependent on the DC voltage and inductance of the winding. Once the current hits the current chopping threshold, the bridge disables the current until the beginning of the next PWM cycle [14].

In stepping motors, current regulation is used to vary the current in the two windings in a semi-sinusoidal fashion to provide smooth motion.

The PWM chopping current is set by a comparator which compares the voltage across a current sense resistor connected to the xISEN pins, multiplied by a factor of 5, with a reference voltage. The reference voltage is input from the xVREF pins.

The full-scale (100%) chopping current is calculated using equation 3.1.

$$\mathrm{I_{chop}} = \mathrm{xVref}/(5 * \mathrm{R_{isense}}) \qquad 3.1$$

Stepper motors typically have a step size specification (e.g. 1.8° or 200 steps per revolution), which applies to full steps. A microstepping driver such as the DRV8825 allows higher resolutions by allowing intermediate step locations, which are achieved by energizing the coils with intermediate current levels. For instance, driving a motor in quarter-step mode will give the 200-step-per-revolution motor 800 microsteps per revolution by using four different current levels. The resolution (step size) selector inputs (MODE0, MODE1, and MODE2) enable selection from the six step resolution. All three selector inputs have internal 100kΩ pull-down resistors, so leaving these three microstep selection pins disconnected results in full-step mode. For the microstep modes to function correctly, the current limit must be set low enough (see below) so that current limiting gets engaged. Otherwise, the intermediate current levels will not be correctly maintained, and the motor will skip microsteps.

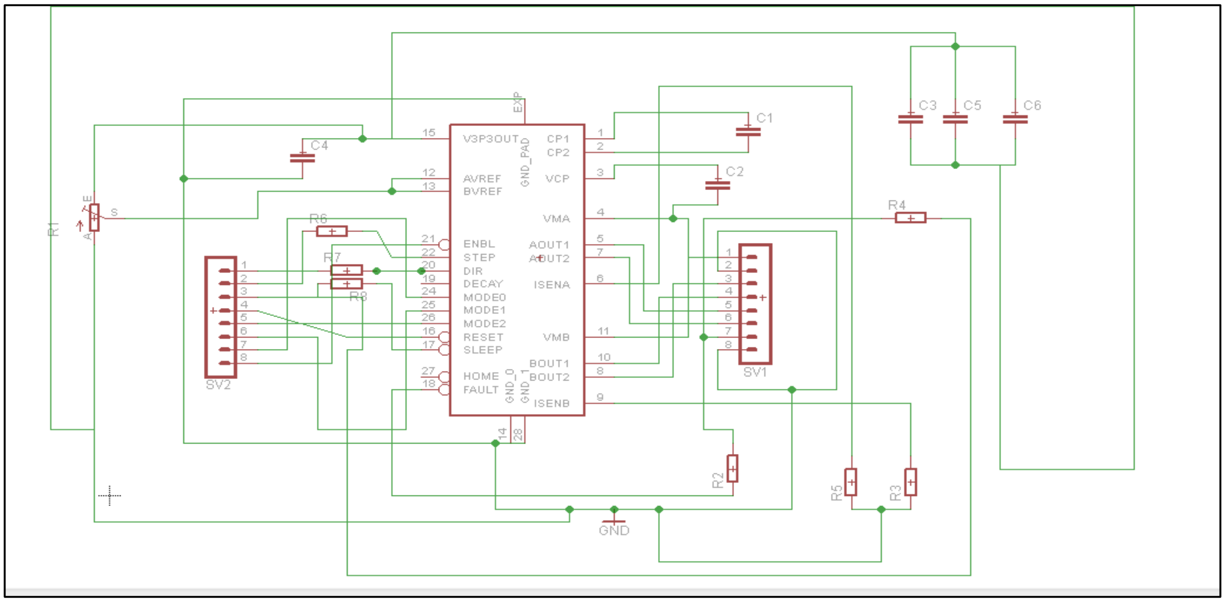


Figure 3.5: Schematic of DRV8825

Each pulse to the STEP input corresponds to one microstep of the stepper motor in the direction selected by the DIR pin. These inputs are both pulled low by default through internal 100kΩ pull-down resistors. If we just want rotation in a single direction, we can leave DIR disconnected. The chip has three different inputs for controlling its power states: RESET, SLEEP, and ENBL. For details about these power states, see the datasheet. Please note that the driver pulls the SLEEP pin low through an internal 1MΩ pull-down resistor, and it pulls the RESET and ENBL pins low through internal 100kΩ pull-down resistors. These default RESET and SLEEP states are ones that prevent the driver from operating; both of these pins must be high to enable the driver (they can be connected directly to a logic “high” voltage between 2.2 and 5.25 V, or they can be dynamically controlled via connections to digital outputs of an MCU). The default state of the ENBL pin is to enable the driver, so this pin can be left disconnected.

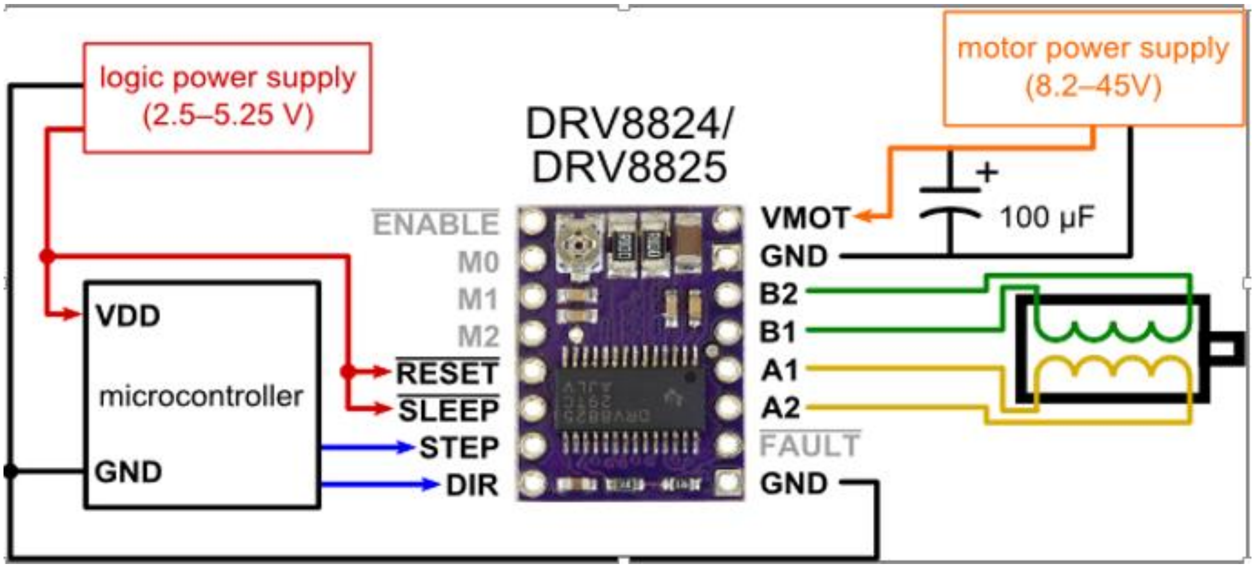


Figure 3.6: Block diagram of Motor Driver

To achieve high step rates, the motor supply is typically much higher than would be permissible without active current limiting. For instance, a typical stepper motor might have a maximum current rating of 1 A with a 5Ω coil resistance, which would indicate a maximum motor supply of 5 V. Using such a motor with 12 V would allow higher step rates, but the current must actively be limited to under 1 A to prevent damage to the motor.

The DRV8825 supports such active current limiting, and the trimmer potentiometer on the board can be used to set the current limit. If we will typically want to set the driver's current limit to be at or below the current rating of our stepper motor. One way to set the current limit is to put the driver into full-step mode and to measure the current running through a single motor coil without clocking the STEP input. The measured current will be 0.7 times the current limit (since both coils are always on and limited to approximately 70% of the current limit setting in full-step mode) [15].

3.4 Thermistor

We have used a thermistor which senses the temperature of the Hot End and Printing bed. Thermistors are resistors that change of resistance with a change in temperature. Good qualities of thermistors are a predictable, accurately known resistance value at every temperature in its operating range. The lowering, or rise, depends on the type of thermistor per degree Kelvin this is called its coefficient. Positive thermal coefficient (PTC) will increase in resistance with an increase in temperature, negative ones (NTC) will decrease. But the formula in practice is not linear, so sometimes an accurate table of measurements is better than the linear formula. We got below measurements from the datasheet the thermistor.

We cannot directly measure resistance. To test the resistance, we can put a voltage on a wire and see how much current will run. Another alternative is to use it together with another resistor of a known value, and measure the potential (or voltage) between the resistors.

Suppose we have two resistors between 0 and 5V. The two resistors are R2 = 4.7K Ohm at the 5V side and R1=1K Ohm at the ground side. The two resistors act as what is known as a voltage divider. Between the resistors, the voltage is based on the ratio of the two resistances. If we have the 5V power source turned on, this means that the voltage will be: 5V – (5V * 4700/(4700+1000)) = ~ 0.88 V. This is also the voltage we would measure at the R2 + R1 junction with a multimeter/voltmeter. If we add a resistor to the mix that changes strongly with a change in temperature, this will affect the value of the voltage divider and the resulting voltage in between. This is because two parallel resistors of which one changes resistance, the total resistance of the total resistance will change as well.

If the thermistor R_{th} is connected between the ground (0 Volts) and the middle of the two resistors, the value of resistance between the middle junction and the ground will be based on the following formula:

$$R_{pair} = 1 / (1/R1 + 1/R_{th}) = 1 / (1/1000 + 1/R_{th}) \tag{3.2}$$

The ADC in Atmega 2560 measures Vout as the fractional voltage between its reference voltage Vref (in our caseVref=Vcc) and 0V, expressed as a count of steps (commonly 0 to 1023) at the resolution of the ADC (commonly 1024 or 10 bits.)

As a ratio, the voltage difference is:

$$Vout/Vcc = R_{pair}/(R2+R_{pair}) \tag{3.3}$$

Our code typically uses a table of values mapping an ADC voltage count to a temperature in Celsius. One could create this table manually by measuring the temperature of the sensor and reading the count from the ADC, or by measuring the temperatures and corresponding voltages (Vout) and calculating the 1024*Vout/Vref [16].

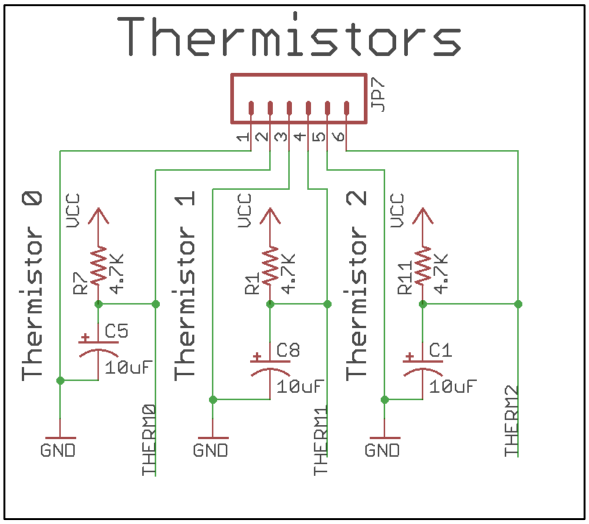


Figure 3.7: Schematic of Thermistor

3.5 <u>Mechanical End-Stop</u>

For our home position we wanted the bed (Y-Axis) all the way back, the X-Axis to the left and the Z-Axis all the way down - this makes the print head home on the front left of the heat bed. To do this the X-Axis end-stop goes on the left side of the X-Axis, the Y-Axis end-stop goes at the back of the printer and the Z-Axis end-stop goes on the bottom left.

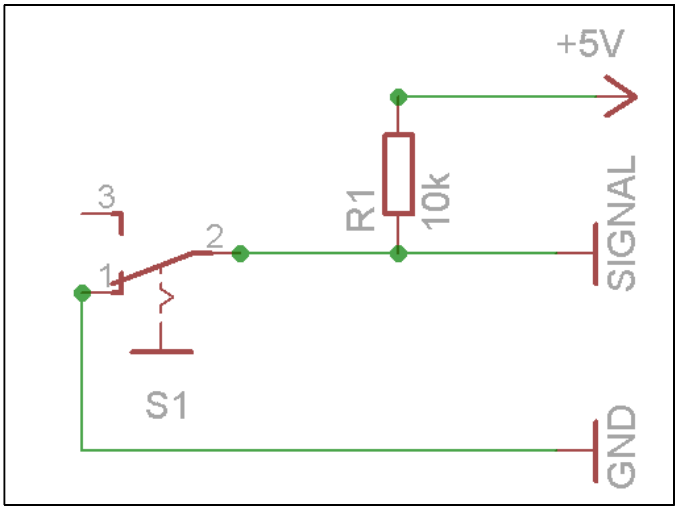


Figure 3.8: Schematic of End Stop

We need a normally closed (NC) switch which connects two poles when not triggered. (A single pole double throw (SPDT) switch will work, if we wire up to the NC side of the switch -- ignore the NO pin). For the z axis, high resolution and high repeatability is needed. The x and y axis resolution is not that important, unless we home the machine during a print.

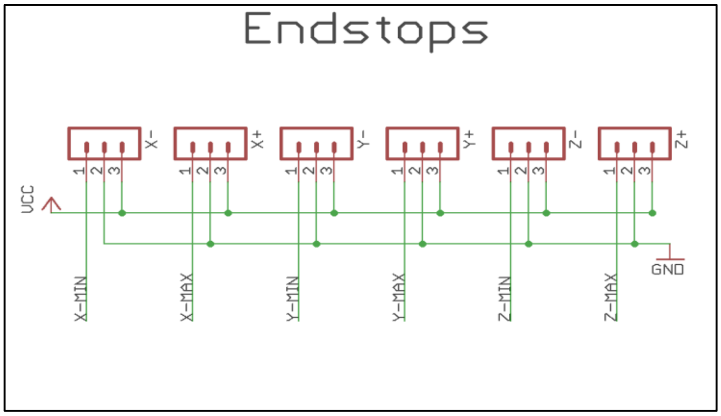


Figure 3.9: Interfacing of End Stop with microcontroller

3.6 <u>Power Supply</u>

5 Stepper motors each pulling 2 to 2.5A of current (i.e 12.5A) and heating bed carries 5~6 A of current. The extruder hot end for melting the material draws about 1~2A. In whole printer about 18~19 A current is drawn. We can see that this printer requires very high current for its operation. So, we are using high quality ripples free power supply module which can give upto 12 volt, output Power is 350 watts and output current upto 30 A. It works on 220V AC supply.

Figure 3.10: Power supply

3.7 Interfacing SD Card with Microcontroller

The microcontroller runs on 5V power supply with a built in crystal frequency of 8 MHz, that read a file from the FAT32 file system of the SD card.[17]

SD CARD MODULE:

The SD card is consisting of two basic semiconductor sections, a '**Memory core**' and a '**SD card controller**'.

The 'memory core' is the flash memory region where the actual data of the file is saved. When we format the SD card a file system will be written into this region. Hence this is the region where the file system exists [17].

The 'SD card controller' helps to communicate the 'memory core' with the external devices like microcontrollers. It can respond to certain set of standard SD commands and read or write data from the memory core in for the external device[17].

The capacity of the 'memory core' is referred to as the size of the SD card. Other than the 'memory core' there are certain registers associated with the 'SD card controller'. These registers store the status of the SD card. The contents of these registers are read only[17].

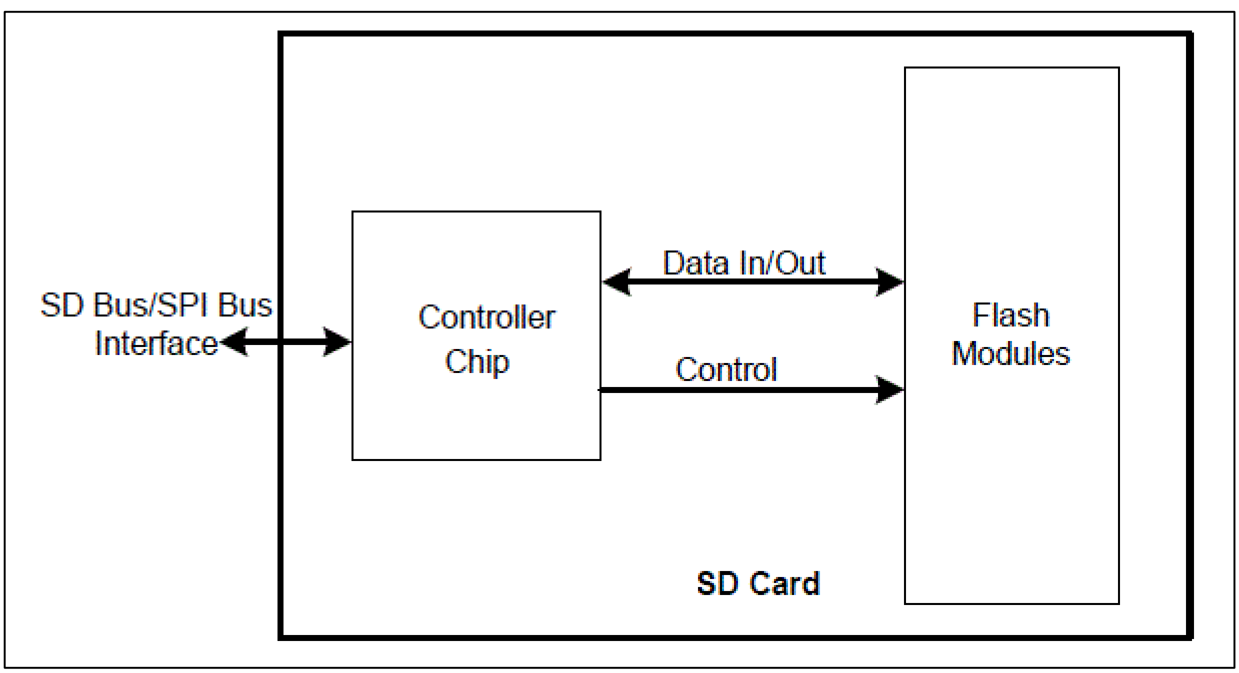


Figure 3.11: SD Card[17]

The SD card can be interfaced with the microcontroller using serial data bus. It can connect using ‘SD buses’ or ‘SPI buses’. The ‘SD bus’ is designed for high speed whereas the SPI bus can operate with much lower speed only. The microcontroller can read or write data the memory core and read the registers using standard SD commands send through these serial buses[17].

3.8 Interfacing Buzzer with Microcontroller:

Buzzer is used many times in embedded systems. For an instance-Digital clock with an alarm-here buzzer can be used an alarm or a fire alarm or an intruder alarm.[18]

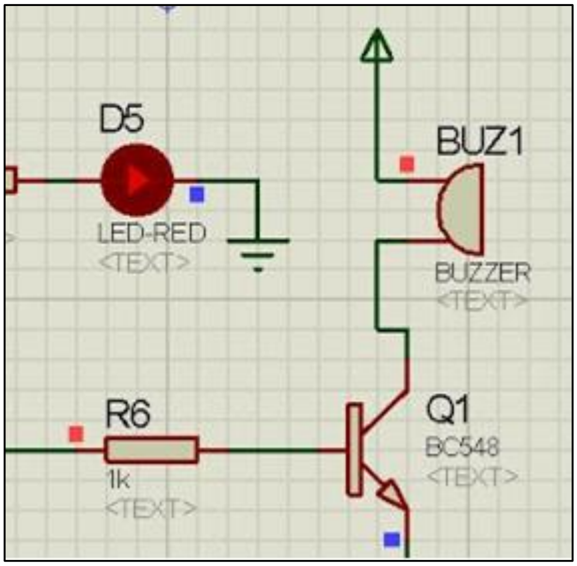


Figure 3.12: Buzzer Model[18]

3.9 Interfacing LCD 20x4 with Microcontroller:

As we all know LCD (Liquid Crystal Display) is an electronic display which is commonly used nowadays in applications such as calculators, laptops, tablets, mobile phones etc[19].

Connecting the LCD to an AVR which support external SRAM mode (e.g. AT90S8515, ATMega) is easy and allows to access the LCD module using simple read/write instructions [19].

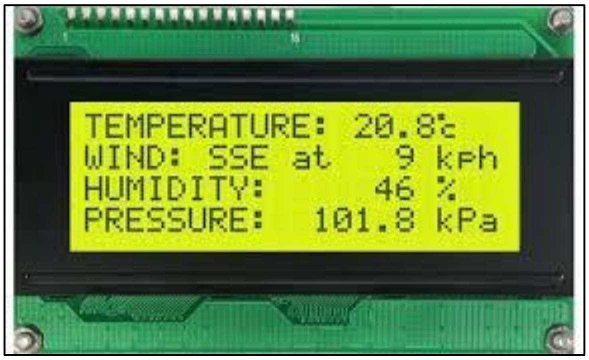


Figure 3.13: 20x4 LCD Display[19]

The main difference is that the data transfer to/from the LCD controller is initiated using a single Enable pulse, the read or write mode must be selected before with the R/W signal. The AVR uses separate signals to initiate read or write data transfers. The RD signal is used to initiate a read from the external device, while the WR signal initiates a write to an external device[19].

Using the above circuit, the following addresses must be used to access the LCD:

Table 3.1: LCD Addresses[19]

Mode	LCD register	Address
write	LCD data register	0xC000
write	LCD instruction register	0x8000
read	LCD data register	0xC100
read	LCD instruction register	0x8100

3.10 Interfacing rotary encoder with Microcontroller:

Interfacing of rotary encoders is simple – only three wires are required to connect to microcontroller (two for signal (quadrature outputs) and one for reference (GND)).

When turned there is a Grey code produced on outputs that allows tracking turn speed and direction. These features allow having convenient user interface with single knob. Many rotary encoders also comes with button – so menu navigation couldn't be easier. In our project we are going to use a 12-step mechanical rotary encoder [20].

Figure 3.14: Rotary Encoder[20]

Here, one of rotary encoder pins is connected to microcontroller interrupt pin. This enables easier detection of encoder turn. Using endless loop isn't recommended because it occupies lots of MCU resources and is inefficient [20].

Another logical solution is to use Timer that periodically generates interrupts so it could check if rotary encoder have been turned or button have been pressed [20].

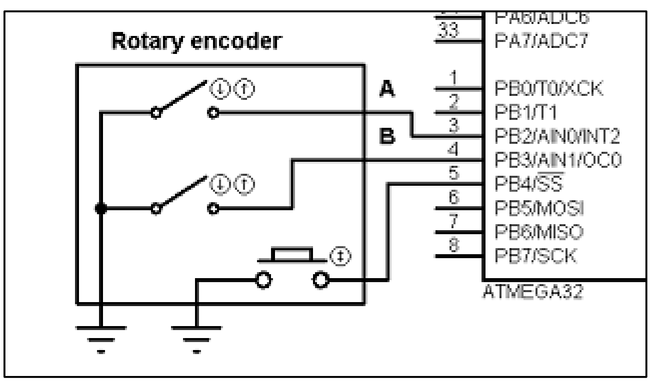


Figure 3.15: Rotary Encoder Interfacing[20]

Chapter 4: Software Tool chain

4.1 Software Toolchain

The software toolchain can be roughly broken down into three parts:

1. CAD tools.
2. CAM tools.
3. Firmware for electronics.

4.1.1 CAD tools

CAD tools in the truest sense are designed to allow easily change and manipulate parts based on parameters. Sometimes CAD files are referred to as parametric files. They usually represent parts or assemblies in terms of Constructive Solid Geometry. Using CSG, parts can be represented as a tree of boolean operations performed on primitive shapes such as cubes, spheres, cylinders, pyramids, etc.

Free/Libre/Open Source Software (*FLOSS*) applications that fall into this category would be OpenSCAD, FreeCAD and HeeksCAD and more. Examples of proprietary and fully parametric CAD tools are PTC Creo (formerly PTC ro/Engineer), DassaultSolidworks, Autodesk Inventor and more.

We are currently dealing with Autodesk student version software for building 3D object models. Typically in such programs the geometry is stored in a feature tree where the dimensions can be modified numerically, and the geometry is then regenerated with great precision. The geometry is a mathematical representation where, for example, a circle is generated from its center, radius and plane parameters. No matter how much we zoom in, a circle is still curved, and the CAD program has no problem finding its center when we click on it. This can be quite beneficial when making drawings with dimensions between the circle and sections that need to be concentrically removed.

Some of the tools mentioned above can also use parametric data to generate the geometries, but a lot just register the positions of the vertices of the polygons making up the models. Some use parameters to generate the geometry but then drops that data once the vertices are placed. A curve is thus actually an approximation, generated from a number of straight lines between points. As such, those tools are better suited for design where the precision of dimensions are less important than looks and ease of use.

If we want to print the object with as less possible material as possible; design parts optimised by volume in function of strains, or we can use topology optimization through non-commercial-use-only software such as Topostruct, BESO, or free-open-source-use such as Topy, a topology optimization software writen in Python by the brillant William Hunter .

There are very few interchangeable CAD file formats. The two most widely used interchangeable CSG file formats are STEP and IGES. Both strip the geometries from parametric data and offer only "dead" solids. Features can be added and removed, but the base shape is locked.

The most widely used interchangeable mesh file format is STL. STL files are important because, as we will see below, they are used by CAM tools. Mesh files cannot be converted into CSG file formats because they contain no parametric data - only the coordinates of the polygon vertices that make up the solid volume. However, CSG file formats can be converted into mesh file formats.

Thus, if we are designing a part, we will design it using a CSG CAD application and save and distribute its original parametric file along with generated STL files.

4.1.2 CAM Tools

In order to turn a 3D part into a machine friendly format, CAM software needs an STL file. The machine friendly format that is used for printing is called G-code. To Convert STL files to G-code, we are using Slic3r.

Slic3r is the tool we need to convert a digital 3D model into printing instructions for 3D printer. It cuts the model into horizontal slices (layers), and generates toolpaths to fill them and calculates the amount of material to be extruded. After we have G-code file, we have to run it through a G-code interpreter. This reads each line of the file and sends the actual electronic signals to the motors to tell the how printer should move. There are two main G-code interpreter options:

1. A workstation program called pronterface which controls the hardware directly or
2. The firmware on arduino board(electronics platform) with an integrated hardware interface that has a G-code interpreter

   Currently we are using Pronterface software for controlling our hardware but we are looking further to remove the complete dependency of the software from our prototype.

To send the G-code files to an integrated hardware interpreter, we can follow two ways:

1. Load the G-code file on an memory card (typically SD card) if supported.
2. Drip-feed the G-codes (usually a line at a time) over a serial port (RS-232 with a USB converter) or a direct USB connection using one of the following programs on the workstation.

Currently we are following second way for sending the commands to the motors. We are looking forward to add SD card interfacing in next semester.

4.1.3 Firmware for Electronics

Electronics are controlled by an inexpensive CPU such as the Atmel AVR processor.

Slic3r can find curves that, although broken into segments, were meant to describe an arc. Our code is able to print those arcs. The advantage of our code is that it can choose the resolution, and can perform the arc with nearly constant velocity, resulting in a nice finish. Also, less serial communication is needed.

To reduce noise and make the PID-differential term more useful, 16 ADC conversion results are averaged while calculating the heat bed and hot end temperature.

If found the PID values of the acceleration and max-velocities and it is unique for every machine. We can set them, and finally store them in the EEPROM. After each reboot, it will magically load them from EEPROM, independent what changes we make in the code.

If an endstop is hit while moving towards the endstop, the location at which the our code thinks that the endstop was triggered is outputted on the serial port. This is useful, because the user gets a warning message. This are some of the instruction send from the serial terminal to the Printer.

- G1 - Coordinated Movement X Y Z E
- G28 - Home all Axis
- G30 - Single Z Probe, probes bed at current XY location.
- G90 - Use Absolute Coordinates
- G91 - Use Relative Coordinates
- G92 - Set current position to coordinates given

Chapter 5: Extension towards Desktop 3D Printer

5.1 Current Features

Our design can act as a desktop 3d printer which can work without computer interface. We have built a smart display which contains a SD-Card reader, a rotary encoder and a 20 Character x 4 Line LCD display. We have it connected to our Atmega2560 microcontroller board.

We don't need any computer any more, the Smart displays supplies power for our SD card. Further more all actions like calibration, axes movements can be done by just using the rotary encoder on the Smart Display. We can print our 3D designs without PC, just with a g-code design stored on the SD card.

5.1.1 Preliminary stage of LCD display

Our hardware can support a LCD and card-reader combination. It will enable us to tune temperatures, accelerations, velocities, flow rates, select and print files from the SD card. Preheating, disabling the steppers, and doing other fancy stuff can also be done in the real time. For true autonomous printing, we need to connect a 12V fan near the extruder.

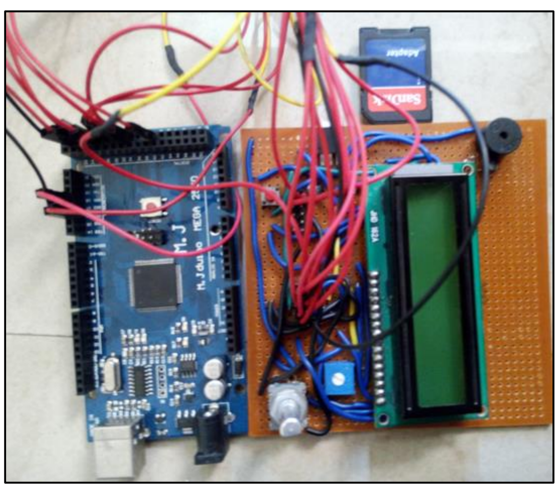


Figure 5.1: Initial Setup of Display panel

5.1.2 Preliminary stage of SD card module

If we have an SD card reader attached to our microcontroller. SD Card interfaces to Atmega 2560 using SPI communication. For testing of our board, we have written a small test program which will continuously try to detect SD card. If it succeeds, it will print information about the card. We have designed our own pcb for the sd card interfacing as Fig 5.1.

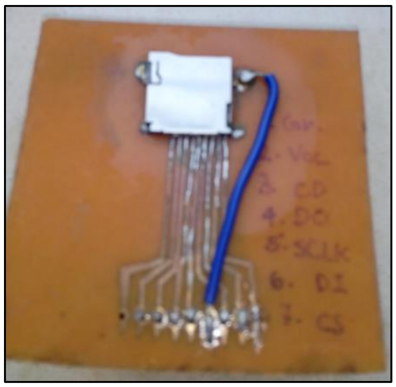


Figure 5.2: SD Card Module

5.2 Various functionalities of display panel

Fig 5.3 screen displays the heating bed and J-hot end temperature, and along with it gives the x, y and z location of the extruder in real time.

Figure 5.3: Final Screen after the heating process is over

It also provides the real time printing status. A timer is being used to continuously monitor the duration required for printing the object.

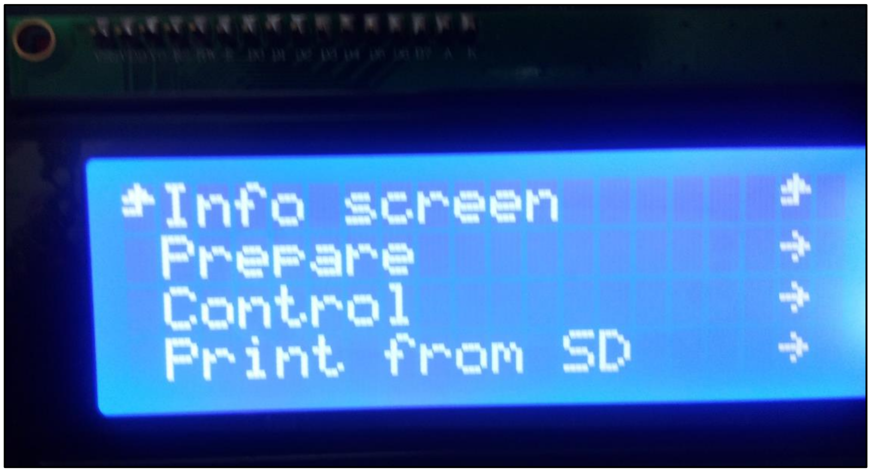


Figure 5.4 : Main four functions of the display unit

On clicking the rotary encoder at current screen above new screen will be appeared. It consists of four main menu:

- Info screen : It provides basic information about 3d printer like hot end, heating bed and sd card presence status.
- Prepare : It helps in moving all the stepper motors to their home location i.e (0,0,0). During calibration process all the stepper motors are required to move, this option provides the user defined movement length.

Figure 5.5 : Functions involved in prepare menu

- Control : It controls the various parameters of 3d printer and provides us option to change these values in real time.

Figure 5.6: Functions involved in control menu

- Print from SD Card: This is the best feature of the display module. We just need all the GCODE file of required objects that we want to print using our 3d printer.

Figure 5.7: Functions involved in print from sd card menu

5.3 Flowchart of the firmware

In any critical situations like shorting of thermistors, we can just press the kill pin present on the LCD panel and the printer will be stopped and all setting will be go its default settings.

We have used a "Power Saving Mode" in which following functions will be performed.

1. Set my Z axis to some desired height.
2. Leave it for about 2mins on standby.
3. Power to all the stepper will be cut, there will no longer be holding torque for all stepper. Z-axis comes crashing down.
4. All stepper lost power until a new G-code is send from Pronterface.

Everything behind mathematics is inside the planner function. For eg: Distance to reach a specific speed with a constant acceleration, Speed after a given distance of travel with constant acceleration etc.

Watchdog timer interrupt will be called if main program blocks >1sec and manual reset is enabled.

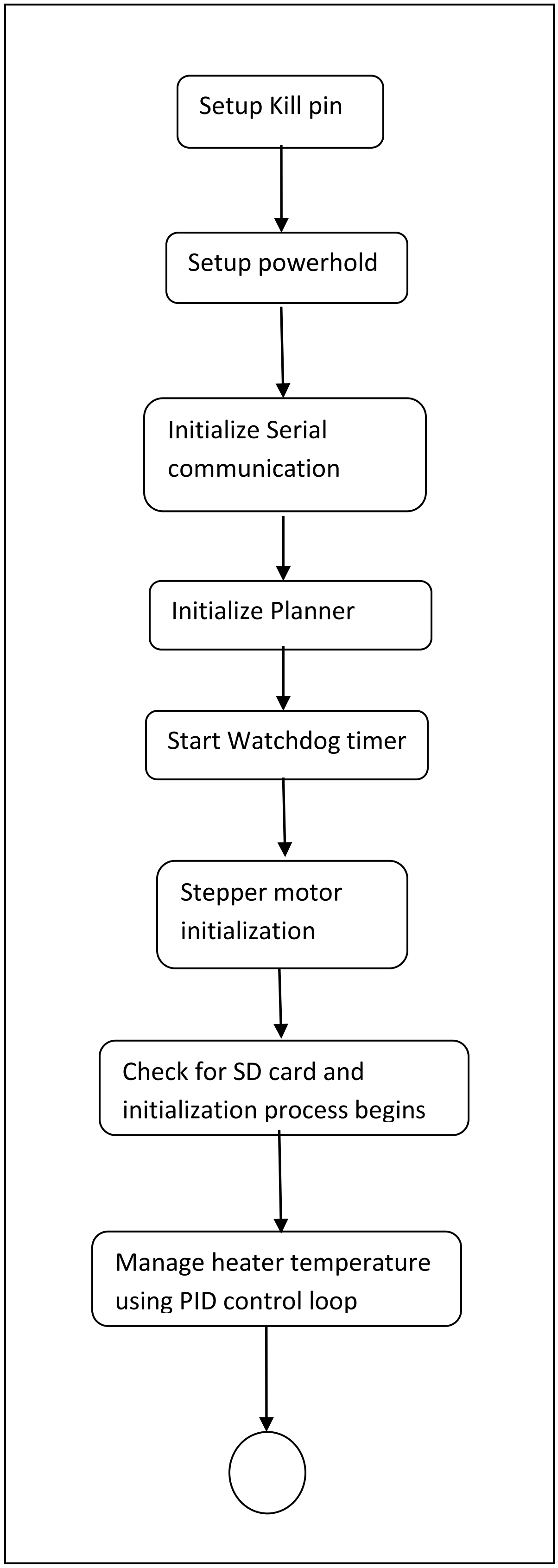
If we have an SD card reader attached to your display, folders are supported to a depth of 10 levels. Listing files in Pronterface shows "/path/subpath/file.g". We can write to files in subfolders by including the path (in lowercase).

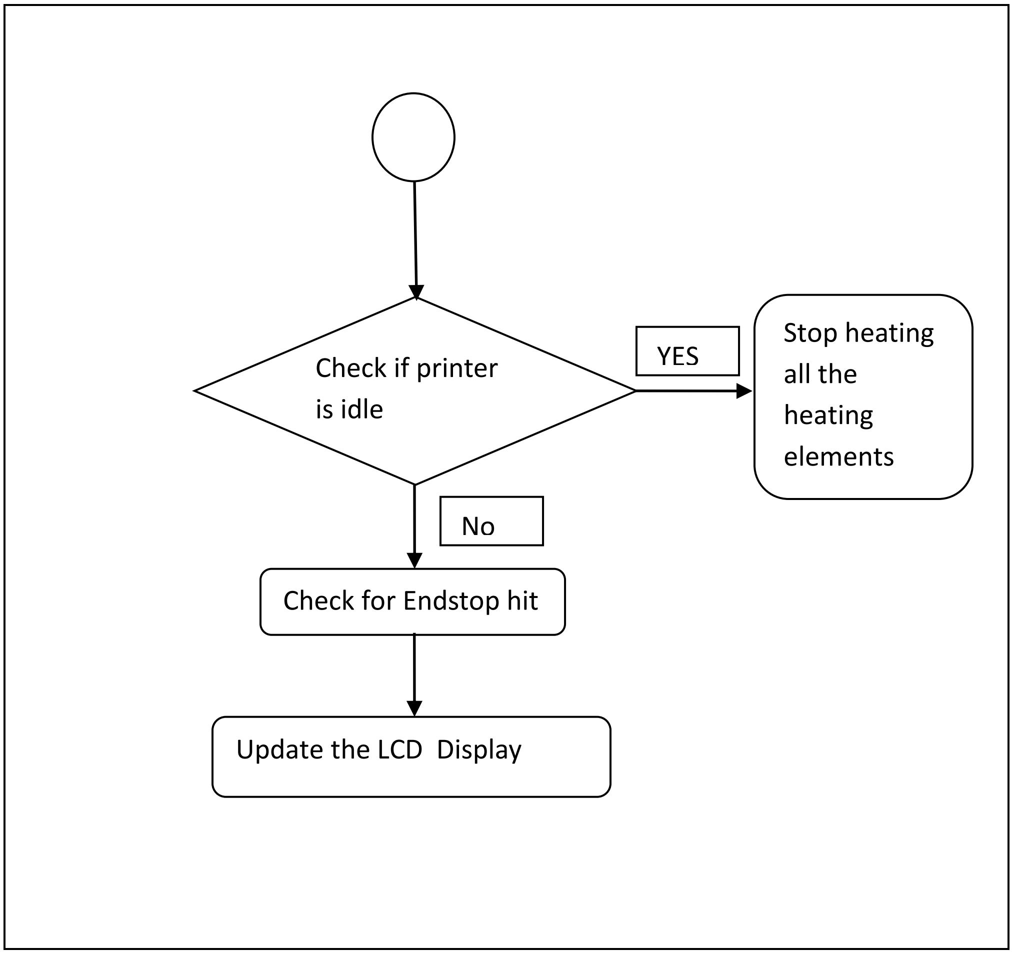
Starting the heater and J-hot end is important process. For reducing the noise and make the PID-differential term more useful, we have averaged 16 ADC conversion results.

Stepper motor initialization includes the step rate rating of the stepper motors.

Step rate means the highest speed at which a particular electronics-software combination can send step pulses to the stepper motor driver. It mostly depends on the CPU used on a controller, its clock frequency and the algorithm used by the firmware to calculate motor movements. As this are typically several thousand pulses per second, it's typically given in Kilohertz (kHz).

ATmega-based electronics are, with exception of the clock frequency, all equally fast. For us it is 80 steps/mm.


Setup Kill pin
Setup powerhold
Initialize Serial communication
Initialize Planner
Start Watchdog timer
Stepper motor initialization
Check for SD card and initialization process begins
Manage heater temperature using PID control loop



Flow Diagram

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Chapter 6: Conclusion and Future prospects

3D Printing technology could revolutionize and re-shape the world. Advances in 3D printing technology can significantly change and improve the way we manufacture products and produce goods worldwide. An object is scanned or designed with Computer Aided Design software, then sliced up into thin layers, which can then be printed out to form a solid three-dimensional product.

Food is one of fundamental ingredients of life which is at the base of the pyramid of human needs. Bringing the food industry to the digital age is one of the essential and revolutionary applications of 3D printing. Applying this technology enables fast automated and repeatable processes, freedom in design, as well as allowing large and easy variability of the cooking process which can be customized for each region or individual. Using robotic layer based food printing systems allows the recipe of the food to be digitized and saved in order to prepare very repeatable and high quality dishes without any margin for operator error. Also, the shape and decoration of the food can be individualized based on the customer or the occasion.

Shelter is another basic human necessity which can be an interesting application for 3D printing. The building industry is one of the last remaining fields where human labor and skills are the norm and mass manufacturing techniques and robots are considered science fiction. Given that a large portion of world population is without permanent shelter or food, it would be logical to think that these basic necessities should be top priority for robotized manufacturing techniques yet both the construction and food industries remain labor intensive. Conventional building methods are hazardous, time consuming, and expensive; 3D printing of buildings can enable automated creation of variety of buildings quickly and efficiently.

Dental industry has been using artificial material for dentures, orthodontics, implants, crown, and bridges for many years. As these parts are custom made for each person, the process is both time consuming and expensive. Direct and indirect 3D printing, namely printing the actual part or a mold, has been shown to be a cheaper and faster alternative to conventional techniques.

Researchers have shown that 3D printed parts can be used as bone replacement for people whom lost part of their skull or jaw in an accident.

The ability to develop and present ideas is one of the most important needs in the society and human development. Regarding this 3D printing can enable the creation of complex geometries which are very difficult, expensive, or impossible to be manufactured using conventional production methods.

The education system plays an important role in aiding people achieve their full potential. 3D printing can revolutionize the learning experience by helping students interact with the subject matter. Affordable 3D printers in schools may be used for a variety of applications which can aid students in finding their field of interest easier and faster. Currently there are different types of educational projects in order to attract students to the various fields by giving them the opportunity to create and fabricate their own designs using 3D printing technology.

One of the main advantages of the industrialization revolution was that parts could be made nearly identically which meant they could be easily replaced without individual tailoring. 3D printing, on the other hand, can enable fast, reliable, and repeatable means of producing tailor-made products which can still be made inexpensively due to automation of processes and distribution of manufacturing needs. If the last industrial revolution brought us mass production and the advent of economies of scale - the digital 3D printing revolution could bring mass manufacturing back a full circle - to an era of mass personalization, and a return to individual craftsmanship.

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