Design and Manufacturing of a Delta 3D Printer

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Abstract

3D printing, also known as additive manufacturing (AM), refers to various processes used to synthesize a three dimensional object. In 3D printing, successive layers of material are formed under computer control to create an object. These objects can be of almost any shape or geometry and are produced from a 3D model or other electronic data source. A 3D printer is a type of industrial robot.

Rapid prototyping is a technique used to quickly fabricate a scale model of a physical part or assembly using three-dimensional computer aided design (CAD/INVENTORY) data. Construction of the part or assembly is usually done using 3D printing or "additive layer manufacturing" technology 3D printers capable of outputting in color and multiple materials already exist and will continue to improve to a point where functional products will be able to be output. With effects on energy use, waste reduction, customization, product availability, medicine, art, construction and sciences, 3D printing will change the manufacturing world.

INTRODUCTION

3D printing, also known as additive manufacturing (AM), refers to various processes used to synthesize a three dimensional object. In 3D printing, successive layers of material are formed under computer control to create an object. These objects can be of almost any shape or geometry and are produced from a 3D model or other electronic data source. A 3D printer is a type of industrial robot.

It all starts with making a virtual design of the object you want to create. This virtual design is made in a CAD (Computer Aided Design) file using a 3D modeling program (for the creation of a totally new object) or with the use of a 3D scanner (to copy an existing object). A 3D scanner makes a 3D digital copy of an object [1-2].

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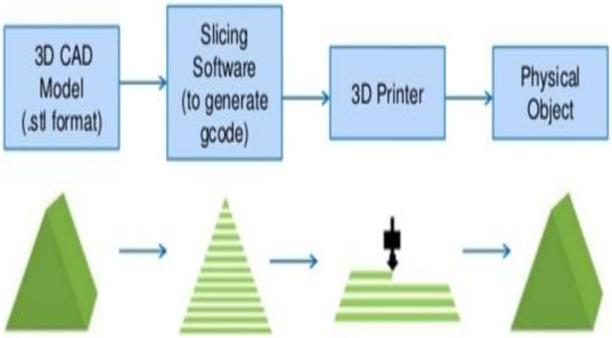
To prepare a digital file for printing, the 3D modeling software "slices" the final model into hundreds or thousands of horizontal layers. When the sliced file is uploaded in a 3D printer, the object can be created layer by layer. The 3D printer reads every slice (or 2D image) and creates the object, blending each layer with hardly any visible sign of the layers, with as a result the three dimensional object.



Processes and technologies

Not all 3D printers use the same technology. There are several ways to print and all those available are additive, differing mainly in the way layers are build to create the final object.

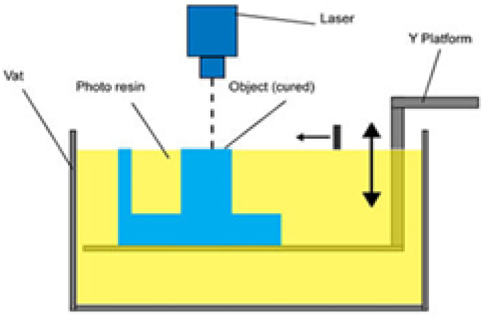
Some methods use melting or softening material to produce the layers. Selective laser sintering (SLS) and fused deposition modeling (FDM) are the most common technologies using this way of printing. Another method of printing is when we talk about curing a photo-reactive resin with a UV laser or another similar power source one layer at a time. The most common technology using this method is called stereo lithography (SLA).

To be more precise: since 2010, the American Society for Testing and Materials (ASTM) group "ASTM F42 – Additive Manufacturing", developed a set of standards that classify the Additive Manufacturing processes into 7 categories according to Standard Terminology for Additive Manufacturing Technologies.

Below you'll find a short explanation of all of seven processes for 3d printing:

Vat Photopolymerisation

A 3D printer based on the Vat Photopolymerisation method has a container filled with photopolymer resin which is then hardened with UV light source [6].



After the pattern has been traced, the SLA's elevator platform descends by a distance equal to the thickness of a single layer, typically 0.05 mm to 0.15 mm (0.002″ to 0.006″). Then, a resin-filled blade sweeps across the cross section of the part, re-coating it with fresh material. On this new liquid surface, the subsequent layer pattern is traced, joining the previous layer. The complete three dimensional object is formed by this project. Stereolithography requires the use of supporting structures which serve to attach the part to the elevator platform and to hold the object because it floats in the basin filled with liquid resin. These are removed manually after the object is finished.

Material Jetting

In this process, material is applied in droplets through a small diameter nozzle, similar to the way a common inkjet paper printer works, but it is applied layer-by-layer to a build platform making a 3D object and then hardened by UV light.

Binder Jetting

With binder jetting two materials are used: powder base material and a liquid binder. In the build chamber, powder is spread in equal layers and binder is applied through jet nozzles that "glue" the powder particles in the shape of a programmed 3D object. The finished object is "glued together" by binder remains in the container with the powder base material. After the print is finished, the remaining powder is cleaned off

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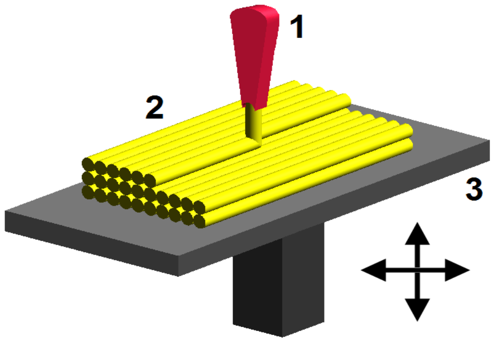
and used for 3D printing the next object. This technology was first developed at the Massachusetts Institute of Technology in 1993 and in 1995 Z Corporation obtained an exclusive license.

Material Extrusion

The most commonly used technology in this process is fused deposition modeling (FDM)

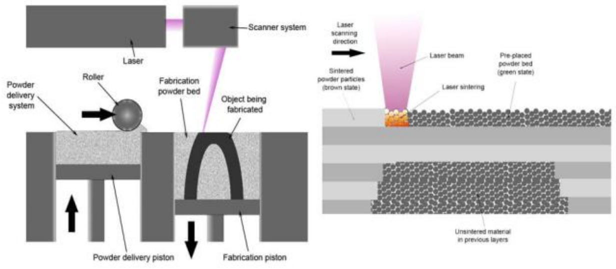


Fused deposition modeling (FDM), a method of rapid prototyping: 1 – nozzle ejecting molten material (plastic), 2 – deposited material (modeled part), 3 – controlled movable table. Image source: Wikipedia, made by user Zureks under CC Attribution-Share Alike 4.0 International license.

The FDM technology works using a plastic filament or metal wire which is unwound from a coil and supplying material to an extrusion nozzle which can turn the flow on and off. The nozzle is heated to melt the material and can be moved in both horizontal and vertical directions by a numerically controlled mechanism, directly controlled by a computer-aided manufacturing (CAM) software package.

Powder Bed Fusion

The most commonly used technology in this process is Selective laser sintering (SLS)



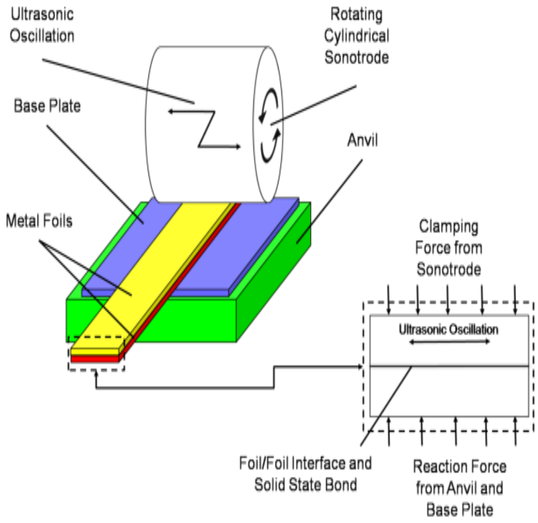
This technology uses a high power laser to fuse small particles of plastic, metal, ceramic or glass powders into a mass that has the desired three dimensional shapes.

The laser selectively fuses the powdered material by scanning the cross-sections (or layers) generated by the 3D modeling program on the surface of a powder bed.

After each cross-section is scanned, the powder bed is lowered by one layer thickness [3-5]. Then a new layer of material is applied on top and the process is repeated until the object is completed.

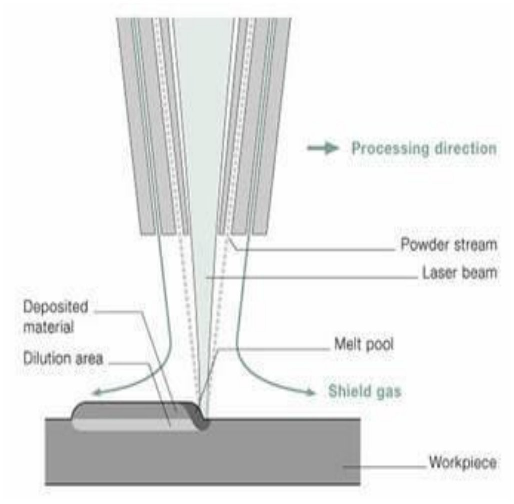
Sheet Lamination

Sheet lamination involves material in sheets which is bound together with external force. Sheets can be metal, paper or a form of polymer. Metal sheets are welded together by ultrasonic welding in layers and then CNC milled into a proper shape. Paper sheets can be used also, but they are glued by adhesive glue and cut in shape by precise blades.



Directed Energy Deposition

This process is mostly used in the high-tech metal industry and in rapid manufacturing applications. The 3D printing apparatus is usually attached to a multi-axis robotic arm and consists of a nozzle that deposits metal powder or wire on a surface and an energy source (laser, electron beam or plasma arc) that melts it, forming a solid object.



Applications of 3D Printing

Applications include rapid prototyping, architectural scale models & maquettes, healthcare (Delta 3d printed prosthetics and printing with human tissue) and entertainment (e.g. film props).

3D printing industry

The worldwide 3D printing industry is expected to grow from $3.07B in revenue in 2013 to $12.8B by 2018, and exceed $21B in worldwide revenue by 2020. As it evolves, 3D printing technology is destined to transform almost every major industry and change the way we live, work, and play in the future.

Medical industry

The outlook for medical use of 3D printing is evolving at an extremely rapid pace as specialists are beginning to utilize 3D printing in more advanced ways. Patients around the world are experiencing improved quality of care through 3D printed implants and prosthetics never before seen.

Bio-printing

As of the early two-thousands 3D printing technology has been studied by biotech firms and academia for possible use in tissue engineering applications where organs and body parts are built using inkjet techniques.

Layers of living cells are deposited onto a gel medium and slowly built up to form three dimensional structures. We refer to this field of research with the term: bio-printing.

Aerospace & aviation industries

The growth in utilization of 3D printing in the aerospace and aviation industries can, for a large part, be derived from the developments in the metal additive manufacturing sector.

NASA for instance prints combustion chamber liners using selective laser melting and as of march 2015 the FAA cleared GE Aviation’s first 3D printed jet engine part to fly; a LASER sintered housing for a compressor inlet temperature sensor.

Automotive industry

Although the automotive industry was among the earliest adopters of 3D printing it has for decades relegated 3d printing technology to low volume prototyping applications.

Nowadays the use of 3D printing in automotive industry is evolving from relatively simple concept models for fit and finish checks and design verification, to functional parts that are used in test vehicles, engines, and platforms. The expectations are that 3D printing in the automotive industry will generate a combined $1.1 billion dollars by 2019.

Industrial printing

In the last couple of years the term 3D printing has become more known and the technology has reached a broader public. Still, most people haven’t even heard of the term while the technology has been in use for decades.Especially manufacturers have long used these printers in their design process to create prototypes for traditional manufacturing and research purposes. Using 3D printers for these purposes is called rapid prototyping.

Why use 3D printers in this process you might ask yourself. Now, fast 3D printers can be bought for tens of thousands of dollars and end up saving the companies many times that amount of money in the prototyping process. For example, Nike uses 3D printers to create multi-colored prototypes of shoes.

Personal printing

Personal 3D printing or domestic 3D printing is mainly for hobbyists and enthusiasts and really started growing in 2011. Because of rapid development within this new market printers are getting cheaper and cheaper, with prices typically in the range of $250 – $2,500. This puts 3D printers into more and more hands.

WORKING COMPONENTS OF DELTA 3D PRINTER:

EXTRUSION

Extrusion in 3-D printing using material extrusion involves a cold end and a hot end.

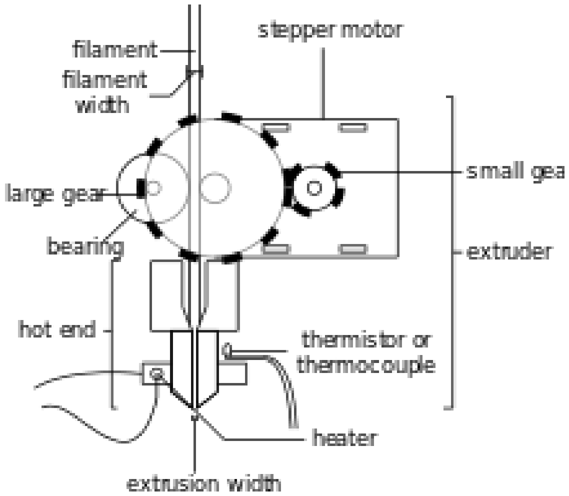
The cold end is part of an extruder system that pulls and feed the material from the spool, and pushes it towards the hot end. The cold end is mostly gear- or roller-based supplying torque to the material and controlling the feed rate by means of stepper motor. Thus, controlling the process rate in result,

The hot end is the active part which also hosts the liquefier of the 3D printer that melts the filament. It allows the molten plastic to exit from the small nozzle to form a thin and tacky bead of plastic that will adhere to the material it is laid on. Hot end consists of heating chamber and nozzle. The hole in the tip (nozzle) has a diameter of between 0.3 mm and 1.0 mm. Different types of nozzles and heating methods are used depending upon the material to be printed.

PROCESS OF EXTRUSION

Flow geometry of the extruder, heating method and the melt flow behavior of a non-Newtonian fluid are of main consideration in the part.

A plastic filament is supplied from a reel commercially available or homemade and fed into a heated liquefier where it is melted. This melt is then extruded by a nozzle while the incoming filament, still in solid phase, acts as a ‘‘plunger.’’



The nozzle is mounted to a mechanical stage, which can be moved in the **xy** plane. As the nozzle is moved over the table in a prescribed geometry, it deposits a thin bead of extruded plastic, called ‘‘roads’’ which solidify quickly upon contact with substrate and/or roads deposited earlier.

Solid layers are generated by following a rasterizing motion where the roads are deposited side by side within an enveloping domain boundary.

Once a layer is completed, the platform is lowered in the z direction in order to start the next layer. This process continues until the fabrication of the object is completed.

HOT ENDS

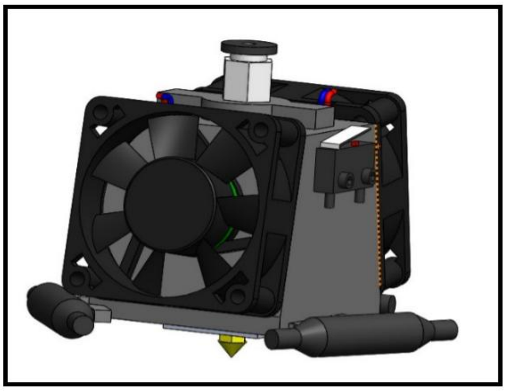
The hot end is arguably the most important part of the printer, without it you simply could not print. Is also the most important features to look for in a hot end are the nozzle, max temperature, filament size, and voltage.

You want to make sure the voltage of the heating cartridge matches other systems on your printer; most are 12V, but 24V is common too. There is no real advantage of one voltage over the other; it just depends on the components you use.

Filament size is dictated by what you want to print. 1.75mm is the most common these days, but many people still prefer to use 3mm. Make sure your hot end matches the filament you intend to use, a 3mm hot end will not work with 1.75mm filament!

The nozzle is very important as it dictates how much plastic can be printed at a time against how detailed your print can be, as well as your maximum layer height. The most common size nozzle is .4 mm, which is a good medium between the speed of .5 mm nozzles and the detail of .35 mm nozzles. Larger and smaller nozzles exist, however most people stay within the practical .35 to .5 mm range.

Extruder



The E3D V6 is the latest version of the popular E3D all-metal hot end. The all-metal claim is a bit false, though, as the E3D does come with a PTFE tube that is inserted into the hot end for thinner (1.75mm) filaments. When the PTFE tube is not used, the E3D can reach 300C with ease, and print with just about any filament on the market, just like the Hexagon. The PTFE Liner never enters the really hot section of the E3D nozzle, so a meltdown is not a concern if used properly.

Pros

- High temperature allows for printing of any material
- All-metal design
- Easy to change nozzles

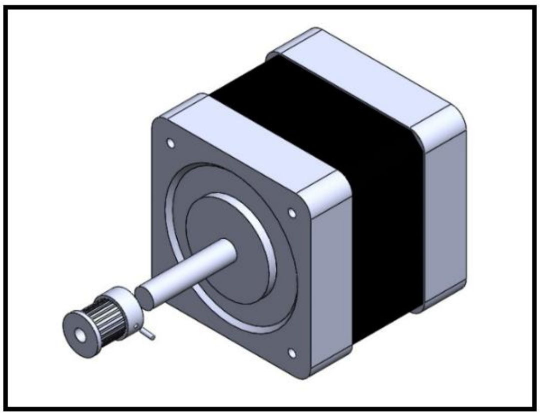
Cons

- PTFE liner tube improves smaller filament performance but limits max temperature
- Needs active cooling fan to prevent melting extruder body and printer jams.

Typically paired with Any J-head compatible extruder body

Stepper Motor:

A **stepper motor** is one kind of electric motor used in the robotics industry. Stepper motors move a known interval for each pulse of power. These pulses of power are provided by a stepper motor driver and are referred to as a step. As each step moves the motor a known distance it makes them handy devices for repeatable positioning.



Properties:

Step angle

Stepper motors have a step angle. A full 360° circle divided by the step angle gives the number of steps per revolution. For example, 1.8° per full step is a common step size rating, equivalent to200 steps per revolution.
Most stepper motors used for a Mendel have a step angle of 1.8 degrees. It is sometimes possible to use motors with larger step angles, however for printing to be accurate, they will need to be geared down to reduce the angle moved per step, which may lead to a slower maximum speed.

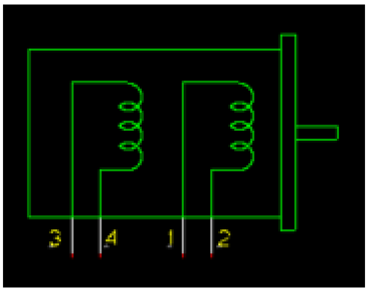
Micro stepping

A stepper motor always has a fixed number of steps. Micro stepping is a way of increasing the number of steps by sending a sine/cosine waveform to the coils inside the stepper motor. In most cases, micro stepping allows stepper motors to run smoother and more accurately.

Micro stepping between pole-positions is made with lower torque than with full-stepping, but has much lower tendency for mechanical oscillation around the step-positions and you can drive with much higher frequencies.

If your motors are near to mechanical limitations and you have high friction or dynamics, micro steps don't give you much more accuracy over half-stepping. When your motors are 'overpowered' and/or you don't have much friction, then micro stepping can give you much higher accuracy over half-stepping. You can transfer the higher positioning accuracy to moving accuracy too.

Bipolar:



Bipolar refers to the internals of the motor, and each type has a different stepper driver circuit board to control them. In theory a RepRap could use a unipolar motor, but in practice most are bipolar. They are also the type of motors we are using in the RepRap Project's Mendel and Darwin designs.

Bipolar motors are the strongest type of stepper motor. You identify them by counting the leads - there should be four or eight. They have two coils inside, and stepping the motor round is achieved by energizing the coils and changing the direction of the current within those coils.

Holding torque

The Mendel officially requires approximately 13.7 N·cm torque (19.4 ozf·in) of holding torque (or more) for each of the X, Y and Z axis motors to avoid issues, although one stepper with less has been used successfully (see below). Recent designs for extruders (ExtruderController) almost exclusively require stepper motors as well, but no torque requirements have been given in those designs. If in doubt, higher is better.

Wade's Geared Extruder (most widely used one as of 2012) it is suggested to use motor that is capable of creating a holding torque of at least 40 N·cm.

Size

The physical size of stepper motors are usually described via a US-based NEMA standard, which describes the bolt-up pattern and shaft diameter. In addition to the NEMA size rating, stepper motors are also rated by the depth of the motor in mm. typically, the power of a motor is proportional to the physical size of the motor.

If using the smaller NEMA 14 motors, aim for the high torque option. NEMA 14s are neater, lighter and smaller, but can be hard to obtain with the appropriate holding torque. NEMA 17's are quite easy to get in the specification that Mendel needs, but are bulkier and less neat. NEMA 14s are running near the edge of their envelope: they will get warm. NEMA 17s are well inside what they can do, and will run much cooler.

NEMA:

Referring to the frame size of the motor as standardized by the US National Electrical Manufacturers Association in its Publication of ICS 16-2001, itspecifies the 'face' size of the motor but not its length. For example a NEMA 23 stepper has a face of 2.3 x 2.3 inches with screw holes to match. Note: just because a motor is bigger does not mean it is more powerful in terms of torque. It is perfectly possible for a NEMA 14 to 'out pull' a NEMA 17 or a NEMA 23.

Based upon the NEMA 17 specification (from what I can find) the mounting holes are spaced 31 mm (1.22 inch) apart along the edge of the motor. This should help if you are using second-hand/salvaged parts [7].

Shaft

Any part that goes on a stepper motor shaft expects the shaft to be roughly Ø 5 mm. If the shaft is a different size, you will need to make allowances for this in the (plastic) parts you obtain/make.

Wiring

Steppers motors come in several wiring configurations. It is fairly common to find 4, 6 and 8 wires, and these works fine with the standard RepRap electronics.

Stepper motors with 5 wires exist but won't work with the standard RepRap electronics, because the 5th wire connects to both coil centers. See stepper wiring for more details.

Heat

Most of the motors specs give the current for two coils that will give an 80 °C rise, i.e. they can run at 100 °C! When using them on plastic brackets you need to under-run them to keep the brackets from melting. With PLA's glass transition temperature between 60-65 °C, you have to seriously under-run them! Fortunately temperature rise is proportional to power, which is in turn proportional to the square of current ($P=I^2R$), but torque is directly proportional so you can keep temperature under control without losing too much torque. For example, running a stepper at 70% of the rated current would result 70% of the torque and 49% ($0.7^2=0.49$) of the power dissipation and thermal rise.

Power and current

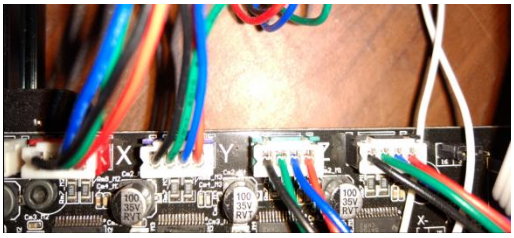
All recent stepper controllers use a current-limiting design. Because of this, the resistance (ohms, Ω) of the coils doesn't matter, as long as it is low enough for the current to rise fast enough for the current-limiting design to come into play. If the resistance is too high (i.e. 24 V steppers) the current simply doesn't raise enough. For this reason, stepper motors rated for 3-5 V and 1-1.5 A are generally recommended, as these motors will perform near their peak torque with a current-limiting stepper controller (such as a Pololu A4988).

Designs which use a separate "extruder controller board" sometimes use H-bridges (which are designed for running a DC motor) instead of a proper current-limiting stepper controller. On these boards, you need to be careful not to turn the current (PWM) too high, especially with low-ohm (low voltage) motors. You run the risk of overheating both the stepper motor and the H-bridge chip.

POWER SUPPLY:

12v DC 30 amp power supply
POWER-230W/110W

- 200x200mm PCB bed heater (12V/10A/1.2 ohms) = 120W
- Hot end heater = 12V 40W
- 5 stepper motors, each run at up to 1.2A @ 4V peak per phase = 5 * 4 * 1.2 = 24W, times 2 to allow (conservatively) for driver losses and back emf during movement = 48W
- Electronics, about 100mA @ 12V (assuming a linear regulator) = 1.2W
- LCD display, servos etc. say 5W
- Two 12V fans @ 150mA = 3.6W

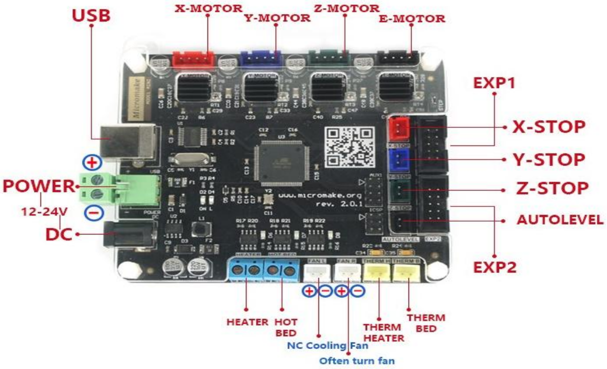


MOTHER BOARD

MICROMAKE DIY is a feature rich all-in-one electronics solution for Riprap and other CNC devices. It features an onboard ATmega2560. Its five motor outputs are powered by compatible stepper drivers.

The board features a developer friendly expansion port supporting giving access the same as Ramps1.4.

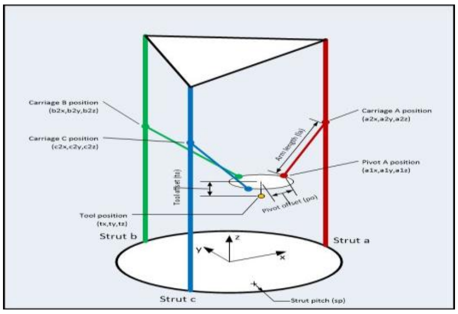
MICROMAKE DIY is designed to be flexible in the user's power source availability, allowing any power supply from 12V-24V.



X,Y,Z DRIVING AXIS

Basic Mechanics

Most desktop 3D printers are designed around Cartesian geometry, just like their milling machine kin. In fact, a CNC mill can be fitted with a “hot end” and extruder to create a 3D printer. However, since there are no “machining forces” when printing – for our purposes, the extruded plastic exerts no force on the machine’s structure as it is laid down – the mechanical structure of a 3D printer does not need to be nearly as rigid as a mill or router. The first RepRap printers had a Tinker Toy-like appearance because they were fabricated from 1/4-20 threaded rod and simple connectors tying them together. This is still a popular design and construction. The framework, shown in the drawing below, supports the X, Y, Z positional mechanics and provides sufficient rigidity for the task of laying down melted plastic filament. Note the X and Y axes movements are left-to-right and front-to-back, respectively and the Z axis is the up and down movement.



These mechanics will be familiar to CNC mill or router operators. Because there is very little mass to move, small NEMA 17 stepper motors and simple timing belts provide the motion control for the X,Y and Z axes. Desktop inkjet printers also use small steppers and timing belts to achieve their remarkable positional accuracy and these work quite well for 3D printers too. Close scrutiny of the drawing above reveals that the Z axis is different – it uses screws to move along Z. Typically a low cost 1/4-20 threaded rod is used for this application. This results in much lower feed rates in Z as compared to X and Y but this is not normally an issue since movement along Z is incremental and one layer at a time from Z=0 (at the print table surface) to +Z as it moves up.

In addition to X, Y and Z motion control, 3D printers have several unique mechanical elements; a plastic filament extruder and a heated nozzle or “hot end”. Many printers also have a heated print bed to minimize part war page and improve filament sticking to the bed surface. In the simple case, the filament extruder and hot end are combined into a single assembly. The extruder itself is stepper controlled and uses knurled rollers to grip the plastic filament in order to push it.

The primary responsibility of the extruder is to move a calculated volume of filament into the hot end where it melts and then extrudes from the nozzle to build the layers of the printed object. The extruder/hot end assembly is usually mounted on a sliding carriage that provides movement in the X direction. The mass of the extruder is not usually problematic but can affect acceleration and speeds. The primary reason the Z axis is moved by screws is to accommodate this additional mass.

The entire build table is moved for in the Y direction. The table itself is relatively light, even with a heater mechanism and large printed object on it, and does not require a lot of force to move. There are 3D printer arrangements similar to many CNC routers that use a moving gantry to move along X and Y and keep the print surface stationary. Both designs work well in practice.

One interesting feature of 3D printing is that no “work holding” is required. There are no fixtures, jigs or clamps. The first layer of the printed part is actually “stuck” on to the build surface. Additional layers are applied to build up the 3D geometry. Getting this first layer of plastic to stick properly and not peal up during a print is the source of much frustration to many beginners. I’ll discuss this and techniques to get good first layer sticking in a future post.

Hardware Implementation

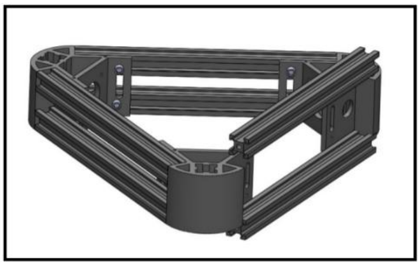
End stopper switch

A mechanical endstop is the simplest type of endstop: a simple mechanical switch positioned to trigger when a RepRap's axis reaches the end of its motion. Mechanical switches are less complicated to implement and cheaper than optical endstops because they do not require a circuit board and only use 2 wires for connecting the switch. Pull up and down resistors can be put close to the main board. You can use contact switches and contact-less (usually magnetically actuated) mechanical switches. Contact-less magnetic switches are calledreed switches. They are proximity switches that close (or switch over) if a magnet comes close enough (usually 1mm or less) and open if the magnet moves away. Reed switches are used as sensors in home alarm systems to detect open windows and doors.

The reasons to use mechanical switches as end stoppers are as follows

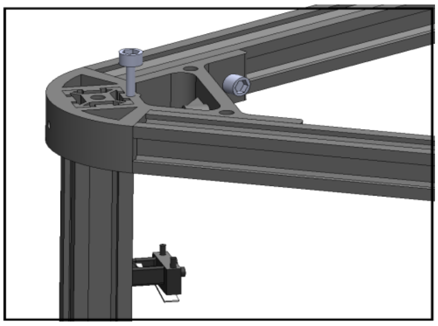
- Switches are the cheapest endstops in most cases.
- Simple switches can be used on x y and z axis.
- You could even make your own contact switch from a few pieces of metal.

Base plate

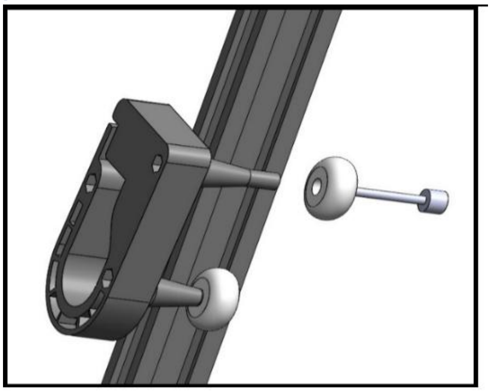


X,Y,Z-axis Motor plates

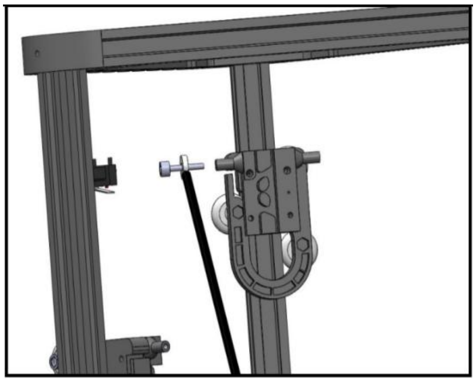
End-Stopers



Bearings

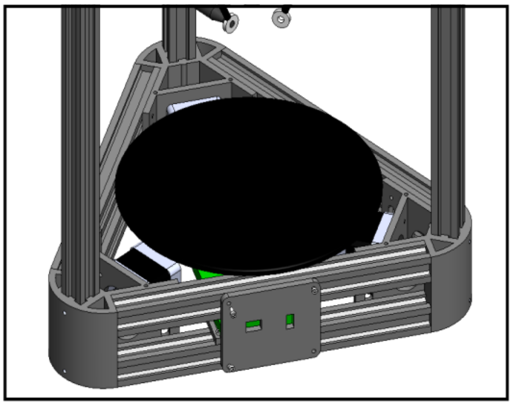


Arms

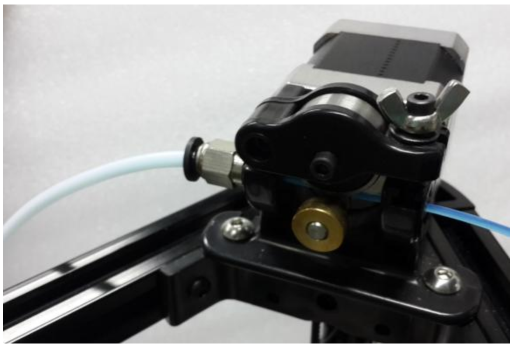


Belts

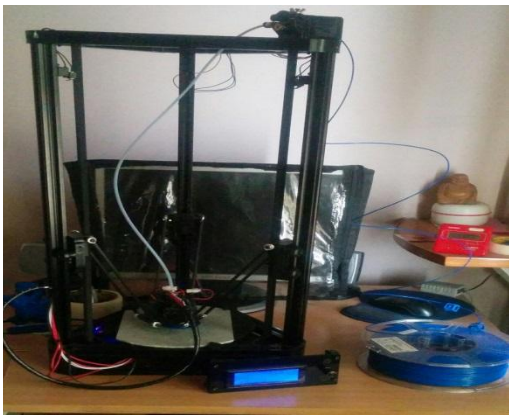
Bed



Extruder motor



Assembled Delta 3D-printer



Printing of sample:

COST ANALYSIS

Cost of electronic components
= 17,500 INR
Motherboard –7000
LCD Display –800
Stepper motors -2500
Base – 2500
Hot end – 1500
Extruder – 1200
End stoppers – 500
Power supply - 1500

Cost of Mechanical components = 6,500 INR
Sheet metal (250*19kg's)
Bearings – 500
MS shaft plain & threaded-500

Cost of filament (Qty-1kg's)
= 3,000 INR

Miscellaneous cost
= 4,000 INR
Belt dives – 400
Workshop costs – 2600
Stationary cost – 500
Tools and screws - 500

Total cost = 31,000 INR

*DELTA 3D printer's of same specifications averagely costs 85,000 INR

CONCLUSION

It is generally believed that 3D printing will be a revolutionary force in manufacturing and prototyping, whether positive or negative. Many Multinational companies have already been using the technology to produce intricate components in various fields.

As3D printers become more affordable, they will inevitably be used for local, small scale manufacturing largely eliminating supply chain for many types of product. There will be major challenges for the conventional manufacturing industry to adapt to these changes in technology.

The outlook for medical use of 3D printing is evolving at an extremely rapid pace as specialists are beginning to utilize 3D printing in more advanced ways. 3D printing of liver or kidney tissues is better than transplantation of organs. This could be a breakthrough in medical history.

3D printers capable of outputting in color and multiple materials already exist and will continue to improve to a point where functional products will be able to be output. With effects on energy use, waste reduction, customization, product availability, medicine, art, construction and sciences, 3D printing will change the manufacturing world.

In this delta type 3D printer we can print the object without using the hot bed. Which is main difference with the existing delta 3D printer as well as cost also low and the filaments used are PLA (WOOD,GLASS, etc.)

REFERENCES

1) http://www.theengineer.co.uk/in-depth/the-big-story/the-rise-of-additive-manufacturing/1002560.article
2) http://www.redorbit.com/education/reference_library/general-2/history-of/1112953506/the-history-of-3D-printing
3) http://readwrite.com/2014/02/17/future-of-3D-printing-what-can-we-3D-print#awesm=~ozykT14wlGsiL5
4) http://whatsnext.blogs.cnn.com/2013/07/31/study-at-home-3-d-printing-could-save-consumers-thousands/
5) http://abcnews.go.com/Technology/story?id=1603783&page=1
6) Hull, C. W. Apparatus for production of three-dimensional objects by stereolithography. U.S. Patent 4,575,330, March 11, 1986.
7) 3DSystems. Solutions. http://www.3dsystems.com/solutions/ overview (accessed September 30, 2013). Bak, D. Assem. Autom. 2003, 23, 340−345.