Comparison of Different Types of 3D Printing Technologies

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Abstract- 3D printing is a form of non-traditional machining. Also known as additive manufacturing, it is a method of creating an object by laying successive layers of material until the whole object is created. Unlike subtractive manufacturing processes which usually result in up to 80-90% of the material being wasted, there is seldom any wastage of material in 3D printing. The concept of 3D printing has been around for a long time and its technology has evolved over the years. Different 3D printers make use of different kind of technologies, printing methods and also different kinds of materials. This paper gives a general introduction to the concept of 3D printing, the different types of printing technologies with their advantages, limitation and compares each of them to different criteria such as surface finish, dimensional accuracy, material used, post processing requirements etc.

Index Terms- Additive manufacturing, Non-traditional machining, 3D printing, 3D printers

I. Introduction

Traditional machining such as turning, milling, drilling and grilling has been around for many years and has helped human beings to build things. Although the technology for traditional machining has evolved in recent years, it has a number of limitations. With the introduction of non-traditional machining such as electric discharge machining or electric chemical machining, the manufacturing world has changed and at present nearly all industrial processes require computers and robot technology. These processes stated all involve removing material from a larger mass of block to get the required shape of the final product. There are constraints such as fixtures and assembly for many traditional designs and their production processes which are often expensive and add cost to the production process.

Compared to traditional machining, 3D printing is a process of creating objects directly by stacking layers of material on each other until the required product is obtained. The layers are stacked up in a variety of ways depending on the technology being used. This technology allows the design of complex components therefore avoiding assembly requirement at no additional cost. 3D printing being a tool-less process, significantly reduces the prohibitive costs and lead times. The printing process usually starts with the making of a 3D digital model. This model can be created using any 3D software programmes or by scanning the product using a 3D scanner [1]. The model is then layered into slices and is converted into a file which is understandable by the 3D printer. The material processed by the 3D printer is layered according to the design.

II. Current 3D Printing Technologies

All 3D printers do not use the same technology. There are numerous means to print the layers so as to form the finish product. Some techniques liquefy the material or simply soften it to make the layers whereas others uses high powered UV laser to cure photo-reactive resin and “print” the object.

Some of the 3D printing technologies that are most broadly utilized these days are:

1) Stereolithography (SLA)
2) Fused deposition modelling (FDM)
3) Selective Laser Sintering (SLS)
4) Laminated object manufacturing (LOM)
5) Digital Light Processing (DLP)

As shown in Figure 1, the very first step to 3D print an object is to make a model of the object using CAD software [3]. The model describes the geometrical properties of the object. The CAD file is then converted to STL file format. This file format defines the external closed surfaces of the original CAD model. The STL file also includes the data for each single layer and can make

calculations for the layers. The STL file is sent to the 3D printer and the printer is setup before build process, where settings include build parameters, like energy source, layer thickness, etc. The part is then printed by an automated process without any supervision. When printing is done, the printed part is removed and sent for post processing. After that, the object is ready for application.

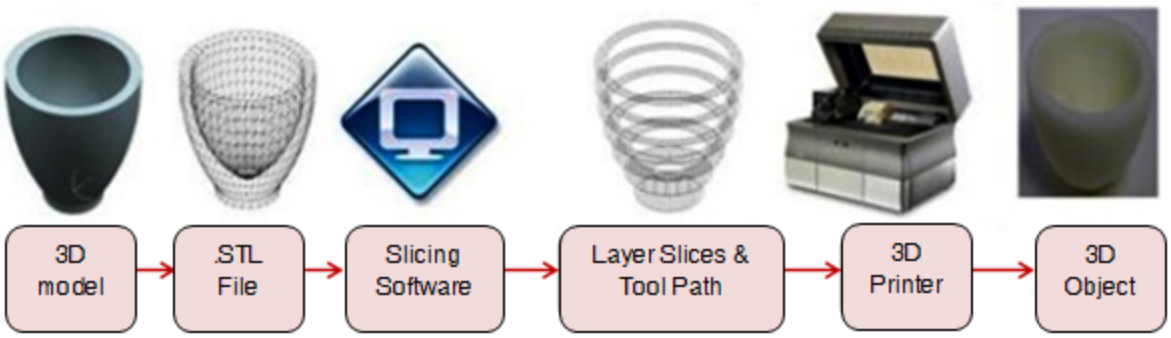

Figure 1: Process of 3D printing (from design to printing)

Since there are different 3D printing technologies, the type to be used depends mostly on the kind of object to be made. Each of them has its claimed benefits and downsides. The next section explains each of the different processes in detail and gives examples of products that can be produced by each of them.

A. Stereolithography

Stereolithography (SLA) is recognized as the original 3D printing process. SLA is used mostly to create models, prototypes and patterns. Being a laser based process; it uses ultraviolet laser and a vat of resin to build parts. The laser beam marks the design onto the surface of the liquid polymer. Exposure to the ultraviolet laser causes the chains of atoms in the polymer gum to connect together [4]. As the photopolymer resins react to the laser, it forms a solid part in a very precise way.

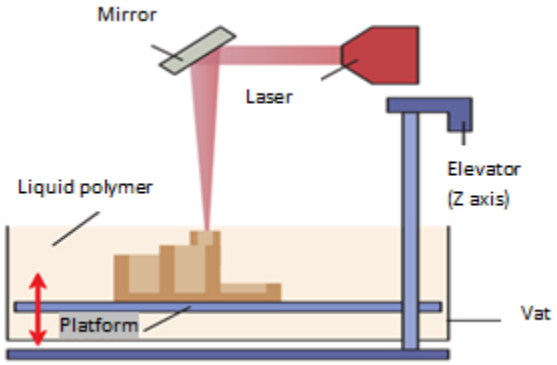

Figure 2: Stereolithography process

The Figure 2 shows the setup of SLA. The vat contains the polymer with a movable platform within. The laser beam is focused on the X-Y axis across the top surface of the resin according to the data input in the printer. The resin hardens precisely where the laser hits the surface. As one layer is finished, the platform in the vat is dropped by a little along the Z-axis and the next layer is then traced over the previous layer. This process goes on until the entire object is printed and the platform is elevated out of the vat for removal.

Figure 3: Objects produced by SLA

Stereolithography is most commonly used for prototyping as it is less time-consuming and it is relatively cheaper compared to other prototyping method. Nevertheless, the SLA process requires support structures for some parts mainly for those with overhangs [5]. These structures need to be manually detached during post processing. Post processes also include chemical bath to clean the object and subjecting the object in an oven-like machine to fully harden the resin.

SLA is one of the most accurate 3D printing processes with excellent surface finish and smoother surface than most other rapid prototyping methods. Smooth surface implies a great level of detail and the design is very accurate. Moreover parts can be printed in a very short period of time depending on its size and shape. Figure 3 show some parts printed using SLA. SLA also allows different options when it comes to material. Although SLA can produce a large variety of shapes, it is often very expensive.

B. Fused Deposition Modelling

Another technique of 3D printing technique is the Fused Deposition Modelling (FDM). This process is also used for making models as well as prototyping. 3D printers that run on this technology build a part layer by layer, from the bottom to the top by heating and extruding thermoplastic filament according to the 3D data supplied to the printer [6]. Each layer solidifies as it is put down and it bonds to the former layer.

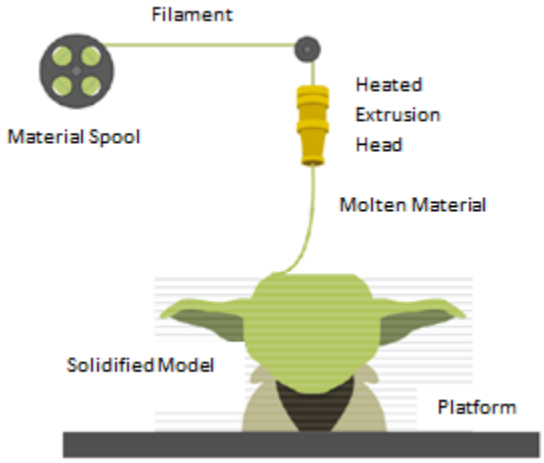

Figure 4: Fused deposition process

FDM also works on the additive principle. The Figure 4 shows how a part can be produced using FDM. The heated extrusion head extrudes little dots of thermoplastic fabric to shape a layer. It can travel in the horizontal and vertical directions by a numerically controlled mechanism. The material hardens straightaway after coming out from the spout.

Figure 5: Typical objects printed by FDM

FDM is cheaper than SLA as it uses actual plastic instead of simulating plastic like material by projecting laser on resin. Similar to SLA, printing parts in FDM requires supports for complex structures. Therefore parts printed by FDM also require some post processing. But compared to SLA, FDM process is less accurate. The process can also be time consuming for some particular geometry. Moreover the material used in FDM is limited to thermos plastic. Figure 5 shows objects printed by FDM.

C. Selective Laser Sintering

Another technology used by today's 3D printer is the Selective Laser Sintering (SLS). During this process, tiny particles of plastic, ceramics or glass are joined by heat from a high powered laser beam to form a solid.

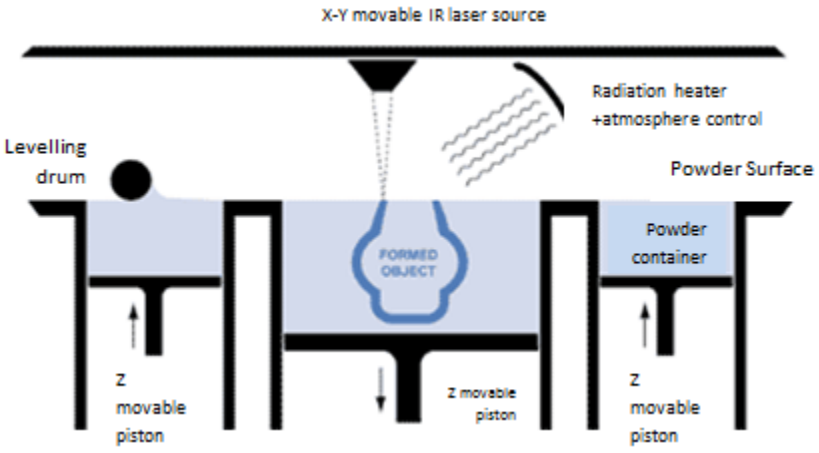

Figure 6: Basic setup of SLS

As shown in Figure 6, the laser is traced across a powder bed according to the data file. The powder inside the powder bed is tightly compressed. The laser moves in the X and Y directions. The laser then hits the surface of the powdered material; it sinters the particles to each other to give form to a solid. When one layer is completed, the powder bed lowers in the Z direction and the levelling drum (roller) smoothes the powder over the surface of the bed. The laser then continues to trace and form the design required. The process repeats itself until the whole object is printed. The object is then left to be cooled down.

The build chamber needs to be completely sealed because it is necessary to maintain the temperature during the process to be the same as melting point of the powdered material. The powder bed is removed from the machine when the process is completed, and the excess powder is easily taken out of the printed object. The Figure 7 displays some parts which are 3D printed by SLS.

Figure 7: Parts printed by SLS

One of the major advantages of SLS is that it does not require any structure support for complex parts as needed in both Stereolithography and Fused Deposition Modelling. Because the part lies on a bed of powdered material, no supports are necessary. This advantage itself helps save material and reduces production cost. There is also no much need of post processing [7]. Moreover SLS is capable of printing geometries that cannot be done using other 3D printed method. Using SLS, parts with complex interior components can also be printed and there is no problem of removing supports and damaging the part. As a result, time is saved on assembly. Parts printed by SLS are usually very durable and robust. This technology now rivals those produced in traditional methods like injection moulding and are already used in many end-use application like automotive and aerospace.

Parts produced by SLS can be in different materials such as plastic, glass, and ceramics and with the advance in its technology it can also print metal. SLS is also widely utilized for printing tailor made products like hearing aids, dental retainers and prosthetics. Moreover objects printed with SLS don't necessitate any molds or additional tooling making it convenient for any user to print high complexity parts or particularly delicate object.

D. Laminated Object Manufacturing

In the method of Laminated Object Manufacturing (LOM), sheets of plastic or plastic materials are laminated or fused together by high temperature and pressure and then shaped to the required form with a computer controlled laser or blade [8].

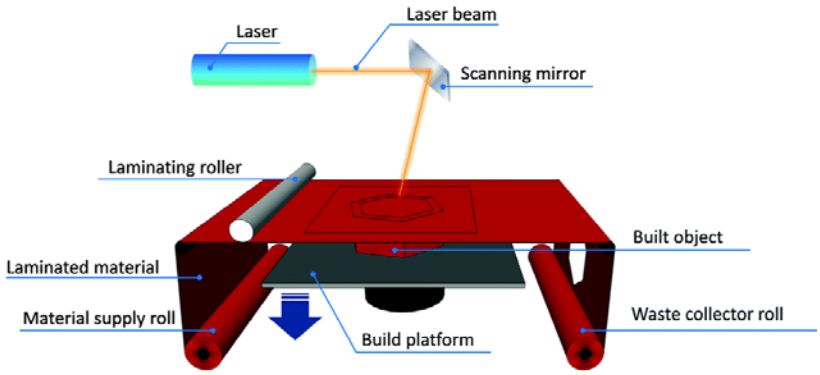

Figure 8: Laminated Object Manufacturing process

As shown in the Figure 8, LOM 3D printer makes use of a continuous sheet of material which may be plastic or paper. A mechanism of feed roller spread the material along the build platform. The material is primarily coated with adhesive. When the laminating roller is heated and passed over the surface of the material, its adhesive melts and the roller press it onto the platform. A computer controlled laser or blade then cuts the material into the wanted form or pattern. Furthermore the laser removes any excess of material so that it is easier to remove the object when all the processes are completed.

After the first layer of the object is formed, the build platform then drops by a small amount. The second layer of material is then drawn across the platform and the heated roller passes over it, binding it to the one beneath. This procedure is performed repeatedly until the whole object has been formed. When printing is completed, the object is removed from the build platform. Excess materials are then cut away [9]. Afterwards some minor post processing is done. This may include sanding, painting or varnish to keep out moisture.

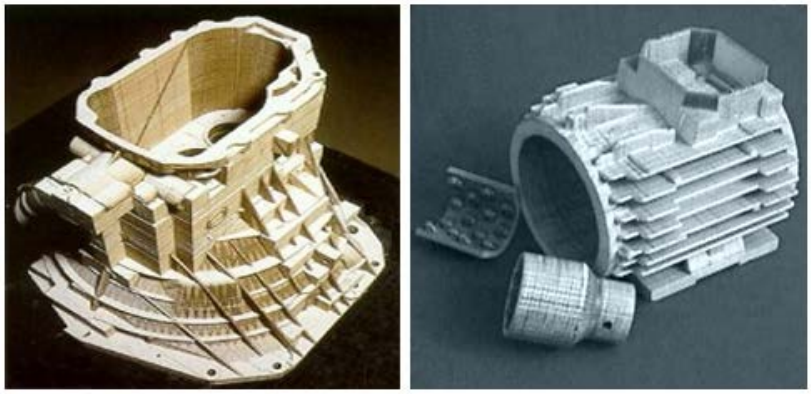

Figure 9: Prototypes printed by LOM

The cost for LOM is very low and the material is readily available. The printed parts have a similar look and feel of wood and can be worked with and finished in similar manner. The Figure 9 shows some prototypes that have been printed using LOM technology. Another advantage of Laminating Object Manufacturing is that it does not involve any chemical process or reaction and no enclosed chamber is needed. Therefore it makes it easier to build larger models. However this method is not ideal for making objects with complex geometries or to produce functional prototypes. For these reasons, LOM is only used to make scaled models and conceptual prototypes that can be tested for design or form.

E. Digital Light Processing

Another technology used by 3D printers is the Digital Light Processing (DLP). DLP is a similar process to Stereolithography. The main dissimilarity between these two methods is the light source. SLA uses a laser whereas DLP makes use of conventional light sources to cure photo sensitive polymer resin.

Figure 10 shows the process of DLP. DLP 3D printer prints objects by projecting them onto the surface of the resin. The exposed resin hardens and meanwhile the machine build platform lowers down to set stage for a new layer of fresh resin to be coated to the object and cured by light. The process is repeated until the 3D model is completed. Once completed, the model is sent for post processing to remove extra support structures and chemical bath for surface finish.

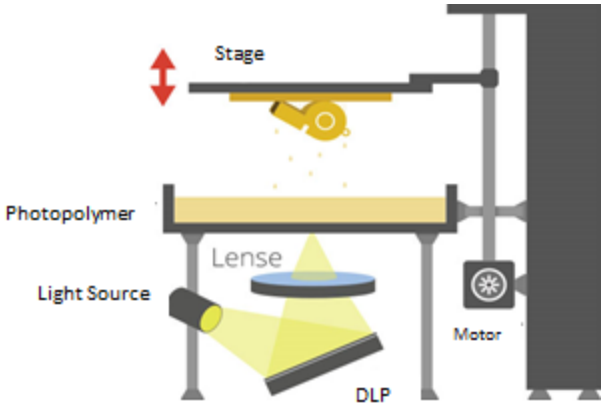

Figure 10: DLP Process

Like Stereolithography, DLP is also produces parts with high accuracy and high resolution. However one advantage that DLP has over SLA is that it requires a shallow vat of resin to facilitate the process. This generally results in less waste and lower running costs. Also DLP can be a faster process than SLA as the light source is applied to the whole surface of the vat of polymer resin at a single pass. DLP based printers makes use of photosensitive resin plastic which is suitable to make non –functional prototypes, highly detailed artworks, patterns for injection moulding, etc. Parts printed with this method have good strength properties. Figure 11 shows some prototypes that have been printed using DLP.

Figure 11: Prototypes printed by DLP

However the DLP services can be costly. And also, when the printing is completed, the object requires post processing to remove unnecessary support structure. Some photopolymer resins can be brittle depending on the object's design but new improved resins are on their way to change this.

III. Comparison of 3D Printing Technologies

As mentioned in the previous section, not all 3D printers employ the same technique to print objects. While some make use of thermos-plastic filament, others use conventional light source or laser source to cure molecules in the polymer resin. There are different filament and resin to be used. Each of these technologies has their benefits and limitations. In this section, a comparison between these five different 3D printing methods mentioned above is given. The comparison is made upon a number of criteria like application, overall accuracy, materials options, finishing options and post-processing.

Table I: Comparison of different types of 3D printing technologies

	SLA	FDM	SLS	LOM	DLP
Applications	Excellent for form testing Best process for water resistant material	Suitable for prototypes Home use applications	Ideal for functional parts with various application Suitable for complex shape object Heat and chemical resistant	Ideal for non-functional prototypes	Similar to SLA
Overall Accuracy	Most accurate printing process	Accurate and reliable process	not very accurate	Slightly less dimensional accuracy	High Accuracy

Material Options	ABS Semi-flexible materials High temperature ABs	Thermoplastic materials	Nylon Glass-Filled Nylon	Paper Plastic Metal	Similar to SLA
Finish Options	Excellent surface finish	Standard Finish	Standard Finish	Wood like characteristics and can be treated similarly	Good finish High resolution
Post Processing Requirement	Requires post processing to remove support structure	Requires post processing to remove support structure	Does not require support structure, less post processing requires	Polishing Painting	Requires Post processing

IV. Discussion and Conclusion

3D printing has revolutionized the way in which manufacturing is done. It improves the design manufacturing and reduces lead time and tooling cost for new products. As mention in the section above, there are several technologies used by 3D printers to build objects. The type of technology to be used depends mostly on the object to be manufactured. A comparison was carried out to show which method is the best fit for a particular job.

Stereolithography is the most popular 3D printing technology. It is widely used nowadays because it provides accuracy along with an excellent surface finish. It also allows printing of objects using a variety of materials. However it can be expensive and is used mostly by industries for making of prototypes. Digital Light Processing is quite similar to Stereolithography. The main difference between these two technologies is their type of light source.

Fused Deposition Modelling is a less expensive process compared to all other 3D printing method. This makes it suitable for home use application. The level of accuracy and surface finish it provides are worth the manufacturing cost. However, the materials that FDM supports are limited mostly to thermoplastics.

Selected Laser Sintering is a good choice for building objects with complex shapes and geometries. It does not require additional support like other 3D printing technologies and does not need much post processing. Nevertheless the final object might not be very accurate and the surface finish is not so good.

Laminated Object Manufacturing is an ideal choice for non-functional prototype. It does not provide good accuracy level and surface finish. It also requires much post processing. The material mostly used for this process is paper.

Even though these technologies are different in their own ways, they bring a host of benefits that conventional manufacturing simply cannot. They can allow customization of products according to the individual needs. They can also build complex products which cannot be produced physically in any other ways.

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