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Design of Parts using Additive Manufacturing (AM) & Reverse Engineering (RE) – A Review

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Abstract- **Rapid prototyping technologies are able to produce physical model in a layer by layer manner directly from their CAD models without any tools, dies and fixtures and also with little human intervention. RP is capable to fabricate parts quickly with too complex shape easily as compared to traditional manufacturing technology. RP helps in earlier detection and reduction of design errors. Rapid prototyping has gained widespread industrial acceptance as a means of quickly and economically producing small quantities of physical objects. In addition to its commercial applications, rapid prototyping tools have the potential to drastically influence the ways people create and their reasons for doing so. Digital fabrication promises individuals means of creating complex objects with virtually no prerequisite skill.**

Companies in the development phase preceding mass production and the individual maker face similar issues. Before committing to producing a million copies of a design, it is imperative that small quantities of prototypes are generated and validated. Production machinery, whose operation relies upon economies of scale, is impractical for the task. Thus was born the field of rapid prototyping (RP). While the term typically evokes mental images of three-dimensional printers, the underlying spirit can be expressed simply: the automated creation of a physical object from a digital representation.

INTRODUCTION

(I) Basic Principle Of Rapid Prototyping Processes

RP process belong to the generative (or additive) production processes unlike subtractive or forming processes such as lathing, milling, grinding or coining etc. in which form is shaped by material removal or plastic deformation. In all commercial RP processes, the part is fabricated by deposition of layers contoured in a (x-y) plane two dimensionally. The third dimension (z) results from single layers being stacked up on top of each other, but not as a continuous z-coordinate. Therefore, the prototypes are very exact on the x-y plane but have stair-stepping effect in z-direction. If model is deposited with very fine layers, i.e., smaller z-stepping, model looks like original. RP can be classified into two fundamental process steps namely generation of mathematical layer information and generation of physical layer model. The first step in the process is creating the digital (i.e. mathematical) representation of a concept. This is accomplished using a computer software package known as a computer aided design (CAD) tool. The second step, therefore, is to convert the CAD file into STL format (Any prototyping technique format). This format represents a three-dimensional surface as an assembly of planar triangles. In the third step, a pre-processing program prepares the STL file to be built. The fourth step is the actual construction of the part. RP machines build one layer at a time from polymers, paper, or powdered metal. The final step is post-processing. This involves removing the prototype from the machine and detaching any supports.

Types of RP technologies now

- Stereo lithography
- Fused Deposition Modelling
- Laminated Object Manufacturing
- Selective laser sintering (SLS)

(II) Additive Manufacturing (AM) is an nearer name to describe the technologies that build 3D objects by adding layer-upon-layer of material, whether the material is plastic, metal, concrete or one day. Human tissue. Common to AM technologies is the use of a computer, 3D modeling software (Computer Aided Design or CAD), machine equipment and layering material. Once a CAD sketch is produced, the AM equipment reads in data from the CAD file and lays downs or adds successive layers of liquid, powder, sheet material or other, in a layer-upon-layer fashion to fabricate a 3D object.

The term AM included many technologies including subgroup like 3D Printing, Rapid Prototyping (RP), Direct Digital Manufacturing (DDM), layered manufacturing and additive fabrication. AM methods have several advantages over traditional manufacturing techniques. First, AM offers "design freedom" for engineers; because of its additive approach, it is possible to build geometries that cannot be fabricated by any other means. Moreover, it is possible with AM to create functional parts without the need for assembly. Also, AM offers reduced waste and minimal use of harmful chemicals (such as etching and cleaning solutions) when compared to traditional manufacturing techniques.

(III) Reverse engineering (RE) is defined as the process of obtaining a geometric CAD model from point cloud acquired by scanning/digitizing existing products without any technical details, such as drawings, bills-of-material. RE has been widely recognized as being an important step in the product development cycles. The use of RE will decrease largely product development time and costs. In contrast to the traditional production sequence, reverse engineering typically starts with measuring an existing products. Then use the reverse engineering software which can make reverse 3D design to restructure CAD model , and CAE/CAM system is used to analysis, redesign and NC machining. The whole process of RE should be computer aided as shown in Fig.1.

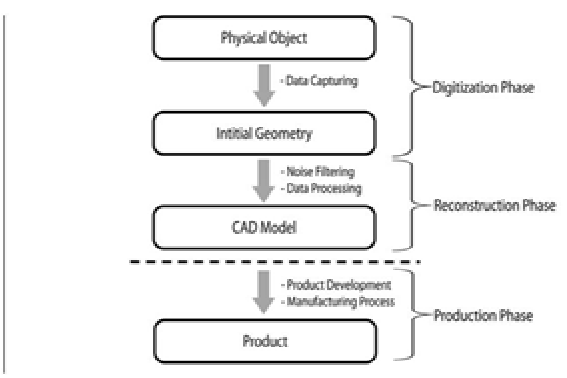

Fig.1.The process of RE should be computer aided

VARIOUS PROCESSES OF ADDITIVE MANUFACTURING

(I) Stereo lithography (SL)

Stereo lithography Apparatus (SLA) is a liquid---based process which builds parts directly from CAD software. SLA uses a low power laser to harden photo sensitive resin and achieve polymerization. The Rapid Prototyping Stereo lithography process was developed by 3D Systems of Valencia, California, USA, founded in 1986. The SLA rapid prototyping process was the first entry into the rapid prototyping field during the 1980's and continues to be the most widely used technology.

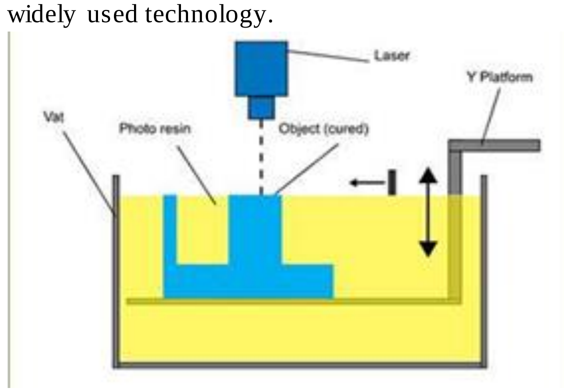

Fig.2 (Stereo lithography (SL) Process)

Materials: Principally photo curing polymers which simulate polypropylene, ABS, PBT, rubber; development of ceramic-metal alloys.

Most accurate Z-resolution: 0.025 mm

Stereo lithography is the most widely used rapid prototyping technology. Stereo lithography builds plastic parts or objects one layer at a time by tracing a laser beam on the surface of a vat of liquid photopolymer, inside of which is a movable stage to support the part being built. The photopolymer quickly solidifies wherever the laser beam strikes the surface of the liquid. Once one layer is completely traced, the stage is lowered a small distance into the vat and a second layer is traced directly on top of the first. The self-adhesive property of the material causes each succeeding layer to bond to the previous one and thus form a complete, three-dimensional object out of many layers. The process begins with a 3D CAD file. The file is digitally sliced into a series of parallel horizontal cross sections which are then provided to a Stereo Lithography Apparatus (SLA) one at a time. A laser traces the cross section onto a bath of photopolymer resin which solidifies the cross section. The part is lowered a layer thickness into the bath and additional resin is swept onto the surface (typically about 0.1 mm). The laser then solidifies the next cross section. This process is repeated until the part is complete. Once the model is complete, the platform rises out of the vat and the excess resin is drained. The model is then removed from the platform, washed of excess resin, and then placed in a UV oven for a final curing. Objects which have overhangs or undercuts must be supported during the fabrication process by support structures. These are either manually or automatically designed with a computer program specifically developed for rapid prototyping. Upon completion of the fabrication process, the object is removed from the vat and the supports are cut or broken off. Stereo lithography generally is considered to provide the greatest accuracy and best surface finish of any rapid prototyping technology. Over the years, a wide range of materials with properties mimicking those of several engineering thermoplastics have been developed. Limited selectively color changing materials for biomedical and other applications are available, and ceramic materials are currently being developed. The technology is also notable for the relatively large size range of objects possible, from parts as big as a car wheel to as small as a sugar cube, with excellent accuracy relative to the scale of the object.

On the negative side, the photopolymers are expensive and perishable, working with liquid materials can be messy and parts require a post-curing operation in a separate oven-like apparatus for complete cure and stability.

(II) Fused Deposition Modelling (FDM)

FDM is the second most widely used rapid prototyping technology, after stereo lithography. A plastic filament is unwound from a coil and supplies material to an extrusion nozzle. The nozzle is heated to melt the plastic and has a mechanism which allows the flow of the melted plastic to be turned on and off. The nozzle is mounted to an X-Y plotter type mechanism which traces out the part contours, There is a second extrusion nozzle for the support material (different from the model material).

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 hardens immediately after being squirted from the nozzle and bonds to the layer below. The object is built on a mechanical stage which moves vertically downward layer by layer as the part is formed. The entire system is contained within a chamber which is held at a temperature just below the melting point of the plastic.

Materials: ABS, ABSi, PC, PC-ABS and PC-ISO, PPS (model material)

Most accurate Z-resolution: 0.13 mm (Range: 0.33mm- 0.13mm

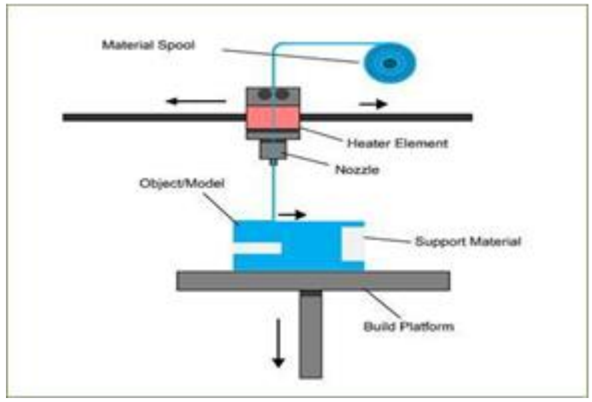

Fig.3 (Fused Deposition Modelling)

Several materials are available for the process including ABS and investment casting wax. ABS offers good strength, while the polycarbonate (PC) and poly phenyl sulfone (PPS) materials offer more strength and a higher temperature range.

Support structures are automatically generated for overhanging geometries and are later removed by breaking them away from the object. A "water-soluble" support material is also available for ABS parts. The method is office-friendly and quiet. FDM is fairly fast for small parts on the order of a few cubic centimeters. It can be very slow for large parts with a lot of volume, however. Depending on the part geometry and orientation, it can also require more support material than the part itself (or virtually none). The finished parts are anisotropic, that is they exhibit different mechanical characteristics in different directions. The resolution is not as fine as with stereo lithography, but the parts are more robust.

(III) Laminated Object Manufacturing (LOM)

Profiles of object cross sections are cut from paper or other web material using a laser. The paper is unwound from a feed roll onto the stack and first bonded to the previous layer using a heated roller which melts a plastic coating on the bottom side of the paper. The profiles are then traced by an optics system that is mounted to an X-Y stage.

After cutting of each layer is complete, excess paper is cut away to separate the layer from the web. Waste paper is wound on a take-up roll. The method is self-supporting for overhangs and undercuts. Areas of cross sections which are to be removed in the final object are heavily cross-hatched with the laser to facilitate removal. It can be time consuming to remove extra material for some part geometries, and there is a lot of inherent waste in the process, as every object uses up an amount of material equivalent to a box that contains the part - even if the part itself is very thin walled.

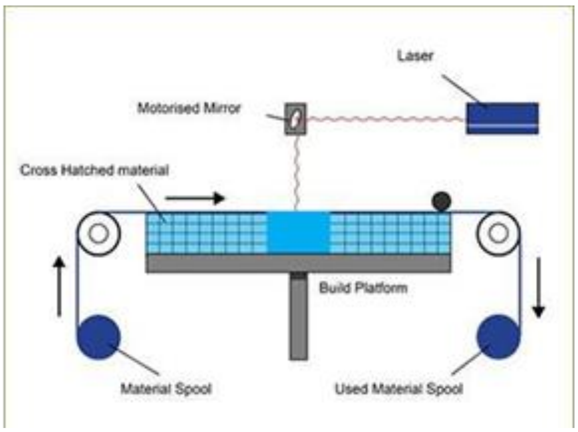

Fig 4 (Laminated Object Manufacturing (LOM)

Materials: Typically paper rolls but recently also plastic films

Most accurate Z-resolution: 0.1 mm (paper) and 0.15(plastic)

Variations on this method use a knife to cut each layer instead of a laser or apply adhesive to bond layers using the xerographic process. There are also variations which seek to increase speed and/or material versatility by cutting the edges of thick layers diagonally to avoid stair stepping.

In general, the finish, accuracy and dimensional stability of paper objects are not as good as for materials used with other RP methods. In addition, the laser cutting of the material creates a lot of smoke and needs to be ventilated to the outside. However, material costs are very low, and objects have the look and feel of wood and can be worked and finished in the same manner. This has fostered applications such as patterns for sand castings. While there are limitations on materials, work has been done with plastics, composites, ceramics and metals.

The principal commercial provider of LOM systems, Helisys, ceased operation in 2000, as this technology did not compete well with other RP methods that were developing. However, there are several other companies working on similar LOM technology, and 3D systems has recently marketed a small, low cost machine (developed by an Israeli company) which uses PVC film (more controllable and stable than paper). These companies are addressing market segments ranging from concept modeling to very large objects for architectural applications.

(IV) Selective laser sintering (SLS)

Three dimensional printing was developed at MIT. It's often used as a direct manufacturing process as well as for rapid prototyping.

The process starts by depositing a layer of powder object material at the top of a fabrication chamber. To accomplish this, a measured quantity of powder is first dispensed from a similar supply chamber by moving a piston upward incrementally. A roller or scraper then distributes and compresses the powder at the top of the fabrication chamber. The multi-channel jetting head subsequently deposits a liquid adhesive (binder) in a two dimensional pattern onto the layer of the powder (similar to inkjet printing). The binder bonds the powder particles together where it has been deposited, solidifying it to form a layer of the object.

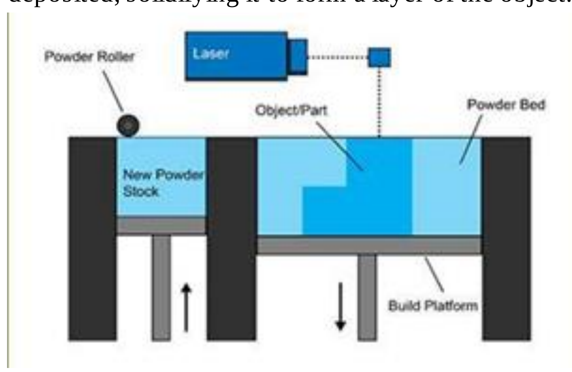

Fig 5 (Selective laser sintering (SLS)

Model materials: plaster, sand, corn starch, acrylic

Binder and infiltration materials: various resins, cyanoacrylates (infiltrating)

Most accurate Z-resolution: 0.1 mm

Once a layer is completed, the fabrication piston moves down by one layer thickness, and the process is repeated until the entire object is formed within the powder bed. After completion, the object must be removed from the chamber still filled with powder (a delicate operation), and the excess powder brushed off, leaving a "green" object. No external supports are required during fabrication since the powder bed supports overhangs.

SLS offers the advantages of speedy fabrication and low materials and system cost. In fact, it's probably the fastest of all RP methods. It is even possible to print colored parts and images onto the part surfaces. However, there are limitations on resolution, surface finish, part fragility and available materials. In order to face the problem of the fragility of the standard 3DP plaster and starch parts, the object can be “infiltrated” with a resin, which hardens the object once it cures, but even then the break resistance does not equal that of some other systems such as FDM.

SLS is also being used with sand and a high temperature resin to create sand casting molds and cores for metal casting, as well as acrylic for creating plastic prototype parts.

CONCLUSION

A review paper concludes that various 3D processes are available for rapid prototype product development but its selection will be based on product dimension, shape, geometry, definition, uses, cost involved, etc. from these processes which one is good process for a particular product cannot be said with easily, neither a strategy is implemented to work on this. So, it is a topic with large opportunities to be researched upon.

Parameters	SL	LOM	FDM	SLS
Supply phase	Liquid	Liquid	Solid	powder
Layer creation technique	Liquid curing	Extrusions of melted plastic	Deposition of sheet material	Binder droplet deposition on the powder layer
Resolution Of layer obtained in product	0.025 mm	0.13 mm (Range: 0.33mm-0.13mm)	0.1mm (paper) and 0.15mm (plastic)	0.1 mm
Operating speed	Medium	Low	High	Highest
Surface finished	Very Good	Good	Good enough	Good enough
Strength	Uniform	Poor in vertical direction	Uniform	Uniform
Support structure	Required	Required	Make used of material itself for support	Required
Dimensional accuracy	Good	Poor	Good	Good
Cost	High	Medium	High	Medium
Materials	Photo curable resins, acrylate based	Thermo plastic material such as wax, ABS plastic & elastomer	Sheet material such as paper, plastic, ceramic, composite.	Ceramic polymer and metal powder with binder

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