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The Study of Various Rapid Prototyping Techniques

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ABSTRACT

Rapid Prototyping(RP) Technology or layer additive manufacturing is a different kind of manufacturing/fabrication process that enables the direct physical realisation of any three dimensional computer model. RP technology converts the 3D computer data which can be obtained from some dedicated file format directly to a physical model, layer by layer with a very high degree of accuracy. It is fast developing and competitive to traditional model building techniques considering time and degree of detail. The paper deals with the study of emerging and advance RP techniques and their applications. A very brief description of the older techniques like Stereo-lithography, SLS, FDM, SGC, LOM, 3D Printing is given. Largely the paper deals with new techniques viz Rapid Freeze Prototyping, Laser Engineered Net Shaping, Contour Crafting, Selective Inhibition of Sintering, Direct Photo Shaping, Electroplating Fabrication.

KEYWORDS: RP, LOM, Contour Crafting, Layer Additive

INTRODUCTION

Rapid Prototyping (RP) Technologies and Rapid Manufacturing offer great potential to the technologists. It focuses on enlarging the view to other ways for producing models and unique parts. Using RP techniques, the reliability of products can be increased, investment of time and money become less risky [1]. Rapid prototyping appeared for the first time somewhere in the mid-1980s. The basis of RP (also known as solid freeform fabrication, desktop manufacturing or layer manufacturing technology) is that initially a computer three-dimensional model of the required design is created. This solid or surface model is converted into a digital file format referred to as STL. A computer program analyses the STL file to control the RP machine for producing the model. The fabrication process is accomplished by adding slices of the original model, layer upon layer until a physical model that closely resembles the original design is obtained. However, depending on the RP process in use, various post-processing tasks are required to get finished RP model. These tasks consist of different secondary processes that include removal of either untreated or excess material from the RP model. The accuracy of these RP models can be greatly affected by the post-processing operations[2]. Spur, Helical and Bevel gears have been simulated in a virtual environment using a form milling cutter and gear hobbing [3]. A real physical model of the hob for the production of spiroid face gear is manufactured with rapid prototyping technique [4]. The 3D microfluidic systems are fabricated using rapid prototyping techniques [5].

OVERVIEW OF BASIC RP TECHNIQUES

Rapid Prototyping((RP) Technology that started emerging at the end of the 80s builds up parts layer by layer[6]. These RP Techniques are classified as Layer Additive, Layer Subtractive, Formative process, LASER based, Non-LASER based, Using Liquids, Solids Material, Powders, Sheets, Gas atoms, etc. In addition to prototypes, RP techniques can also be used to make tooling (Rapid Tooling) and even production-quality parts (Rapid Manufacturing). For small batch production and complicated objects, rapid prototyping maybe the optimal manufacturing process available. Although RPT started with plastic materials, today there is a big choice of metallic and ceramic materials available for almost every major RP process. Also CNC can be used for RP[7]. Accuracy and surface finished has improved significantly during the last years.

Procedure

The basic steps are same for all these RP technologies and these are described below[1]:

1. **Design:** Creating a 3D CAD solid model of product,
2. **Converting:** Converting the CAD model to STL format,
3. **Pre-Process:** Slicing the STL file into thin cross-sectional layers (generated by a dedicated Software),
4. **Building process:** Constructing the model one layer atop another and
5. **Post-Process:** Cleaning and finishing the model.

The CAD representation is done using a 3D solid modeler. These CAD data are generally obtained from the design process, or from a 3D measuring device's point cloud, or from computer tomography (CT). Most of the 3D solid modelers offer an interface to the .STL file format that is used as input into the RP machines. The RP software packages slice the 3D model into layers, add support structures where necessary and then the actual production can be done.

Rapid is a bit misleading for the actual manufacturing part of the procedure, as the part production will take hours and days rather than minutes as for the conventional process. What is really rapid is the fast start of the process as the part can be manufactured nearly without any additional programming tasks.

Depending on the actual RP process used, more or less time consuming procedures are necessary for cleaning and, in some cases, post curing the finished parts.

Uses of RP Models

These physical models can complement the computer models[1]:

1. They enable a better quality of communication between team members working on different functions of a system (i.e. sensor engineers and mechanical designers of abyssal stations, ROV's, AUV's and robotics) by providing hands-on models and thereby reducing the risk of misunderstanding.
2. They can be used for different physical experiments to verify the computer simulations. For example, an aerospace engineer might mount a model airfoil in a wind tunnel to measure lift and drag forces.
3. They enable the comparison of different alternative solutions in early phases of development, thereby minimizing risks and costs in mass production.
4. They can be used to validate the functioning of complex, interacting mechanical systems.
5. They can be used to present the results of offshore engineering and research to the public and to the sponsors.

EMERGING OR ADVANCED RP TECHNIQUES

Apart from the basic RP techniques mentioned above, the following gives a short overview of the major emerging or advance RP technologies.

Rapid Freeze Prototyping (RFP)

This RP technique was developed by Dr. Ming Leu of the University of Missouri-Rolla. In this process ice is used as material to make rapid prototype models. The system involves droplets of water deposited from a nozzle onto a surface within a freezing chamber. The RFP system first builds up a shell of ice then fills the enclosed interior with a steady stream of water that freezes. This reduces the time required to fabricate the prototype. Ice patterns are easier to remove. The method is cheaper, faster, and cleaner compared to other emerging or advance RP techniques. It is also possible to make silicone molds with ice patterns[8].

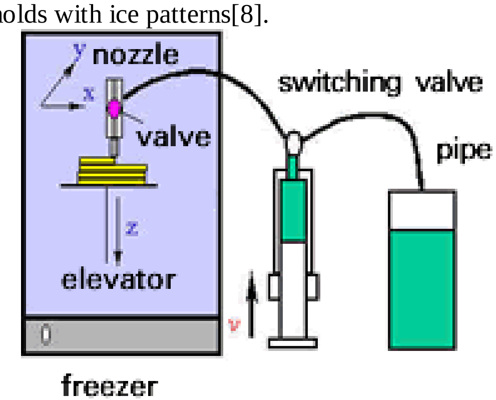

Figure 1: Rapid Freeze Prototyping

Contour Crafting (CC)

The Inventor of the process is Mr. Khoshnevis. In this process a pair of movable, flat control surface, termed as "trowel", is added just above and to the side of the nozzle. The trowel movements, shaping the material coming out of the nozzle before it sets, are controlled by a computer. The nozzle and trowel arrangement creates the object's outside walls as a thin but strong shell. A separate pouring mechanism fills in solid objects by adding material in bulk, layer by layer and trowel. The chief advantages of the Contour Crafting process over existing technologies are the superior surface finish that is realized and the greatly enhanced speed of fabrication. Actual scale civil structures such as houses may be built by CC. Contour Crafting has been under development under support from National Science Foundation and Office of Naval Research[9].

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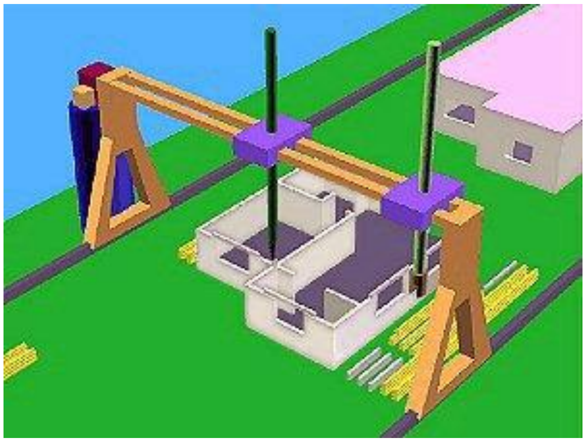

Figure 2: Contour Crafting

Selective Inhibition of Sintering (SIS)

As the name implies, selective inhibition of sintering (SIS) is based essentially on inhibition of selected powder particles from sintering. There are four steps in building each layer, as shown in Figure 3.

These steps are explained below[9]:

1. Laying Thin Powder Layer: This is generally done by a roller that sweeps a horizontal surface slightly above the previous layer and carries the powder material in front while rotating in a manner that its front surface makes an upward motion. This approach, used by SLS and 3D printing, is able to create thin and uniformly dense powder layers. Other alternative approaches for powder spreading may be used.
2. Deposition of Sintering Inhibitor: In this step a sintering-inhibitor liquid is deposited on selected areas (i.e. layer profiles and possibly some hatching patterns and some horizontal separation surfaces) using raster printing by multi-nozzle inkjet printer, or using vector printing with a single printing nozzle having a fine orifice.
3. Minimizing Radiation Frame: This step is used for conservation of the powder material by means of reflective plates that expose only the required portion of each layer to radiation. Without these plates, the entire powder base would be sintered. The position of these plates is controlled by computer and may be different for each layer, depending on the layer outside profile.
4. Sintering by Thermal Radiation: In this step, a planar surface that radiates heat using electrically heated nichrome filament, or a gas burner, is used to sinter the selected areas of the powder layer all at once. After all layers have been sintered, the final part is extracted as shown in Figure 4. The unsintered powder may be reused and the excess material that is sintered may be crushed and recycled back into powder form.

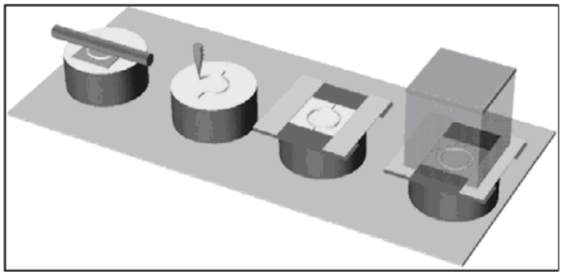

Figure 3: Stages of SIS Process

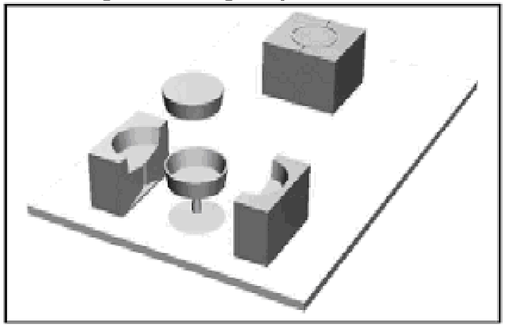

Figure 4: Extraction of Fabricated Parts

Laser Engineered Net Shaping (LENS)

A high power laser is used to melt metal powder supplied coaxially to the focus of the laser beam through a deposition head (C). The laser beam typically travels through the center of the head and is focused to a small spot by one or more lenses (B). The X-Y table (D) is moved in raster fashion to fabricate each layer of the object. The head is moved up vertically as each layer is completed. The laser beam may be delivered to the work by any convenient means. A simple right angle mirror (E) is shown, but fiber optics could also be used. Metal powders (A) are delivered and distributed around the circumference of the head either by gravity, or by using an inert, pressurized carrier gas (G). Even in cases where it is not required for feeding, an inert shroud gas (F) is typically used to shield the melt pool from atmospheric oxygen for better control of properties, and to promote layer to layer adhesion by providing better surface wetting. Objects fabricated are near net shape, but generally will require finish machining. They are fully-dense with good grain structure, and have properties similar to, or even better than the intrinsic materials. Initial applications are concentrated on the fabrication and repair of injection molding tools and the fabrication of large titanium and other exotic metal parts for aerospace applications[10].

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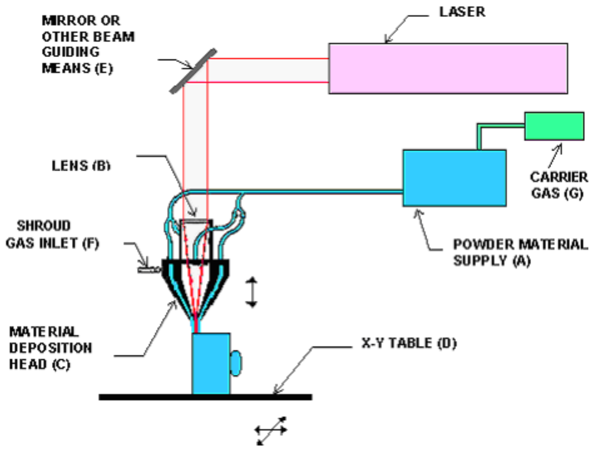

Figure 5: Laser Engineered Net Shaping

Electroplating Fabrication (EFAB)

EFAB[10] is an additive micro-fabrication process based on multi-layer selective electro-deposition of metals. The process is designed to rapidly stack large numbers of independently patterned metal layers on top of each other, allowing designers to create intricate 3-D complex geometries with micron-level precision. The essence of the approach is a basic three-step process that is used to generate each layer. This is repeated as many times as there are layers to build the desired complex devices.

These steps are described below:

1. Patterned Layer Deposition: In this step, a layer of metal (the structural metal in this case) is deposited in a pattern corresponding to a cross section of the device to be fabricated.

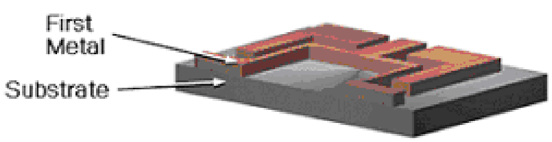

Figure 6: Patterned Layer Deposition

2. Blanket Layer Deposition: Here a second material is electroplated onto the substrate, covering the previous layer completely.

Figure 7: Blanket Layer Deposition

3. Planarization: Finally the two materials are planarized to yield a single two-material layer.

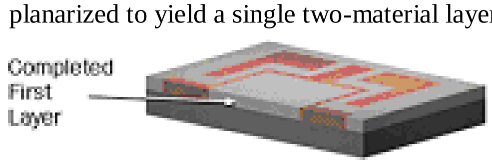

Figure 8: Planarization

To continue building the device, the same process is repeated over and over, adding layer after layer until all cross sections of the original 3-D CAD design have been constructed in the desired structural material. After all of the layers are formed, a release etchant removes the sacrificial material, leaving behind the free-standing final device.

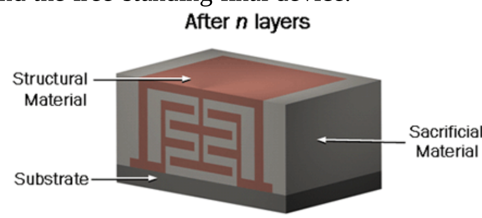

Figure 9: Complete Body with Sacrificial Material

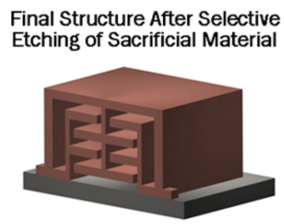

Figure10: Final Structure

This basic EFAB process used two materials, one structural, and one sacrificial. In practice, multiple sacrificial and structural materials can be used, creating complex multi-material devices to meet the needs of specialized applications.

Direct Photo Shaping (DPS)

Direct Photo Shaping[11] is a new multi-layer fabrication process developed at SRI International for fabrication of ceramic, metal, or polymer components. The process is based on the layer-by-layer photocuring of polymerizable compositions curable by visible light. Each layer is selectively photo-imaged by digital light projection via a Digital Micromirror Device (DMD array, which uses more than 500,000 microscopic mirrors. At speeds greater than 1,000 times per second, the mirrors are electronically tilted and the light is digitally reflected on the photocurable slurry, thus performing the function of an electronic maskless tool. The unique use of visible light in this process allows the photocuring of highly filled suspensions of ceramics with high refractive index, such as silicon nitride. A leveler (same type as a doctor blade) levels on a movable platform a film of photopolymerizable slurry. The slurry is dispense through three holes located in front of the leveler. After a short delay, the exposed slurry is photocured. Later the platform goes down and the cycle restart.

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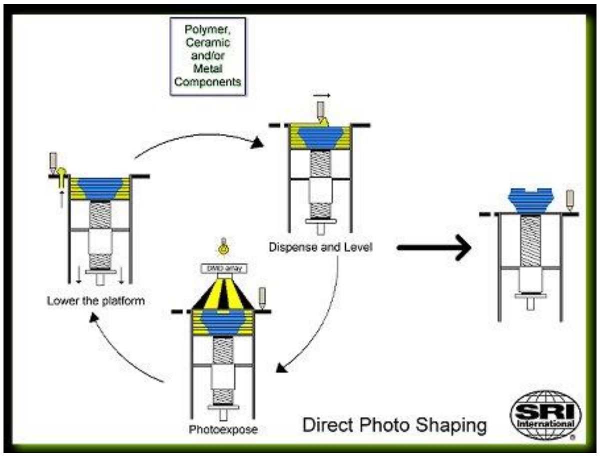

Figure 11: Direct Photo Shaping

SOME EXAMPLES

A variety of products can be manufactured using the basic and emerging RP techniques. To give a general idea of what are the end products of these types of techniques few examples are shown in the figures given below [12].

Figure 12: RFP Parts

Figure 13: SIS Parts

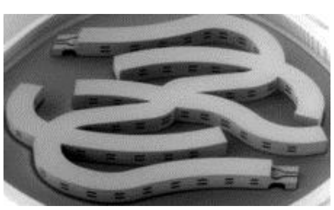

Figure 14: EFAB Part

Figure 15: CC Part

Figure 16: LENS Parts

Figure 17: DPS Part

CONCLUSION

With the advent of new technologies, the conventional methods can be improved and replaced. RP technology also offers the use of new types of products/parts and in developing other procedures. As these technologies will evolve further, these will be able to use various materials to accommodate a wider range of desirable mechanical properties. RP technology represents the nascent state of computationally-based manufacturing. RP technology is fast evolving technique and different procedures are used for various fields in many applications. With the use of all these processes it will be possible to make the models which can not be produced by conventional methods

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