Technical Innovations: The Expansion of Rapid Prototyping

Autumn Price

University of Wisconsin-Stout

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Introduction

The next time you break, say, a lens cover for your camera or a case for your phone, how handy would it be to have a new one resting in the palm of your hand within minutes. No need to leave your house, let alone your chair, no searching the web for the best bargain, no need to even construct your own devise out of spare parts and duct tape. This could sound a little "sci-fi", but the technology today has given people this amazing option.

Many people are astonished when they first hear about a 3D printing opportunity. Mike Sanderson, the man who runs the rapid prototyping lab at the University of Wisconsin-Stout says, "It's amazing what these machines can do, you can make virtually anything you can draw up on the computer." This process may even sound like the devise shown in the 2009 film, Cloudy with a Chance of Meatballs, in which an imaginative inventor was able to create any food entre by simply entering it into the computer system. Astonishing, but we haven't made it that far—yet!

Unlike a Child's fantasy of having mass amounts of junk food rain from the sky, real 3D printing is quite comprehensible and a lot like the technology we use every day. An office printer prints an object layer by layer across the page and down; well 3D printers construct your object layer by layer too but from the floor, up. Take your normal laser printer and turn it 90 degrees; 3D printing is just printing upward rather than across and down a page.

Office desks will need to either get cleared off or built larger because this printing technology is here and these machines will soon be sitting side by side with your current laser/ink printer. After more than a decade of only high end industry use, engineers can be creating 3D models and prototypes on the spot and at their desk too. This process only takes a few hours depending on the size and complexity of the object but that dwell time is decreasing.

Progression of Printing

There have been many discussions, articles, and reports talking about the potential transformation of this process for home users but more importantly— engineers in the manufacturing industry. This 3D printing technology surfaced commercially as rapid prototyping over two decades ago. Back then; this printing method was restricted to large, expensive, and complex systems. The early 90's was when manufacturers repurposed the print-head technology so smaller, less expensive units were feasible to create. Since then, there have been significant advances with the processes and technologies, turning this market into an extensive growing phenomenon. Prices have continued to fall more and more, and markets are becoming available for manufacturers, customers, and soon 3D printing will be affordable for small design firms, single architects or engineers, schools, and even home users.

Crisis of Costs

Even though this amazing process has grown substantially over the years, it has really grown relatively slow considering its capabilities; the reason being that, it has remained financially unaffordable.

Price has always had a negative impact on 3D printing's way into new markets, but not anymore. This printing process has so many advantages in that whoever uses it can reduce development time and costs, improve time-to-market, and simply have a larger amount of freedom when it comes to the design process. In reality, advances in this technology have already surpassed expectations being that there are so many competitors out on the market.

The vice-president of sales, marketing, and business development at Z Corporation, John Kawola clarifies (as cited in "3D Opens up the Desktop Market," 2007, p.32) "In the past, rapid prototyping could only be used by the biggest companies. The biggest trend is that, over three to four years, it's moved away from being highly specialized and is now available to smaller companies because of the price point." For example, the market in color kits sold by Z Corporation has gone from 20% to 70% in the last three to four years just from prices decreasing so rapidly (“3D Opens up,” 2007). According to “3D Opens Up,” (2007) Z Corporation does face competition in this competitive industry (p. 32). Desktop Factory, a much smaller corporation has had the goal in mind that this technology should be available to the consumer market. “3D Opens Up” says that Desktop factory has come out with a color machine (monochrome 125ci) that is a quarter of the price of the leading black and white rivals. The monochrome came out on the market for $4,995 and plans to have another kit out for under $1,000 within the next five years (p.31).

If companies and package engineers could have access to this technology daily, the development process would be so much simpler. Ideas could be understood easier by merely creating models that would normally just be talked about and trials could be run without actual containers made by a supplier. If prices keep dropping as the progression of technology furthers than hopefully this trend will come sooner rather than later. Chief executive Cathy Lewis from Desktop Factory says “We believe that, as the prices drop, the consumer market will embrace 3D printing. It may never be as ubiquitous as 2D printing, but the home market will be an important one” (as cited in “3D Opens up the Desktop Market,” 2007, p.31). If the home market seems feasible at this stage, the everyday packaging company can’t be too far off track.

Processes of Printing

There are many different rapid prototyping or 3D printing processes available on the market. They are all a little different but no matter which one you choose to use; they all are based on the same principle—building the design additively, layer by layer. They also all make use of five basic steps. The first two steps include creating a CAD file of the design, and then converting it to STL (stereolithography) format. A designer can use a pre-existing CAD file or can create one from scratch. To establish consistency between all the different CAD packages out today, STL format was adopted as the standard for the rapid prototyping industry because it was the first RP technique ever used. This format represents a three-dimensional surface as an assembly of planar triangles. The STL file encloses the coordinates of the vertices and the direction of the outward normal of each triangle. That file is then prepared to be built by a pre-processing program slicing it into thin cross-sectional layers, and the design starts being created one layer atop another using different polymers, paper, or powdered metal. All that is then left to do is clean and possibly surface treat the model. Remove the object from the machine and remove the supports that may be connected to it. Surface treating involves sanding, sealing, and/or painting; any of these treatments will most likely always improve appearance and durability. This approach to manufacturing parts and prototypes is very different from all the traditional methods of milling, molding, casting, or machining.

Processes of Printing: Stereolithography

The first commercial 3D printer, based on a technique called stereolithography started the rapid prototyping revolution. This was invented by Charles Hull in 1984 and patented in 1986. This basic method can build a 3D model from liquid photosensitive polymers that solidify when exposed to UV light. This procedure first positions a perforated platform right below the surface of a vat filled with liquid photocurable polymer. With an ultraviolet laser beam, it then traces the first slice (layer) of an object on the surface of this liquid. When this is done, it causes that layer of photopolymer to harden. The platform then lowers slightly and another slice is traced out and again hardened by the laser. This cycle continues until the completion of an object is formed.

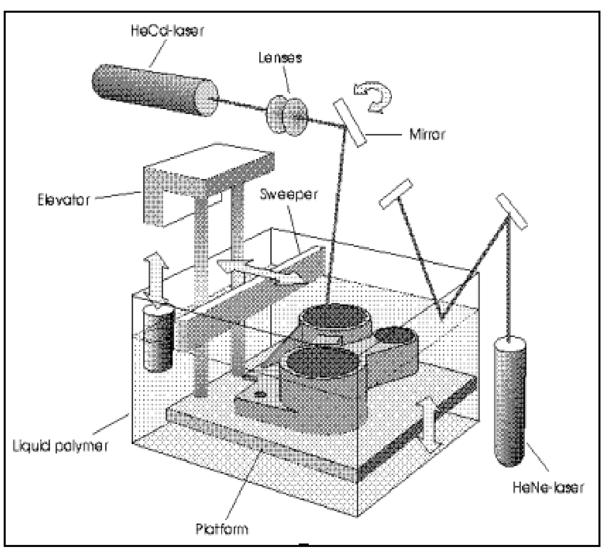

Figure I: Stereolithography diagram ("Rapid Prototyping Primer," 2002, section 3.1)

After the prototype or model is made, the solid part is removed from the vat and then rinsed and cleaned from the access liquid. Supports are taken off the model as well and then the model is placed in an ultraviolet oven for complete curing. According to "3D Print Making: Making the Digital Real" (2010) Stereolithography machines have been made since 1988 and to this day remain as one of the most accurate types of hardware for 3D fabrication (current technologies section, para. 1).

Processes of Printing: Laminated Object Manufacturing

This technique of rapid prototyping was developed by Heisys of Torrance, CA. In this process, layers of adhesive-coated sheet material are bonded together—and this forms the prototype.

As seen in figure II, a feeder mechanism advances paper laminated with heat activated adhesive and rolled up onto spools over the build platform. Next a heated roller applies pressure to bond the paper to the base it is now on. A laser then cuts the outline of the first layer into the paper and cross-hatches the excess area which breaks up the extra material. This will make the removal process a bit easier at the end and it also makes for a good support during the creation process for over hangs and thin wall sections. After the first layer is cut, the platform rises slightly below the previous height and the process begins again. The final product will have a wood-like texture because it is made from paper. For this reason, they must be sealed and finished with paint or varnish to prevent moisture damage. There are limitations on materials, but work has been done dealing with plastics, composites, ceramics and metals. Some of these materials are accessible on a limited commercial basis.

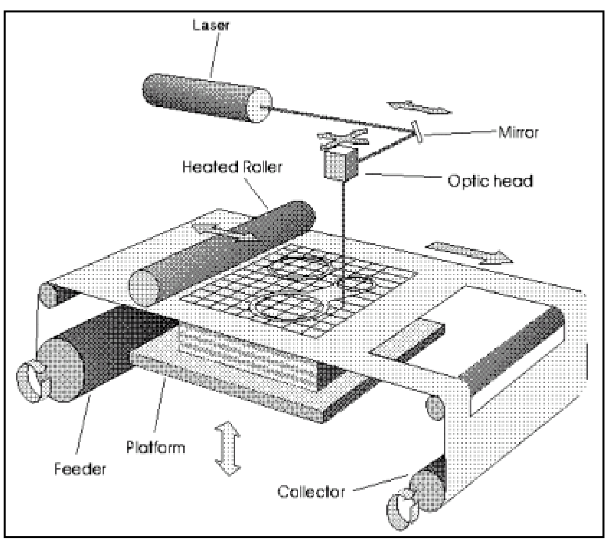

Figure II: Laminated object manufacturing diagram ("Rapid Prototyping Primer," 2002, section 3.2)

Processes of Printing: Selective Laser Sintering

Carl Deckard was the man behind selective laser sintering when he developed it for his thesis to get his master's degree at the University of Texas. This process was then patented in 1989.

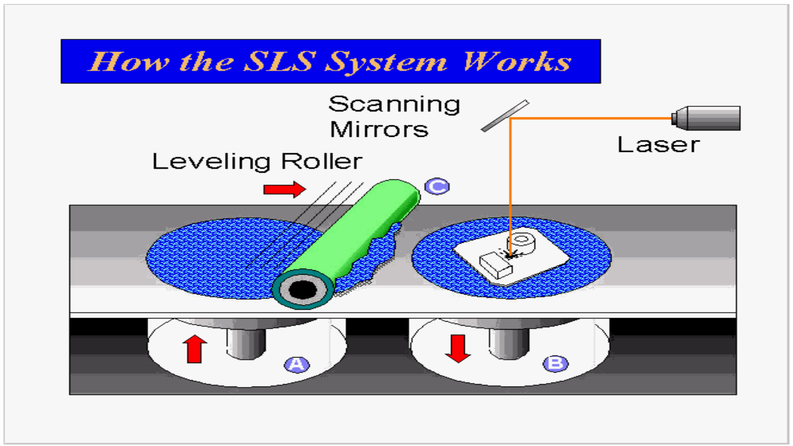

Figure III: Selective laser sintering diagram ("Rapid Prototyping Primer," 2002, section 3.3)

The technique in figure III shows a laser beam selectively fusing powdered materials, such as nylon, elastomer, or metal, into a solid object. Just below the surface in a bin filled with heat-fusible powder is a platform in which the parts are built. A laser traces the pattern of the first layer, sintering it together and then the platform is lowered to the height of the next layer where powder is reapplied and the new layer can then be formed. This process continues until the completion of the object.

Processes of Printing: Fused Deposition Modeling (FDM)

This technique has heated thermoplastic fibers that get extruded from a tip that moves from the x plane to the y plane. To make sure that the thermoplastic hardens quickly, a platform with a lower temperature is used. The platform will keep lowering and each time it lowers, a new layer is formed upon the layer before by the extrusion head. Supports are also built by fastening them in conjunction with the production of the object with either a weaker material or with perforated edges.

Processes of Printing: Solid Ground Curing (SGC)

Solid ground curing is almost the same as stereolithography in which they both use UV light to select what polymers should be hardened. One of the differences between the two is that SGC cures an entire layer at one time. The first step in this process is the photosensitive resin is sprayed onto the build platform. The machine then develops a photo-mask of the layer that needs to be built and it is printed onto a glass plate. The mask is then exposed to UV light from above and when the light makes it through the transparent portions of the glass, it hardens the polymer it comes in contact with.

When a layer is formed, it immediately vacuums up the excess resin and sprays wax in its place so the model will be supported during the build process. The top surface is then milled flat and then continues on to the next layer. After the whole process is complete, the object gets de-waxed by immersing it in a solvent.

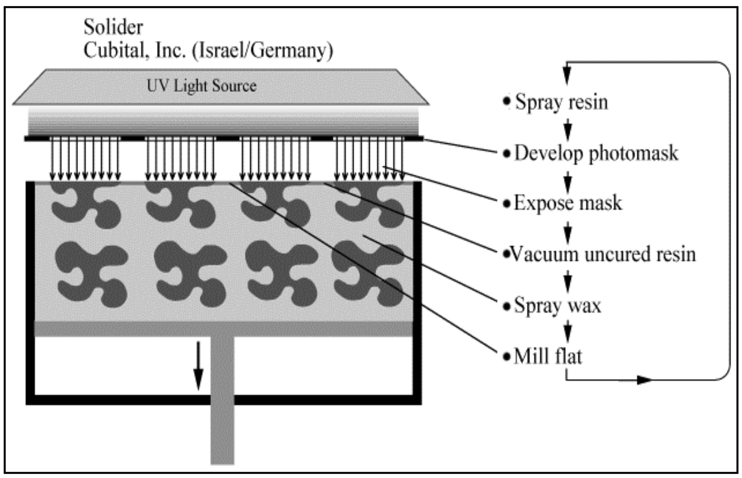

Figure IV: Solid ground curing diagram ("Rapid Prototyping Primer," 2002, section 3.4)

Processes of Printing: 3D Inkjet Printing

The 3D inkjet printing process refers to any class of machine that employs ink-jet technology. The simple process includes building the object on top of a platform situated in a bin full of powder material. An ink-jet print head selectively prints a binder fluid to fuse the powder together in selected areas. The unbounded powder stays put and helps act as a support throughout the process. The process is repeated till all the layers are added. Once done, the object is removed from the powder and the remaining powder is blown off.

Current Applications

The 3D printers in use today are not used often to create final consumer products; they are generally employed for rapid product prototyping, or to produce mould masters that can produce the production of final items. This type of technology has already enabled engineers to check the fit of various parts long before they commit to costly production. With prices decreasing on these systems, it is only going to get more common for companies to create their own mould masters without having to use large expensive resources.

The range of products this 3D technology has produced for mould masters and final moulds is continuously growing. Today we are seeing rapid prototyping creating all sorts of plastic bottles, packaging, and containers. Stereolithography can build an object with each layer having a minimum thickness of only 0.06mm (0.0025 of an inch). A single mould can cost thousands of dollars especially when having details produced so small and intricate as these prototyping machines can fabricate when going through an outside company; 3D printing has changed that forever.

Figure VII: Bottle prototype made from rapid prototyping ("College of Engineering," 2010)

Whether or not 3D printers arrive in the home, this technology has a very promising future in the business world. Rapid prototyping is already starting to change the way companies design and build products. Soon to come are several developments that will only make things better from a manufacturing standpoint.

One expected future improvement is the development of accuracy and surface finish. Today accuracy lies around ~0.08 millimeters in the x-y plane, but less in the z direction. Improvements in laser optics and motor control will increase accuracy in all three directions, meaning that models are going to be more precise when they are finished. In addition to the accuracy advancement, rapid prototyping companies are trying their best in developing new polymers that will be less prone to curing and temperature-induced damage/warp. The introduction of non-polymeric materials, such as metals or ceramics, represents another development that is much anticipated according to Rapid Prototyping Primer (2010). These materials would allow RP users to produce functional parts instead of just models (Future Developments section, para. 4). Today's prototypes work great for visualization tests but they are usually too weak for functional testing. Introducing more rugged materials would allow for prototypes to be subjected to actual service conditions. Metal and composite materials would also expand the range of products able to be manufactured bringing this technology to hundreds of more applicants.

Another improvement that keeps surfacing is the increased speed of the process. Machines today are still slow by some standards but by using faster computers, more complex control systems, and improved materials—manufacturers can reduce the time it takes for object completion. Rapid Prototyping Primer" (2002) found that in January of 1998, Stratasys Systems introduced a 3D printing machine (FDM Quantum) that produced a finalized ABS plastic model 2.5-5 times faster than the previous FDM model just years before(Future Developments section, para. 2). The faster the machine time, the more diverse the products can be. Even though it is difficult to estimate the time it takes to have a model produced from nothing to something because build time is dependent on part size, layer thickness, laser power, resin and many other factors. Sanderson, UW-Stout's own Instrument Maker-Journey Technology, confirms this change by relating the university's own two prototyping machines. The machines are about eight years apart, but he states the newer model reproduces at double the speed.

Recently there have been optical advances that have sped up rapid prototyping technology. The optical components of a stereolithography system have two main types: a laser system and a scanning system.

There are many different gas lasers used in these operations that have dominated the stereolithography playing field for years, but they are bulky and expensive. Newer and more efficient Diode Pumped Solid State (DPSS) lasers are now getting into this market and proving themselves to be more efficient, consume less power, have a long life, and a compact size. According to "Optical Advances Speed Rapid Prototyping (2010)," there are several types of lasers ranging from 193 nm to 355 nm in wavelength. The most common DPSS used in stereolithography is a frequent-tripled Neodymium-doped Yittrium Aluminum Garnet (Nd: YAG) laser with a 335 nm wavelength (For Lasers, optics are Key elements section, para.3). This being said, the larger the wavelength—the more accurate and efficient the stereolithography machine will be. From these new lasers, new photopolymer resins have found their way into the market as well—complimenting both the laser and material when used together. The delivery of laser energy is a stereolithography system; it can be a continuous wave (CW) or it can be Q-switched pulses. Q-switching is a new method that allows the laser to construct very high peak power pulses at a relatively low repetition rate. The main advantage here is high energy levels that induce substantial curing, reducing the need for lengthy post processing.

As new applications are emerging, new machines with smaller, faster, and lower-priced scanning systems are evolving as well. These systems use galvanometer-rotated mirrors to position the arm instead of an articulated arm. The lower size and weight of the mirrors compared to the arms allow higher speed scanning with a long mechanical life. These systems do have one downfall— they can no longer use a simple lens. Simple singlet lenses create a curved focal surface which then in turn complicates the control system that is trying to trace out a flat layer with the polymer. To eliminate this complexity, systems must use special scanning lenses that provide a flat surface at the image plane, but another option is available called the F-Theta scanning lens. The F-Theta lens will minimize distortion and provide a flat field at the image plane as well. This lens will also make the relationship between incident angles and spot position linear. This linear relationship eliminates the need for complex scan correction algorithms, which just actually means it simplifies the electronics and that makes the scanning system cheaper.

Together with the DPSS UV lasers, the availability of F-Theta lenses has altered the traditional equipment of rapid prototyping by making it faster, more accurate, and less expensive.

Conclusion

There are many existing technologies and factors relating to 3D printing but they are gradually improving their capabilities every day. A huge shifting factor is that of cost; pricing for these printers and the print media continue to fall making this technology more accessible for the everyday engineer. Eventually we will see them appearing in offices and homes across the country and then we can expect significant change in manufacturing technology.

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