



ENGINEERING STEREOLITHOGRAPHY FOR DENTISTRY

Dental Science

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ABSTRACT

Stereolithography is first commercial rapid prototyping device commonly known as three dimensional printing. Understanding and properly implementing it is essential for optimum results .

KEYWORDS

Three dimensional printing, Stereolithography, Medical applications

INTRODUCTION

During recent years , advances in computer technology have aided the diagnostic and clinical process for the management of complex craniofacial anomalies. The development of high resolution computed imaging and modeling technologies , also known as rapid prototyping systems is useful when diagnosing and planning the treatment of these anomalies . *Stereolithography* , a new technology, is a rapid prototyping system designed to create solid and detailed, three dimensional physical models that can accurately replicate complex anatomical structures directly from computer data . Combining the scanned information of reconstructed Computed tomography images with an Ultraviolet laser beam sequentially passed over a photosensitive resin , it is possible to produce , from a two-dimensional image , a dimensionally accurate three dimensional anatomical model , as a complete replica of the external surface and internal structures (including soft tissues) in a layer by layer fashion . This process is accomplished with predictable results quickly , and cost effectively . 1

Rapid prototyping has been first described by *Charles Hull* in the early 1980's . *Hull* and *Raymond Freed* initially worked on creating various plastic objects from photopolymers , they developed the first three dimensional printer . The printer was known as " stereolithography apparatus" and converted liquid plastic into solid objects . Researchers quickly made use of this emerging technology , creating applications across diverse scientific fields from engineering to medicine . Medical applications of three dimensional printing began appearing in the mid 1990s , opening the path to many subsequent biomedical uses . 2 The stereolithography process first appeared in the early 1970s , when Japanese researcher *Dr. Hideo Kodama* invented the modern layered approach to stereolithography , using ultraviolet light to cure photosensitive polymers. *Herbert* designed the layer by - layer method for replicating solid objects . 3

In 1989 *Carl Deckard* issued patent for selective laser sintering rapid prototyping process , which uses a laser to fuse powder instead of solidifying a plastic as in stereolithography technology .

In health care , the primary approaches utilizing three - dimensional printer include *stereolithography* , *selective laser sintering* , *electrospinning* , and *bioprinting* . These methods facilitate the degree of precision and control needed to handle structurally fragile cellular materials , and require computer aided design software that uses computed tomography , and magnetic resonance imaging information to create three dimensional models that are eventually converted into a "printable" three - dimensional data matrix . *Bioprinting* , or an extension of traditional three - dimensional printer combines cells and other biomaterials to fabricate tissue like constructs . It utilizes bioinks or hydrogels (various natural and synthetic polymers) loaded into a printer that uses high pressures to expel these materials in a controlled fashion to create the intended object / structure in a predetermined configuration . *Electrospinning* is a three dimensional printer method , it enables researchers to generate ultrathin fibers from a diverse number of materials (e.g ., ceramics , composites , polymers) . It is used to create fibers and scaffolds at the nanometer level that can withstand a significant amount of stress , providing a potentially useful platform for creating matrices for cartilage regeneration or bone repair . 2

Three dimensional printing in general , fused deposition modeling and stereolithography in particular are significant aid for improvement of local clinics . Three dimensional printers aids the medical science by

printing cells , organs and fabricating tissues . 4

Stereolithography is used to create models , prototypes , patterns and in education . It is also used to make surgical guide for implant placement. 5 *Stereolithography machines* are built around a large tank containing the liquid photopolymer (resin), and the build platform. The ultraviolet laser focuses onto the surface of the resin , tracing a cross section of the three dimensional model .

Stereolitho Graphy

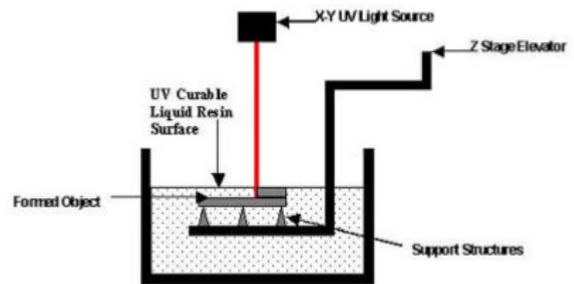


Figure 1 ME308 Summary of RP processes Qingwen Huang.

1. Machine accept part as an .stl file and slices the file into thin layers (0.004"-0.006" is typical) .
2. The part is built in a vat of resin . A layer of photocurable resin sits above the z_ stage elevator shown in diagram .
3. A laser scans the surface of this resin, drawing the bottom layer of the part .
4. When one layer is complete , the platform drops lower into the vat of resin , fresh resin washes over the part and the layer proceeds to build the next layer 5. When all layers are complete , the part is cleaned and post-cured .

During the stereolithography three dimensional printing process , the components of the resin form covalent bonds . This provides high degrees of lateral strength , but the polymerization reaction is not driven to completion . The print process is modulated in a way that keeps the layer in a semi-reacted state called the "green state" which differs from the completely cured state in that there are still polymerizable groups on the surface , that subsequent layers can form covalent bonds with . As the next layer is cured , the polymerization reaction includes the groups on the previous layer , forming covalent bonds.

Printing Process

Each stereolithography printer includes software to specify printing settings and slice the digital model into layers for printing . Adjustable printing settings include orientation , support structures , layer height , and material . Once setup is complete , the software sends the instructions to the printer via a wireless or cable connection . 3

Hull designed / established the *STL file* i.e "standard tessellation language" format , is widely accepted for defining three dimensional images in three dimensional printing software , and established the digital slicing and in fill strategies common in most three - dimensional printing processes . 6 Customized STL format has been devised as a three dimensional printer industry reference standard. Information saved in

STL files is interpreted by the computer and sent to the three dimensional printer, where the data conversion into a materialized three dimensional structure takes place. The three - dimensional printer resolution is based on the density of "triangles" within a specified area; therefore, the more "triangles", the higher the quality of the object being printed. The intermediary data format between the STL file and the three dimensional printer is the called "g - file" which breaks down the information further for interpretation by the printer. The "g - file" facilitates the conversion of information into a two dimensional horizontal field which is required to initiate the process of printing. As a result, the three dimensional printer effectively "prints" consecutive cross sectional areas of the intended object, gradually "building up" the final three dimensional structure one layer at a time. 2

After a quick confirmation of the correct setup, the printing process begins and the machine can run unattended until the print is complete. In printers with a cartridge system, the material is automatically refilled by the machine, while in other cases the user might need to add more material for large prints. Adding a post cure chamber to the printing process finalizes the polymerization process and stabilizes the mechanical properties. 3

Rapid prototyping advantage are the ability to build almost any three-dimensional shape with complex geometry which may be difficult to manufacture by conventional methods, the time needed to build a part depends a lot upon its geometrical complexities. It has been observed that complex internal details of a part get distorted greatly during post curing operation, due to release of internal stresses, which build up during curing of liquid resin by the laser beam while the rapid prototyping model is being built. The larger the value of layer thickness, the more energy it will need to get cured resulting in more internal stresses, other drawback of stereolithography and rapid prototyping processes is poor surface quality, especially on inclined surfaces due to stair stepping effect which becomes more prominent when larger values of layer thickness are used. 7 The amount of shrinkage, warpage, and dimensional inaccuracies for stereolithography produced parts may be reduced by using very low scan rates (and low laser power) or, alternatively, developing a resin that shrinks rapidly compared to typical scan rates. 8

The stereolithography setup

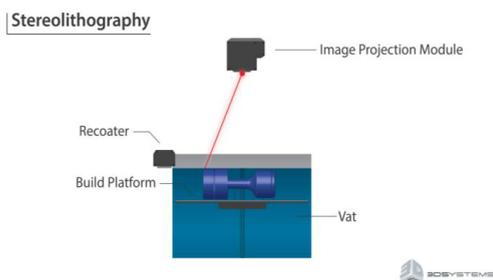


Figure 2

Stereolithography process 6

Stereolithography is a vat polymerization method, where layers of the liquid precursor in vat are sequentially exposed to ultraviolet light and thereby selectively solidified. A photoinitiator molecule in the resin responds to incoming light and upon irradiation, locally activates the chemical polymerization reaction, which leads to curing only in the exposed areas.

The required light for solidification of the resin can be applied in two distinct manners; either from above in the free surface approach, or from below through a transparent vat in the constrained surface approach. Irradiation can either be implemented by scanning of each point of the desired cross - section with a laser in laser stereolithography, or by projecting the entire pixelated image onto the layer in *digital light processing stereolithography*. A more uncommon method is illumination through a *liquid crystal display photomask*.

Laser - stereolithography

In Laser stereolithography also known as vector - based stereolithography each layer is cured by scanning of a ultraviolet laser onto the resin film. This x - y motion of the laser is implemented by two galvanometers in combination with a dedicated optical system. Methods to further improve the resolution to sub - micron regions include two photon polymerization and pinpoint solidification.

Two - photon polymerization

It was first proposed by Strickler *et al.* In its excitation of the photoinitiator in the resin, and thereby activation of the curing reaction, does not occur in the entire illumination path of the laser, as in conventional stereolithography, but only in the region of its focal point, called a volume pixel or voxel. A high intensity femtosecond pulsed laser can cause molecules to absorb two photons simultaneously. Instead of ultraviolet light, a laser at twice the wavelength (i.e. half the energy) with near - infrared light such as a Titanium-sapphire laser is employed.

Pinpoint solidification

A method similar to two-photon polymerization, pinpoint solidification, was proposed by Ikuta *et al.* in 1998 under the name of *super integrated hardened polymer stereolithography process*. A tightly focused laser is used and as with two - photon polymerization, due to the high intensity in the focal point of the laser, curing of the resin can only be achieved in this voxel. Mechanism, is of conventional single photon polymerization.

Bulk lithography

In bulk lithography, three dimensional textures can be created by variation of exposure energy. The cure depth, is a direct function of laser power or scan velocity (i.e. of the applied energy), defines the depth of the features. One can see the entire part as only existing of one layer with varying thickness. This eliminates the sometimes abrupt steps in z - direction, which are generated with conventional stereolithography methods, and vastly speeds up printing.

Digital light processing stereolithography is a method, which can reach resolutions in the order of 25 μm . In contrast to laser - stereolithography, the entire cross-section of a layer is illuminated simultaneously by it. The digital micromirror device is the key component and functions as a dynamic mask for the process. When linked with a computer for image processing, a light source, and optics, it can project desired cross - sections of light quickly and precisely. With its pixel - based exposure mechanism, it is excellent for illumination of sharp corners but can cause saw - tooth type surface roughness on otherwise curved surfaces.

Liquid crystal display stereolithography

Since its development in 1997 by Bertsch *et al.*, using an LCD device as a dynamic mask for stereolithography has been almost completely replaced by the digital light processing counterpart. The latter benefits are from superior switching speeds at higher accuracy. 9

Applications of stereolithography in dentistry

In dentistry, computer aided manufacturing has been applied in the creation of crowns, which are used to cover a damaged tooth, and dentures, which are removable or fixed devices to replace lost teeth. It can be employed to speed up the process between the acquisition of the geometrical data and implantation of the device into the patient. It can reduce the manufacturing time of these custom - made devices from more than a week to less than a day while also improving wear comfort. Medical applications are not limited to the fabrication of implants, prostheses, or other medical devices, but drug delivery systems such as micro-needles, capable of administering drugs by painlessly penetrating the skin, or three - dimensional printed tablets for individual dosage regulation have also been established.

Stereolithography can be used in medical imaging to create three dimensional models for preoperative planning or educational purposes. Three dimensional cell culture for more accurate in vitro models to study diseased, as well as healthy tissues, can be created. Tissue engineering constructs in regenerative medicine have also been fabricated with stereolithography methods and even bioprinting, where live cells are incorporated into the printed scaffold.

CONCLUSION

Health - care applications of stereolithography represent a rapidly growing and highly dynamic area. The promise of stereolithography in medicine is great - from better, more customizable implants to the development of fully functional, immunocompatible three dimensional printed tissues and organs suitable for human implantation.

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