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Stereolithography: Potential Applications in Forensic Science

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Abstract

In the present era, technological innovations are taking centre stage in the scientific world and the same stands true for the field of forensic science. Three dimensional modeling by virtue of rapid prototyping is relatively a novel area of exploration in the forensics. Stereolithography is one such area which involves production of three dimensional models (also known as prototypes) from complex mathematical, biological and chemical data. Three dimensional modeling can find its effective use in various sub-fields of forensic science as facial reconstruction, 3D crime scene remodeling etc. Thus, the following article endeavors to give a brief introduction to this rapidly emerging field and its possible applications in forensic science.

Keywords: Crime scene modeling, 3D modeling in forensics, rapid prototyping, stereolithography.

Introduction

Stereolithography (SLT) a rapid prototyping process that fabricates a part layer wise by hardening a photopolymer with guided laser beam. Thus, it is a method which involves transferring of three dimensional design details from a conventional Computer Aided Designing (CAD) system to produce accurate prototype models for product development and casting. Development of stereolithography technique aided the rapid prototyping procedures and this technology was patented way back in 1986. The term "stereolithography" was coined by Charles W. Hull. A machine that performs stereolithography is known as **S**tereo**l**ithography **A**pparatus (SLA)[1].

Literal meaning of the word "Prototype" is first or preliminary form from which other forms are developed or copied[2]. Prototype is essentially an operational model which is used for testing and evaluation purposes. Prototyping is the last step prior to mass production.

Rapid prototyping (RP) refers to layer- by- layer fabrication of three dimensional physical models directly from computer aided designs (CAD)[3,4]. It can be described as an imaging process in three dimensions which includes jetting of photopolymers in an inkjet type of equipment. Several RP techniques exist like stereolithography, fused deposition, selective laser sintering, and 3D printing. They adhere to similar basic principle but with the differences mainly from the materials and methods used to produce the model[5].

How Stereolithography works?

The fundamental replication production process is based on the fact that a liquid polymer (base material) could be changed instantaneously into a solid state when exposed to some specific type of radiation. As per the original patent details, a concentrated beam of ultraviolet light is focused onto the surface of a vat filled with liquid photopolymer. The light beam, moving under computer control, draws each layer of the object onto the surface of the liquid. Wherever the beam strikes the surface, the photopolymer polymerizes/crosslink and changes into solid state. Advanced CAD/CAM/CAE software mathematically slices the computer model of the object into a large number of thin layers[6].

The historical development of RP and related technologies is presented below[7]:

Year of Inception	Technology
1770	Mechanization
1946	First computer
1952	First Numerical Control (NC) machine tool
1960	First commercial laser
1961	First commercial Robot
1963	First interactive graphics system (early version of Computer Aided Design)
1988	First commercial Rapid Prototyping system

The process then builds the object layer by layer starting with the bottom layer, on an elevator that is lowered slightly after solidification of each layer.

A variety of liquid photopolymers are available for stereolithography. Epoxy-based systems and hybrids have replaced previously used acrylates because of higher strength, higher temperature resistance, lower moisture absorption and lower shrinkage of former. Main disadvantage of utilization of radiation cured acrylates are the hindrance created by oxygen inhibition in the prototype modeling process. The hybrids cure the photo-polymeric material under light by cationic as well as free radical polymerization[7]. Prominent examples of the materials used in the stereolithographic procedures are silicone rubber, urethane, epoxy or any type of medical grade FDA approved material. Photopolymer resins with mechanical properties similar to engineering plastics such as ABS (acrylonitrile butadiene styrene), nylon and polycarbonate are also used for prototype production. Stereo lithography Apparatus (SLA) machines have been made since 1988 by 3D Systems of Valencia, CA[3].

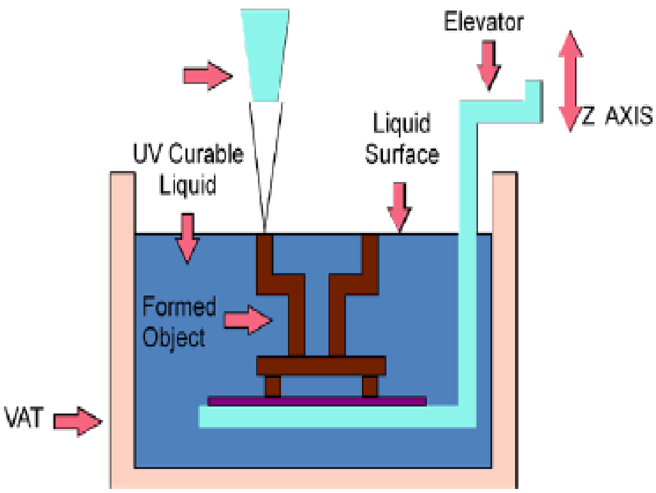

Figure-1
Schematic diagram showing prototyping unit illustrating different parts of the unit[8]

Applications of Stereolithography

Stereolithography finds its functional use in a number of applications associated with the manufacturing of the models. First, and probably the most common use for stereolithography is the manufacturing of functional prototypes which can also be used in mimicking the production parts. Moreover, stereolithography can be used for producing concept models which are typically finished to a higher, smoother level for sales presentations and marketing purposes. Casting patterns used in the plaster, sand, and spin casting processes are also created by SLT process.

Stereolithography finds its major application in the production of stereolithographic bio-models that allow visualization of facial skeletons that are being used increasingly in diagnosis and planning of treatment for congenital, developmental and post traumatic factors affecting the facial region. These models help the maxillofacial surgeon to know about the spatial displacements in three dimensions and to make accurate determination of the deformity. Thus stereolithography is playing a vital role in planning post traumatic, oncologic as well as reconstructive surgeries[10].

Stereolithography also finds its extensive use in oral implantology in which three dimensional models of maxillary and mandibular structures with true dimensions are reproduced. This served to reduce the problems related to bone density, dimensions and assured superior location of fixtures in the bones. Stereolithographic surgical templates are also used as guides during implant placements [11]. Present and future areas in which automated modeling can find use are listed in the table 1.

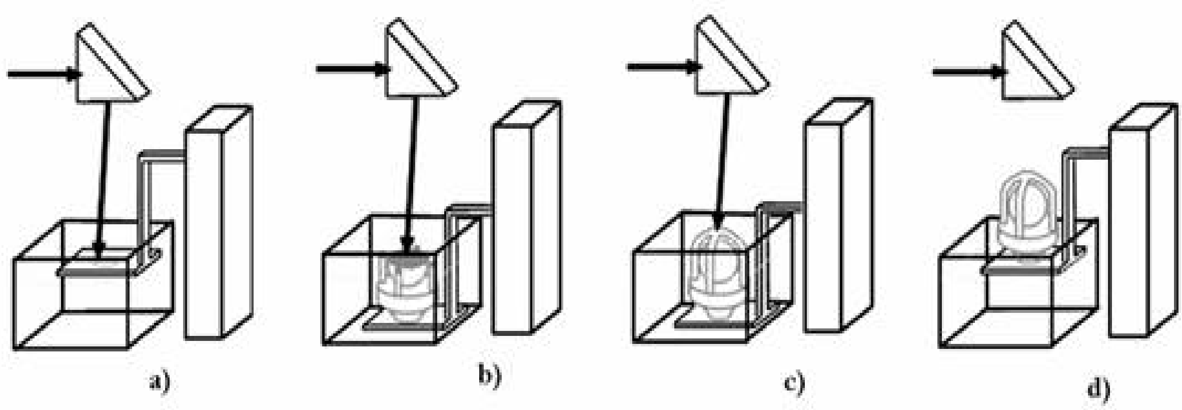

Figure-2
Sequence of layer-by-layer manufacturing of three-dimensional objects by using the laser stereolithography method: formation: a) of the first layer of the object; b) N layer; c) last layer of the object; d) object, fabricated by layer-by-layer method by using the focused laser beam on vertically moving platform, and taken from the vat with liquid resin[9]

Table-1

Applications of Automated Fabrication (Discpline Wise)					
Current Users	**Prototypes**	**Master Patterns**	**3D Imaging**	**Production**	**Art**
Manufacturers	*	*		*	
Industrial designs and Model Makers	*	*		*	
Surgeons, plastic surgeons and prosthetics	*	*	*	*	
Archaeologists and museum curators			*		
Sculptors				*	*
Jewelers	*	*		*	*
Future Users					
Theatre and film prop makers	*	*		*	
Architects and urban planners	*				
Decorators and display artists	*	*		*	
Chemists, physicists and biologists			*		
Mathematicians and statisticians			*		
Engineering instructors			*		
Forensic Scientists, Police artists	*		*		
Military strategists			*		
Astronomers and terrestrial topographers			*		
Photocopy shop operators	*	*	*		*
Photographers					*
Hobbyists				*	*

With the large variety of different types of stereolithography materials now available it is becoming more and more common for end use production parts and even assemblies to be manufactured right off a SLA machine check the statement. Though it is not always the right solution, it does offer a tool-less alternative to very costly machining and other manufacturing methods.

In nutshell, the SLT can be used for manufacturing of: i. Aesthetic and conceptual models, ii. Parts requiring detail and accuracy, iii. Master patterns for castings and secondary processes, iv. Medical models and fabrication of custom prosthetic devices.

Advantages of Stereolithography: i. Objects can be produced with any amount of geometric complexity, ii. Highly detailed parts with a smooth finish, iii. Very accurate tolerance even down to thousandths of an inch, iv. Large array of materials ranging in rigidity, clarity, color, detail and temperature deflection, v. Variety of finishing capabilities such as painting or plating for show presentation or demos, vi. Rapid turnaround time of most parts typically within a few working days.

Apart from the above listed factors, another advantageous factor is the associated cost which is dependent upon the structure complexity of the model under consideration. According to market reports, the cost is at par with the traditional two dimensional (2D) models used and three dimensional (3D) models can act as effective alternative to the two dimensional technology.

Forensic Applications of Stereo lithography: i. Stereolithography adds another, real world, dimension to the presentation of forensic evidences. Same information used in creating the animation can be used to create complimentary 3D models for use as exhibits in trial. This aids to isolate important areas for further discussion with expert witnesses, and to educate and persuade the jury[12]. ii. Production of 3D models could be useful in court to demonstrate injuries and convey information to jurors that would be more useful than standard photographs and diagrams[13]. iii. The fabrication of 3D models of the craniofacial complex (Skull) is being used for the technique of forensic facial approximation in the individual human identification. A variety of methods such as Stereolithography and laser sintering are used to accurately reproduce both the internal and external anatomy of craniofacial structures[14]. iv. Rapid prototyping stereolithographic technique has also been used along with MDCT/CT scan data to perform the facial reconstruction of wrapped Egyptian mummies. E.g.: The facial reconstruction of mummy of Harwa from Egyptian Museum, Torino, Italy, dating from XXII or XXIII dynasty, 945–715 BC, was done by rapid prototyping technique[15, 16,17]. v. In another case, when in year 1991, a mummified corpse was discovered in receding ice of the Similaun glacier in the Tyrolean Alps, the non invasive and non destructive techniques like radiologic investigation that included conventional radiography, digital radiography, and whole-body computed tomography (CT) was performed. From the CT data, the skull was duplicated by means of stereolithography. The copy of the prehistoric skull was validated by means of comparison of measurements obtained from the original CT images and from external physical measurements of the intact head of the mummy. This body proved to be an astonishingly well-preserved man from the late Neolithic Age or early Bronze Age[17,18]. vi. Stereolithography is presently in use to reproduce accurately the anatomy of body structures. vii. Current medical uses of stereolithography include preoperative planning of orthopedic and maxillofacial surgeries, the fabrication of custom prosthetic devices; and the assessment of the degree of bony injury caused by trauma. Computer aided tomography and magnetic resonance imaging data is being used for making 1:1 replicas[12].

Conclusion

Therefore, it could be concluded that rapid prototyping techniques such as stereolithography should be finding their extensive use in the field of forensic science in the light of technological advances. Stereolithographic techniques will also help to make the presentation of evidences more illustrative in the court of law.

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