



Rapid Prototyping Applications in Medical Sciences

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Abstract: *Rapid prototyping is impacting medicine in several important ways. Perhaps the most obvious application is as a means to design and develop medical devices and instrumentation. The most interesting and challenging applications of rapid prototyping technologies are in the field of medicine. Rapid prototyping medical models have found application for planning treatment for complex surgery procedures, training, surgical simulation, diagnosis, design and manufacturing of implants as well as medical tools. This paper explores the procedure for making medical models using Rapid Prototyping, and presents the applications of rapid prototyping technologies in different fields of medicine and their future trend.*

Keywords: *Rapid prototyping (RP), 3D printing, prototype, process, product*

I. Introduction

Rapid prototyping technologies for easy production of prototypes, parts and tools are new methods which are developing unbelievably quickly. Successful product development means developing a product of high quality, at lowest cost, in the shortest time, in at a reasonable price. The development of the part and its introduction to market is time consumption process. But “time is money” and therefore could be said that money saving is greatest when time to market is minimalized utmost. The technology is also known by several other names like digital fabrication, 3D printing, solid imaging, solid free form fabrication, layer based manufacturing, laser prototyping, free form fabrication, and additive manufacturing [1]. The use of Rapid prototyping for medical applications although still in early days has made impressive strides. Its use in orthopedic surgery, maxillo-facial and dental reconstruction, preparation of scaffold for tissue engineering and as educational tool in fields as diverse as obstetrics and gynecology and forensic medicine to plastic surgery has now gained wide acceptance and is likely to have far reaching impact on how complicated cases are treated and various conditions taught in medical schools [2].

II. History

The roots of rapid prototyping technology can be traced to practices in topography and photo sculpture. Within TOPOGRAPHY Blather (1892) suggested a layered method for making a mold for raised relief paper topographical maps. The process involved cutting the contour lines on a series of plates which were then stacked. Matsubara (1974) of Mitsubishi proposed a topographical process with a photo-hardening photopolymer resin to form thin layers stacked to make a casting mold. Photo sculpture was a 19th-century technique to create exact three-dimensional replicas of objects. Most famously Francois Willeme (1860) placed 24 cameras in a circular array and simultaneously photographed an object [3-5]. The silhouette of each photograph was then used to carve a replica. Morioka (1935, 1944) developed a hybrid photo sculpture and topographic process using structured light to photographically create contour lines of an object. The lines could then be developed into sheets and cut and stacked, or projected onto stock material for carving. The Munz (1956) Process reproduced a three-dimensional image of an object by selectively exposing, layer by layer, a photo emulsion on a lowering piston. After fixing, a solid transparent cylinder contains an image of the object. The technologies categorized under Solid Freeform Fabrication are recognized at present to be Rapid Prototyping, 3D Printing or Additive Manufacturing: Swainson (1977), Schwerzel (1984) worked on polymerization of a photosensitive polymer at the intersection of two computer controlled laser beams. Ciraud (1972) Considered magnetostatic or electrostatic deposition with electron beam, laser or plasma for sintered surface cladding [6-7]. The National Additive Manufacturing Innovation Institute (NAMII) is a tech incubator recently [2012] organized by US government agencies, academia and industry. It has been started in part because in the last 10 years the US additive manufacturing tool industry's lead has been replaced by those of Europe and Asia

III. Basic principle of rapid prototyping processes

Rapid prototyping 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 rapid prototyping 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 [8]. If model is deposited with very fine layers, i.e., smaller z-stepping, model looks like original. Rapid prototyping can be classified into two fundamental process steps namely generation of mathematical layer information and generation of physical layer model. Typical process chain of various rapid prototyping systems is shown in figure 1.

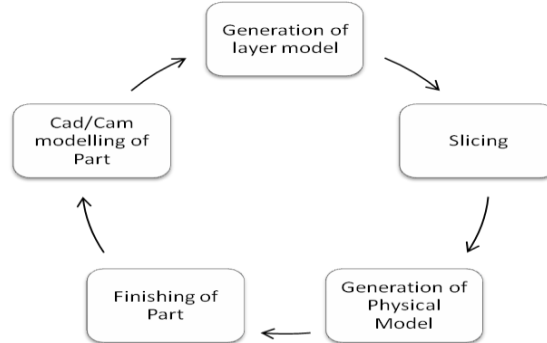


Fig 1 Rapid prototyping process chain showing fundamental process steps

It can be seen from figure 1 that process starts with 3D modeling of the product and then STL file is exported by tessellating the geometric 3D model. In tessellation various surfaces of a CAD model are piecewise approximated by a series of triangles (figure 2) and co-ordinate of vertices of triangles and their surface normal's are listed. The number and size of triangles are decided by facet deviation or chordal error as shown in figure 2. These STL files are checked for defects like flip triangles, missing facets, overlapping facets, dangling edges or faces etc. and are repaired if found faulty. Defect free STL files are used as an input to various slicing software's. At this stage choice of part deposition orientation is the most important factor as part building time, surface quality, amount of support structures, cost etc. are influenced. Once part deposition orientation is decided and slice thickness is selected, tessellated model is sliced and the generated data in standard data formats like SLC (stereolithography contour) or CLI (common layer interface) is stored [9].

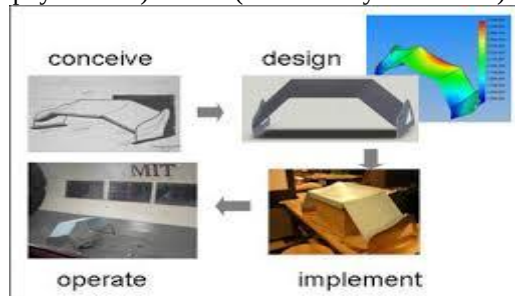


Fig 2 CAD model

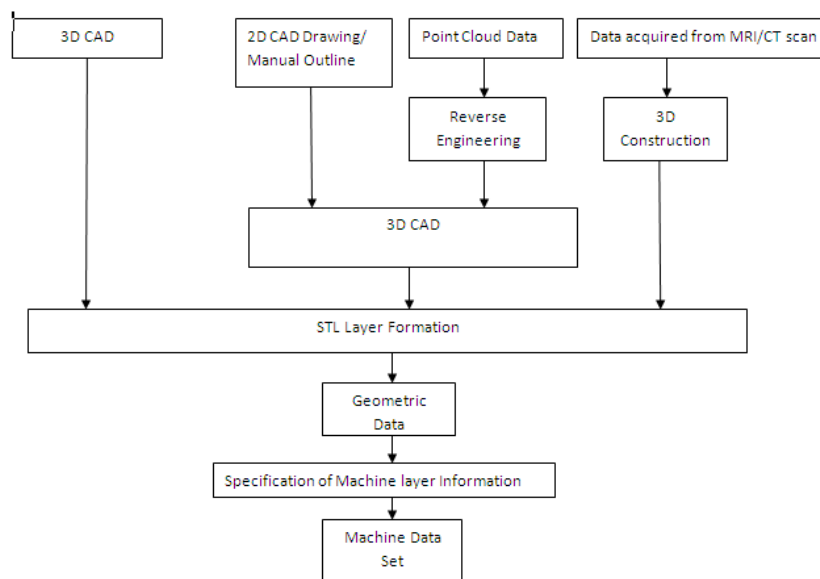


Fig 3 Generalized illustration of data flow in Rapid Prototyping

This information is used to move to step 2, i.e., generation of physical model. The software that operates rapid prototyping systems generates laser-scanning paths (in processes like Stereolithography, Selective Laser Sintering etc.) or material deposition paths (in processes like Fused Deposition Modeling). This step is different for different processes and depends on the basic deposition principle used in rapid prototyping machine. Information computed here is used to deposit the part layer-by-layer on rapid prototyping system platform. The generalized data flow in rapid prototyping is given in figure 3. The final step in the process chain is the post-processing task. At this stage, generally some manual operations are necessary therefore skilled operator is required. In cleaning, excess elements adhered with the part or support structures are removed. Sometimes the surface of the model is finished by sanding, polishing or painting for better surface finish or aesthetic appearance. Prototype is then tested or verified and suggested engineering changes are once again incorporated during the solid modeling stage.

IV. Rapid prototyping processes

The professional literature in rapid prototyping contains different ways of classifying rapid prototyping processes. However, one representation based on German standard of production processes classifies rapid prototyping processes according to state of aggregation of their original material and is given in figure 4.

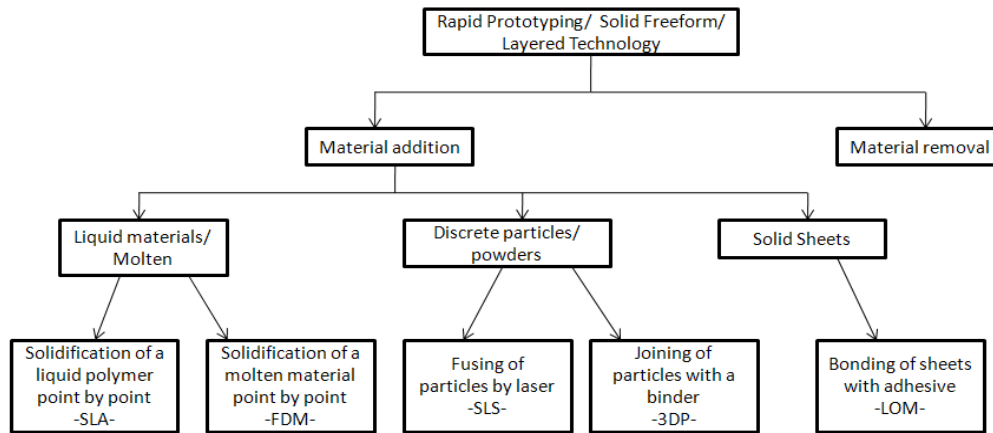


Fig 4 Classification of rapid prototyping processes

V. Steps in production of rapid prototyping models

The various steps in production of an RAPID PROTOTYPING model (Figure 5).

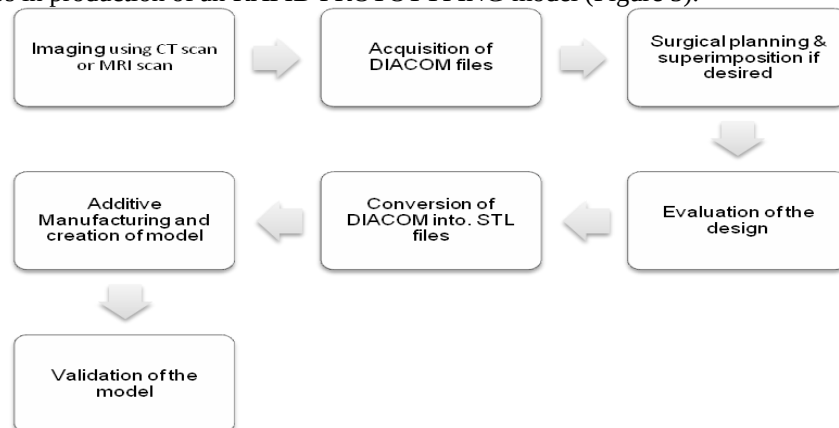


Fig 5 Steps of rapid prototyping process

In short, the procedure involves getting a CT scan or MRI scan of the patient. It is preferable that the CT scan is of high slice calibre and that slice thickness is of 1- 2mm. Most of the MRI and CT software give output in form of digital imaging and communication in medicine format popularly known as DIACOM image format [10].

Acquisition of DIACOM files and conversion to .STL file format: After the data is exported in DIACOM file format, it needs to be converted into a file format which can be processed for computing and manufacturing process. In most cases the desired file format for Rapid manufacturing is .STL or stereolithographic file format. The conversion requires specialised softwares like MIMICS, 3D Doctors, and AMIRA are shown in Figure 7 & 8. These softwares process the data by segmentation using threshold technique which takes into the account the tissue density. This ensures that at the end of the segmentation process, there are pixels with value equal to or

higher than the threshold value. A good model production requires a good segmentation with good resolution and small pixels.

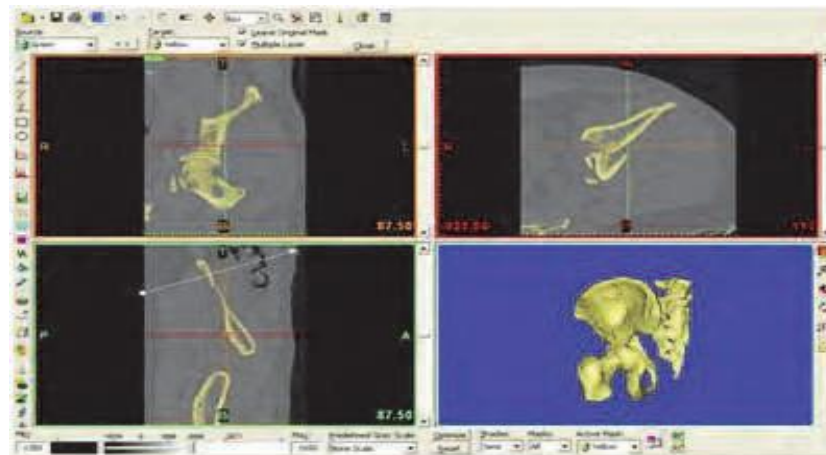


Fig 6 Segmentation using the software

VI. Applications of Rapid Prototyping technologies

This is the field where applications of rapid prototyping show the best results. It specially applies to hearing aids but also to other surgical aid tools. Rapid prototyping technologies gave significant contribution in the field of tissue engineering through the use of biomaterials including the direct manufacture of bioactive implants.

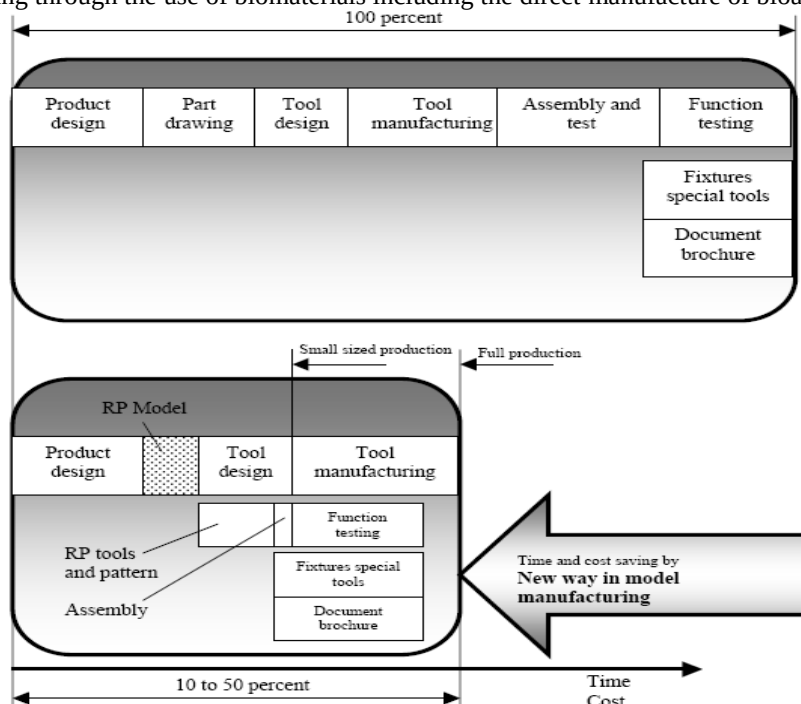


Fig.7 Result of introduction of rapid prototyping in design cycle (after Chua and Leong, 2001)

Tissue engineering is a combination of living cells and a support structure called scaffolds. Rapid prototyping systems like fused deposition modeling (FDM), 3D printing (3-DP) and selective laser sintering (SLS) have been proved to be convenient for making porous structures for use in tissue engineering. In this field it is essential to be able to fabricate three-dimensional scaffolds of various geometric shapes, in order to repair defects caused by accidents, surgery, or birth. FDM, SLS and 3DP can be used to fabricate a functional scaffold directly but rapid prototyping systems can also be used for manufacturing a sacrificial mould to fabricate tissue-engineering scaffolds [11]. Rapid prototyping technology has potential to reduce time required from conception to market up to 10-50 percent (Chua and Leong, 2000) as shown in figure 8. It has abilities of enhancing and improving product development while at the same time reducing costs due to major breakthrough in manufacturing (Chua and Leong, 2000) in figure 7.

VII. Recent and future trends

Recently this technique was used for the separation of Siamese twins who was born by the attaching of the skull portion as shown in Figure 8



Fig 8 RP modeling for surgical planning to separate Siamese twins

It is a very significant discovery in medicine and the first step on the way to making other complex human organs. Further development in rapid prototyping in tissue engineering requires the design of new materials, optimal scaffold design and the input of such kind of knowledge of cell physiology that would make it possible in the future to print whole replacement organs or whole bodies by machines [12]. There are also many new trends of applying rapid prototyping in orthopedics, oral and maxillofacial surgery and other fields of medicine.

VIII. Conclusion

Technologies are definitely widely spread in different fields of medicine and show a great potential in medical applications. Various uses of rapid prototyping within surgical planning, simulation, training, production of models of hard tissue, prosthesis and implants, biomechanics, tissue engineering and many other cases open up a new chapter in medicine. Due to rapid prototyping technologies doctors and especially surgeons are privileged to do some things which previous generations could only have imagined. However this is just a little step ahead. There are many unsolved medical problems and many expectations from rapid prototyping in this field. Development in speed, cost, accuracy, materials (especially biomaterials) and tight collaboration between radiologists, surgeons and engineers is necessary and so are constant improvements from rapid prototyping vendors. This will help rapid prototyping technologies to give their maximum in such an important field like medicine. Benefits resulting from the use of rapid prototyping equipment may include:

- Reduction of current operating costs (including labor, quality, purchasing, etc.)
- Improved sales and marketing due to the ability to respond to customer requests for bids with actual models
- Improved product development, including improved customer satisfaction and improved product manufacturability
- Improved process development as lead times and costs are reduced, leading to more iterations

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