https://dx.doi.org/10.22161/ijaers/3.12.3 *ISSN: 2349-6495(P) | 2456-1908(O)*

Rapid Prototyping Assistance to Medical Science

Sidharth Kasturi, Amol Nayakappa Patil, Parashuram Nandi, Nagaraj Raikar

Assistant Professor, Department of Mechanical Engineering, Agnel Institute of Technology and Design, Assagao, Goa, India

***Abstract*— *This article focuses on overview of Rapid prototyping application in Medical Science. Study covers briefing about rapid prototyping along with the medical model preparation and various techniques used in Rapid prototyping. This article covers medical application of rapid prototyping in field of prosthetics and implantation, simulating and planning surgery, tissue engineering, developing medical devices and instrumentation, anthropology, forensic and medical teaching aids. The findings of article are based on case studies and article beneficial to application engineers and medical practitioners.*

Keywords*— *CT Scan, Medical model, Rapid Prototype, SLA, SLS, LOM, FDM.

I. INTRODUCTION

Rapid Prototyping can be defined as group of techniques used to quickly fabricate a prototype of model to required scale using a three dimensional computer aided design data [1]. Rapid Prototyping deals with layer by layer material deposition technology. Rapid Prototype is highly promising advanced technology that has the potential to change fundamentally in some of the regions in medical science [2]. The process involves building of prototypes or functioning models in very short time, which can be used for certain design feature testing, analysis and verification of ideas [3]. Rapid Prototyping is very helpful in the field of medicine, as this technology can be used to directly fabricate model of various complex shaped anatomical parts directly from scanned data such as computerized tomography (CT) images. The models prepared from RP can be used for many applications in medical field. Such as presurgical planning and for assistance in the intensive planning of surgical procedures. The prototypes can also be used by surgeons and medical students to rehearse different surgical procedure realistically [4]. RP products can also be used for manufacturing of custom prosthesis, implants, surgical devices and also functions as a communication tool between surgeons and patients. The RP technique that are commercially available are Stereolithography (SLA), Selective Laser Sintering (SLS), Laminated Object Manufacturing (LOM), Fused Deposition Modeling (FDM), and Three-Dimensional Printing (3DP) [1].The common procedure followed in medical model prototyping starts with virtual phase in which a CAD is prepared by using medical imaging data technologies such as CT, MRI and Laser Digitizing. The data then processed in the commercially available RP software to produce a 3D virtual CAD model [5]. Nowadays, with advancement in material technology different varieties of materials are available. Some of the medical grade material can be used to RP models on the basis of their use in different medical applications. This review article only deals with RP techniques best suited for fabrication of medical prototypes and their application with case studies from literature where RP and associated technology have been successfully used for medical applications.

II. MEDICAL MODEL PRODUCTION

The steps involved in production of 3D medical model using RP processes are as follows

1. 3D digital image
2. Data transfer, processing and segmentation
3. Design Evaluation
4. RP medical model production
5. RP medical model validation

1. 3D DIGITAL IMAGE

Data creation for digital image for medical model is created using the data directly imported from CT or MRI or Laser Digitizing techniques used for this purpose. The data information taken from these techniques will be highly accurate as they use a spiral technique which allows to do full volume scanning. This helps to produce high number of slices for more accuracy. Most CT and MRI units have the ability to export data in common file digital imaging and communication in medicine (DICOM) [6]. Laser digitizing is technique which uses laser probe, which scans the surface of anatomy and produces the model with only surface featured model without any inside information. This method captures only external surface data for examples like dental applications. Advantage of laser digitizing is that it won't emit any radiation. [4]

2. DATA TRANSFER, PROCESSING AND SEGMENTATION

Image data acquired from MRI, CT and Laser Digitizer will be in DICOM format to be converted into standard tessellated language format used by many of RP systems. The platforms used for conversion are MIMICS, 3D Doctor and Voxim. This software converts the image data to (STL) standard tessellated language with necessary segmentation of the anatomy through sophisticated 3D editing tools. This software provide various modification tools required for the data file like defining various tissue density to colour code the required region of interest [4]. To achieve the high degree resolution and small dimension of pixels demands the collaboration of RE engineers with surgeons and radiologist who will help to achieve accurate 3D virtual model [6].

3. EVALUATION OF DESIGN

In this step, the good communication between the doctor treating the patient and application engineer operating the RP software plays vital role. The data which contains unnecessary information needs to be discarded and the data that contains the useful should be retained. This eliminates the major errors and also reduces the cost of production. The design generated using RP software needs to be processed in CAD package. In this evaluation of design, errors are also eliminated with help of experienced doctor. The doctor have a very important role in validation of virtual model, because errors are caused due to misunderstanding of anatomical structure by engineers and also because of some disturbances in the scanned images are get evaluated and eliminated[6]. The model which is processed and evaluated by doctors and engineers is tested with the help of finite element method or analysis software like Ansys, NASTRAN etc. and later 3D virtual model is ready for production

4. RP MEDICAL MODEL PRODUCTION

The RP techniques have their own merits and demerits. Depending on the requirements of end application a RP techniques is chosen. RP selection is based on properties such as accuracy, surface finish, cost, visual appearance of internal structure, number of desired colors in the model, strength and availability of build materials and mechanical properties [4]. Finally, 3D model in STL format is sent to the selected RP machine. Accuracy of model built directly depends on accuracy level of STL file orientation and material used to build it. The parameters of RP machine are selected and building of part starts.

5. RP MEDICAL MODEL VALIDATION

After the fabrication of model, needs to be evaluated and validated by the engineers and surgeons. If model has no error then it is put in actual application.

III. RAPID PROTOTYPE TECHNIQUE STEREOLITHOGRAPHY

The term stereolithography (SLA) was first introduced by Charles W. Hull in 1986, who defined it as a method based on photo-polymerization of liquid monomer resin for fabricating solid parts. Produced by 3D Systems, Corp., in Valencia, CA, the Stereolithography Apparatus (SLA) has progressed through a long succession of models and advancements since its inception. SLA deals with building of model through the use of low powered UV laser for curing photosensitive liquid polymer. SLA machine consists of VAT of liquid resin, movable elevator platform and UV laser. The resin on platform is cured selectively by UV laser and upon curing one complete layer platform moves downwards to a distance of one slice. Next layer of resin is applied and cured. These steps are repeated until the part is complete. The advantages of SLA include smooth surface finish and high part building accuracy, whereas disadvantages of this process involves time-consuming post processing and use of expensive and poisonous material. [4]

SELECTIVE LASER SINTERING (SLS)

SLS creates 3-D models out of a heat-fusible powder, such as polycarbonate or glass-filled composite nylon, by tracing a CO2 laser beam across a platform covered with the powder. Heating the particles causes them to sinter together to create a solid layer. The solid layer is then covered by powder with the help of roller mechanism and the next slice formed on top of it, until the object is completed. The same process can be performed with a combination of metal and polymer mixture like low-carbon steel and thermoplastic binder powder, resulting in a 'green state' part. The binder is then burned off in a furnace and the metal particles are allowed to sinter together. The resulting skeleton is subsequently infiltrated with copper, resulting in a metal-composite part. [2] The advantage of this technique is that it has ability to use different types of thermoplastic powders, easy postprocessing and the unsintered loose powder acts as support structure. Disadvantages of this method include high costs and the abrasive surface of sintered models

THREE-DIMENSIONAL PRINTING (3DP)

Binder printing methods were developed in the early 1990s, primarily at MIT. They developed the 3D printing (3DP) process in which a binder is jetted using print onto a powder bed to form part cross sections. This method is very similar to selective laser sintering. Here the Laser is replaced by an inkjet head. The "three dimensional printers" allow designers to quickly print prototypes of required designs. The three-dimensional printing system receives input CAD file in STL format. The model is sliced by using RP Slice Software. Powder is supplied on a flat bed and a roller spreads the powder layer evenly. Printing head as in inkjet printer, releases jets of binder to bond powder material. The platform is lowered to one slice thickness and the next layer is built on the previous layer and is continued until the part is complete. One advantage of 3DP is that, no support structure is needed. This process is very fast and produces parts with a slightly rough grainy surface. Machines with different colour printing capability are available.

FUSED DEPOSITION MODELING (FDM)

FDM was developed by Stratasys, Inc. of Eden Prairie, MN, in the early 1990s as a concept modeling device that is now used more for creating casting masters and direct-use prototyping. Fused deposition modeling (FDM) is an extrusion-based rapid prototyping (RP) process, although it works on the same layer-by layer principle as other RP systems. FDM uses the standard STL data file for input, and is capable of using multiple build materials in a build/support relationship. FDM builds 3-D models out of heated thermoplastic material, extruded through a nozzle head positioned over a computer controlled platform which moves in x-y axis. The table is moved to accept the material until a single thin slice is formed. The next slice is built over it until the object is completed. FDM utilizes a variety of build arterials, such as Polycarbonate, polypropylene and various polyesters which are more robust than the SLA models.

LAMINATED OBJECT MANUFACTURING (LOM)

Laminated Object Manufacturing (LOM) is a rapid prototyping (RP) technique that produces three-dimensional models with paper, plastic, or composites. Helisys, Corp. in Torrance, CA developed LOM, led by Michael Feygin. LOM is actually more of a hybrid between subtractive and additive processes, in that the models are built up with layers of material, which are cut individually by a laser in the shape of the cross section of the part. Hence, as layers are being added, the excess material not required for that cross section is being cut away. Plastics, composites, ceramics, metals and various organic and inorganic materials with different chemical and mechanical properties for a variety of applications can be processed. LOM is well suited for complex and large parts. The build speed is very fast, but a high effort is needed for decubing, finishing and sealing the parts.

IV. APPLICATION

1 - IN THE FIELDS OF PROSTHETICS AND IMPLANTATION

RP techniques are very useful in making custom prosthetics and implants. The RP can produce prosthesis to patients' unique proportions. They are capable of building knee joints, hip sockets, ear implants, nose implants and spinal implants. One interesting example is maxillofacial prosthesis of an ear which is obtained by creating a wax cast by laser sintering of plaster cast of existing ear.

A patient with congenital absence of right ear was provided with RP developed auricular prosthesis. The anatomical morphology of the prosthesis was developed by RP method. The CT scanning was done on missing ear anatomy and contralateral ears. The tomography images were developed with help of MIMCS by comparing CT data with the contralateral normal ear on reverse order and joining them together. A CAD model was obtained and suitable RP system considered and produced the prosthesis. The accuracy was checked by comparing with CAD model. The researcher concluded that RP produces the high degree accuracy prosthetics. It also enables the engineers and surgeons to produce customized product without required sculpting skills and faster than conventional methods [4].

2 – SIMULATION AND PLANNING OF SURGERY.

RP techniques plays important role by creating 3D solid model which can be used by surgeons to pre-operate. This pre-operating is necessary in difficult cases as it gives surgeons an opportunity to plan a complex procedure before actual performance. This also enables the surgeons to study the fracture configuration and design a proper implant according to bony anatomy [3]. The surgical planning is often done with help of SLA RP method because model will have high accuracy and surface finish [2].

A patient with multiple fractures was treated using RP techniques and ultimately reduced operative time. The CT scan data showed a fracture involving the iliac blade starting 3cm below the iliac crest and extending forward, with the femoral head protruded and fracture line till the superior pubic rami. RP system was used to preoperative planning by designing template, sizing and aligning the implant. Slice thickness in CT scan data chosen was 1mm. In preoperative planning, a template of reconstruction plate with 4.5mm contour was used. The screw sizes and position of plate and holes for screws were decided and marked on 3D model. This helped the surgeons to reduce total surgical time to 3h 10min in which only 20min took for the instrumentation. The blood loss noted to be 600ml. The postoperative evaluation showed that accuracy and sizing of implant were fine and working successfully [3].

RP techniques were also applied to treat an 18 year old male with an injury to right kneed and ankle. The radiography was conducted after stabilization. CT data of his right knee was used to make 3D RP model, showing fracture pattern. The model helped the surgeons to study pattern of fracture, possible reduction in manoeuvre and to decide sizing and trajectory of screws. This resulted in early recovery [3].

3 – TISSUE ENGINEERING AND SCAFFOLDS

Contribution of RP techniques in the field tissue engineering is significant. Tissue engineering is use of combination cells, biomaterial and physiochemical factors to improve or replace tissues. It is also combination of cells and scaffolds. RP methods like SLS, 3DP and SLA have been proved their efficiency in making models for use in tissue engineering. In this field scaffolds are to be manufactured as porous structure, serves as an adhesion substrate for RP model. RP technology has advanced to create highly complex anatomy, customized and highly accurate features.

4 – MEDICAL DEVICES AND INSTRUMENTATION

In this field of application various different methods of RP can be used to design, develop and manufacture different medical implants and instruments. Some of the noted devices produced by these methods are hearing aid, dental devices and surgical aid tools [10].

Baxter Healthcare is a company which produces medical devices. This company relies on two RP process SLA and SGC. They produce master pattern used for urethane mold, which is used to produce prototypes. The prototypes are sent for design analysis to check errors. The changes in designs verified and incorporated in final device. The product is Biopsy Needle Housing.

Mask Produced for Burnt Victims, these are the masks which are used for burnt victims to control the healing process by controlling the scar tissues growth. In conventional method it is impossible to produce exact replica. The RP uses digital scanning method to create a virtual model of a patient’s anatomy. The data is converted and transferred to SLA machine to produce exact replica. The SLA is prepared because of its various advantages.

5- ANTHROPOLOGY

In this application, study related to fossils of human bone, teeth and other artifacts are scanned and the replica of the same is produced with help of RP methods. The models are used for molding, measuring and dissecting study without harming the originals. The RP is very advantageous where only 1 or 2 specimens exists, then RP models plays a important role in finding the evolution and various studies done by researchers [4][7][8].

6 – TEACHING AID

In this field of application, RP can help the students to understand the concepts in better way than the conventional method of learning. Some of the RP methods can produce models with different colour coding. In medical colleges an anatomy model can be produced with different colour which will help the students to understand in more creative way. In RP software a provision is there to add notations to the models, where a surgeon can write small note to particular anatomical features. For example a cancer anatomical model with different colour and notation by surgeon gives more information while studying and also helps in planning surgery [2].

A 3DP model of protein-protein interaction can help to study the cause and development of disease and provide new healing approaches. Protein-Protein interactions study is done by deducing the complex structure arrangement. This is done by comparing the protein structure with known protein structure. Structure of known proteins data can be taken from Protein Data Bank. This data is used for CAD model creation and a RP model is printed which is used for study and analysis purposes.

7 - FORENSICS

RP adds, real world, dimensions to the presentation of forensic evidences. Production of 3D model of craniofacial complex will help in forensic facial approximation. RP also enables the forensic doctors to produce all internal and external anatomy of craniofacial structures [9]. The RP models also help in studying the anatomy of wounds and especially in surviving victim with difficult access wounds, like in skull. Using RP models scenes can be recreated and aid courtroom deciding the final verdict [4].

V. CONCLUSION

Rapid Prototyping is emerging approach which uses mechanical and computer knowledge, to create prototype before actual application. RP has wide spread in different field. Rapid Prototyping is assistance to medical science having its variety of application and significant impact in medical. Rapid prototype potential in medical science is demonstrated using different applications. CT scanning followed by CAD model was used to create ear to patient with congenital absence of right ear. This technology can be used as an alternative to conventional fabrication methods within the field of tissue engineering, customize implant and medical devices. Further research is required to reduce the overall cost of Rapid Prototyping, for the development of suitable biomaterials and for the development of RP systems designed specifically for medical applications.

REFERENCES

[1] D. Chandramohan, and K. Mariamuthu, “Rapid Prototyping/Rapid Tooling- A Overview and its Application in Orthopaedics,” International Journal of Advance Engineering Technology, Vol. 2, Issue 4, pp. 435-448, 2011.

[2] M. M. Deoa, T. V. Tanay, A. M. Wankhade and M. N. Sayed, "Application of CAD/CAE & Rapid Prototyping Technology in Medical Field," International Journal of Engineering Trends and Technology, Vol. 4, Issue 5, pp. 1674-1678, May 2013.

[3] V. Bagaria, D. Rasalkar, S. J. Bagaria and J. IIyas, " Medical application of Rapid Prototyping – A New Horizon", Advance application of Rapid Prototyping Technology In Modern Engineering, 2011

[4] S. Negi, S. Dhimani, and R. K. Sharma, " Basic and applications of Rapid Prototyping Medical Models", Rapid Prototyping Journal, Vol. 20, Issue 3, pp.256-267, 2014

[5] R. Kumaravelan, V. C. Sathish Gandhi, S. Ramesh, and M. Venkatesan, "Rapid Prototyping Application in Various filed of Engineering and Technology," International Journal of Mechanical, Aerospace, Industrial, Mechatronics and Manufacturing Engineering, Vol. 8 Issue 3, pp.610-614, 2014

[6] R. Kumaravelan, V. C. Satish Gandhi, S. Ramesh, M. Venkatesan, " Rapid Prototyping Application in Various Field of Engineering and Technology," International Journal of Mechanical, Aerospace, Industrial, Mechatronics and Manufacturing Engineering, Vol.8, Issue 8, pp. 610-614, 2014

[7] P. Raos, A. Stoic and M. Lucic, " Rapid Prototyping and Rapid Machining of Medical Implants," 4th International Conference on Advanced Technologies for Developing Countries, 2005

[8] G. W Weber, K. Schafer, H. Prossinger, P. Gunz, P. Mitterocker and H. Seidler, "Virtual Anthropology: The Digital Evolution in Anthropological Science," Journal of Physiological Anthropology and Applied Human Science, March 2001.

[9] P. M. Puri, H. Khajuria, B. P. Nayak and A. Badiye, "Stereolithography: Potential Application in Forensic Science", Research Journal of Engineering Science, Vol.1, Issue 5, pp. 47-50, 2012

[10] Van Noort, Richard. "The future of dental devices is digital.", Elsevier Inc. Vol. 28, Issue 1, pp. 3–12, 2012