A Study on Use of 3D Printing Techniques in Medical Field

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Abstract:3D Printing (3DP) is an innovative technology. It has evolved in the design and manufacturing industries in recent years. Particularly, the 3DP technology has led to drastic improvement in the field of medical. The improvement are delivered in various field such as 3D visualization of a specific anatomy, surgical planning, implant design, prosthesis production, polymeric drug delivery devices, etc. In this article, a study of the latest technologies available in 3DP for medicine applications are presented. Further the future trends are highlighted as special cases.

Index Terms: 3D Printing (3DP), computer aided design (CAD), medical modeling process, applications.

I.INTRODUCTION:

3D Printing is the automatic construction of physical objects using solid freeform fabrication. The first technique for rapid prototyping was available in the late 1980s.[1] It was used to make models and prototype parts. 3D Printing requires virtual designs from Computer Aided Design (CAD) or animation modeling software, transforms them into thin, virtual, horizontal cross-sections and creates each cross-section in physical space, one after another until the model is finished. Each 3D Printing platform uses the same principles of slicing, layering and bonding to build parts. Many commercial organizations & research institutions have integrated Computer-aided Design (CAD), 3D Printing systems with medical imaging systems to fabricate medical devices or generate 3D physical models of these objects for use in surgical rehearsal, custom implant design and casting. In manufacturing, models are conceived and planned entirely on the computer screen, then converted to physical model. In bio-medical applications, the objects normally already exist physically. Prior to building the physical model, before transferring to a 3D Printing system, this highly complex data needs extensive pre-processing to provide a format that a CAD program can utilize. **[7]**
Very well known, the term "rapid prototyping" refers to a number of various related technologies that can be used for developing very complex physical models and parts of prototype from 3D CAD model. These technologies are stereolithography (SLA), selective laser sintering (SLS), fused deposition modeling (FDM), laminated object manufacturing (LOM),
inkjet-based systems and three dimensional printing (3DP). RP technologies can use wide varieties of materials like paper, plastic to metal and recently biomaterials. Rapid Prototyping including Rapid Tooling has been developed for manufacturing industry to speed up the process of development of new products. Rapid prototyping have showed a great impact in the area of (prototypes, concept models, form, fit, and function testing, tooling patterns, final products - direct parts. Preliminary research shows prominent potential in application of Rapid Prototyping technologies in various different areas including medicine. Use Rapid Prototyping in medicine is a very complex task and incorporates a multidisciplinary approach and very good knowledge of engineering as well as medicine. It also demands human resources and collaboration between doctors and engineers. With years of research and development rapid prototyping technologies are now being applied in medicine for manufacturing dimensionally correct and person specific human anatomy models from high resolution medical imaging data. [15]

II. 3D PRINTING TECHNIQUES:

There are many a number of 3D Printing technologies on the market, based on special sintering, layering or deposition methods as described below.

2.1. Stereo lithography (SLA):

Developed by 3-D Systems Inc, of Valencia, CA and patented in 1986, this is the leading technology, with over 500 SLA machines installed worldwide. Stereo lithography creates 3-D models made up of acrylate photopolymer or epoxy resin, by tracing a low powered ultraviolet laser across a vat filled with resin. A solid thin slice is created by curing the material using laser. The solid layer is then lowered and the next slice formed on top of it, till the object is completed[1-3]. It is regarded as a benchmark technology by which other technologies are judged. A recent development by Zeneca is a translucent resin which changes to red when acted upon by higher laser energy. This can be used to display local regions of interest, and an application would be for the surgeon to draw round a tumor on the medical image slices and have it to build into the model.[1]

2.2. Selective laser sintering (SLS):

This technology was developed by Carl Deckard at the University of Texas. This technology was patented in 1989 and commercialized by DTM Co, of Austin, TX. SLS creates 3-D models from a heat-fusible powder, such as polycarbonate or glass-filled composite nylon. This process is done by tracing a modulated laser beam across a bin covered with the powder. Heating the particles, fuses or sinters together to create a solid thin slice. This solid layer is covered by more powder and the next slice formed on top of it, until the object is completed. The same process can be carried out with a combination of low-carbon steel and thermoplastic binder powder, resulting in a 'green state' part. The binder is then burned off in a furnace and the steel particles are allowed to sinter together[4]. The resulting steel skeleton is infiltrated with copper, resulting in a metal-composite part.[1]

2.3. Solid Ground Curing (SGC):
This technology was developed by Cubital, and is somewhat similar to stereolithography (SLA) as both use ultraviolet light to selectively harden photosensitive polymers. SGC cures an entire layer at a time. It is also known as the *Solider process*. Initially, photosensitive resin is sprayed on the build platform. Next, the machine develops a photomask (like a stencil) of the layer to be built. This photomask is printed on a glass plate above the build platform using an electrostatic process. The mask is then exposed to UV light, which passes only through the transparent portions of the mask to selectively harden the shape of the exposed layer. After the layer is cured, the machine vacuums up the excess liquid resin and sprays wax in its place to support the model during the build. The top surface is milled flat, and the process repeats to build the next layer. When the part is complete, it is de-waxed by immersing it in a solvent bath. [1]

2.4. Fused deposition modeling (FDM):
This technology was developed by Stratasys Inc, of Eden Prairie, MN. FDM creates 3-D models from heated thermoplastic material, extruded through a nozzle positioned over a computer controlled x-y table. The table is moved to accept the material to form a thin slice. The next slice is built on top of it until the object is completed. FDM can use a variety of materials, such as polycarbonate, polypropylene and various polyesters which are more robust than the SLA models. FDM models can also be made in wax, enabling custom-made implants to be investment cast for individual patients.[1]

2.5. Laminated object manufacturing (LOM):
This technique was developed by Helisys of Torrance, CA, USA. In this technique, layers of adhesive-coated sheet material are bonded together to form a prototype. The original material consists of paper laminated with heat-activated glue and rolled up on spools. A feeder/collector mechanism advances the sheet over the build platform, where a base has been constructed from paper and double-sided foam tape. Next, a heated roller applies pressure to bond the paper to the base. A focused laser cuts the outline of the first layer into the paper and then cross-hatches the excess area (the negative space in the prototype). Crosshatching breaks up the extra material, making it easier to remove during post-processing. During the build, the excess material provides excellent support for overhangs and thin walled sections. After the first layer is cut, the platform lowers out of the way and fresh material is advanced. The platform rises slightly below the previous height, the roller bonds the second layer to the first, and the laser cuts the second layer. This process is repeated as needed to build the part, which will have a wood-like texture. Although these models are robust, it is difficult to remove unwanted regions of paper from areas of complex geometry.[1]

2.6. Multiphase jet solidification (MJS):
This technology was developed by the network of\ Fraunhofer Institutes in Germany. MJS creates 3-D metal or ceramic models out, of various low-viscosity materials in powder or pellet form, by extruding the build material through a jet in liquid form. Each layer that is deposited solidifies on to the previous one, until the entire object is created. This technology is still in the development phase.[1]

III. FABRICATION OF MEDICAL MODELS:
The medical modeling process is broadly split into three areas, 1) Data acquisition, 2) Image processing, and 3) Model production.

3.1. Data Acquisition:
In medical imaging, the two most common systems used in acquiring detailed anatomical information are Computed Tomography (CT), and Magnetic Resonance Imaging (MRI). CT and MRI represent the finest resolution capability available in diagnostic systems achieving volumetric resolutions. During the scanning process, the patient is stepped through the measurement plane 2-3mm at a time. The information from each plane can be put together to provide a volumetric image of the structure as well as the size and location of anatomical structures. The scanned model becomes a virtual volume that resides in a computer, representing the real volumes of the patient's bone(s). The virtual volume is displayed on-screen by reformatting the data to create orthographic projections, or by a creating a pseudo 3D representation using surface-rendering algorithms[6, 7].

3.2. Data reconstruction/Processing:
When a series of CT images is reassembled to illustrate a 3D presentation of an anatomic structure, the medical practitioner or prosthetic designer can use this information directly and the overall shape of body structures is more clearly understood or visualized. This process requires a good visualization software packages. These software packages take anatomical data from CT and MRI scans and create computer models of anatomical structures. A user can modify the image by defining various tissue densities for display. This allows separation of data of interest from the general information available from the scanner. By combining the data generated with a traditional CAD system, design of new parts can be undertaken by comparison with the reconstructed 3-D anatomical shape. When segmentation and visualization is completed the data can be translated into instructions for manufacture of parts often by RP6.

3.3. Evaluation of Design:

This step depends on a case-to-case basis. Sometimes the created model is directly used as an input for RP machine (biomodels). This is necessary for evaluation of design, quality of the made model, checking possible errors or other important steps which depends on the concrete case.

3.4. RP Medical Model Validation:

When the RP medical model is manufactured it should be validated by surgeons. If there are no errors the model is ready for application. The Materialize package has two modules: *MIMICS* and *CTM* suites.

***A) Mimics*:** Mimic is a software suite that performs the segmentation of the anatomy through sophisticated three dimensional selection and editing tools. The program also generates high-resolution 3D renderings in different colors directly from the slice information as shown in fig-1. After visualization, the data can be interfaced to CTM.

B) *CTM*: CTM is a software suite that interpolates the medical slice in very thin layers, and interfaces directly with most RP systems. Because of this direct interface and the use of higher-order interpolation mathematical algorithms such as Bilinear and C-Spline functions, it produces very accurate models in a very short time. A resolution enhancement technique is necessary when creating the RP models so as to minimize the effect of stair-stepping, and to retain the natural curvature of the surface.

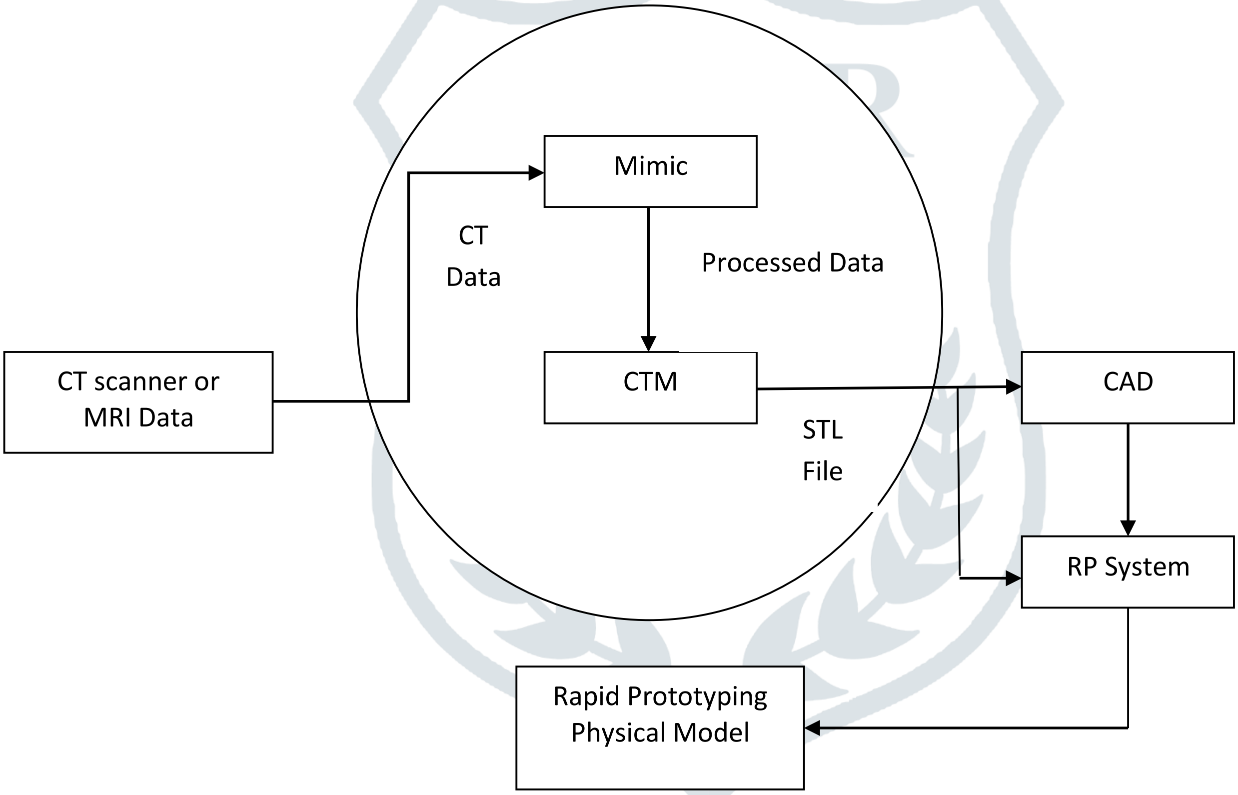

Fig- 1: Conversion of scanned data to physical 3D model

IV. APPLICATIONS:

4.1. Design and development of medical devices and instrumentation:

This is the field where applications of 3D Printing show the best results. It specially applies to hearing aids but also to other surgical aid tools[8].

4.2.Improvements in the fields of prosthetics and implantation:

RP techniques are very useful in making prostheses and implants for years. The ability to quickly fit prosthesis to a patient's unique proportions is a great advantage. The techniques are also used for making hip sockets, knee joints and spinal implants for quite some time. Both the release of and the improvement of the properties of used materials have had a significant influence on the quality of prostheses and implants made by 3D Printing. One interesting example is maxillofacial prostheses of an ear which is obtained by creating a wax cast by laser sintering of a plaster cast of existing ear. Due to 3D Printing technologies it is very easy to manufacture custom implants. The made model could be used as a negative or a master model of the custom implant. Many researchers explored new applications of 3D Printing in this field[9, 10].

4.3. Complex surgical operations:
This is very important role of 3D Printing technologies in medicine which enable pre-surgery planning. The use of 3D medical models helps the surgeon to plan and perform complex surgical procedures and simulations and gives him an opportunity to study the bony structures of the patient before the surgery, to increase surgical precision, to reduce time of procedures and risk during surgery as well as costs (thus making surgery more efficient). The possibility to mark different structures in different colors (due to segmentation technique) in a 3D physical model can be very useful for surgery planning and better understanding of the problem as well as for teaching purpose. This is especially important in cancer surgery where tumor tissue can be clearly distinguished from healthy tissue by different color[11, 12]. Surgical planning is most often done with stereolithography (SLA) where the made model has high accuracy, transparency but limited number of colors and 3DP (for more colored models, presentation of FEA results).

4.4. Design and manufacturing of biocompatible and bioactive implants and tissue Engineering:
3D Printing technologies gave significant contribution in the field of tissue engineering through the use of biomaterials including the direct manufacture of bioactive implants. Tissue engineering is a combination of living cells and a support structure called scaffolds. 3D Printing systems like fused deposition modeling (FDM), 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 can be used to fabricate a functional scaffold directly but 3D Printing systems can also be used for manufacturing a sacrificial mould to fabricate tissue-engineering scaffolds[14].

V. RECENT AND FUTURE TRENDS:
It is a very significant discovery in medicine and the first step towards making other complex human organs. Further development in 3D Printing in tissue engineering needs 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. There are also many new trends of applying 3D Printing in orthopedics, oral and maxillofacial surgery and other fields of medicine.

VI. CONCLUSION:
3D Printing technology can make significant impact in the field of biomedical engineering and surgery. Physical models enable correct identification of bone abnormality, intuitive understanding of the anatomical issues for a surgeon, implant designers and patients as well. A precise RP model helps in the pre-operative planning of an optimal surgical approach and enables selection of correct or appropriate implants. In the UK, 3D Printing has been used to help plan treatment in more than 20 patients; however, the cost of the modeling process is currently a significant limitation to its use. Surgical procedures continue to be more effective day by day with reduced risk and expense to both the patient and the hospital.

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