Medical 3d Printing, Case Study

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Abstract- While Additive manufacturing (AM) popularly known as Rapid Prototyping (RP) or 3D Printing technology has primarily been developed for the manufacturing Industry to assist in speeding up the development of new products, its vendors and users were quick to realize the technology was also suitable for applications in the medical field. Doctors and surgeons have always been looking for better ways to describe, understand and diagnose the condition of individual patients for the customization of individual human anatomical structure. Diagnostic tools have become increasingly more sophisticated and the latest CT, MRI and other medical imaging technology can now present patient data in many ways and with great clarity and accuracy. There are, however, many cases where doctors or surgeons might like to have a physical model in front of them rather than have to look at images on a computer screen. Before RP, such models could only be generic and were not necessarily useful to describe an individual condition. With RP there came a way to create such physically solid models of an individual directly from the 3D data output by the medical imaging system. The production of a copy of an existing object of complex shape is one of the typical applications of the integration between two modern computer based technologies, Reverse engineering (RE) and Additive manufacturing (Fused Deposition Modeling) which is the mostly known technology of Rapid Prototyping. The method is extremely versatile and can be used in various applicative domains e.g., Replacement anatomical parts with prostheses (artificial device used to replace a missing body part) replication of skeletal remains for medical applications and can be used for customization of dummy parts.

Keywords –3D printing, Medical reverse engineering, human face, scanning

I. INTRODUCTION

Medical Reverse engineering (RE) with integration of Rapid prototyping (RPT) or 3D technology for, medical applications.A case study taken and thoroughly investigated to apply RE and RP. In this project we have gathered cloud data of face mask, generated CAD surface and then 3D printed the object with scale down. The following technologies were used in executing project. Medical Reverse Engineering (MRE) is aimed to use the Reverse Engineering (RE) technology to reconstruct 3D models of the anatomical structures and biomedical objects for design and manufacturing of medical products as well as BME research and development. Understanding, controlling and manipulation of patient data as well as shape, geometry and structure of the biomedical objects are important for developing Biomedical Engineering (BME) applications.

REVERSE ENGINEERING

Reverse engineering is a modeling process from original data (which are often digitized from an object) that results in a concise geometric model exportable to CAD/CAM packages. The data points are digitized from the products, which may have been designed before CAD/CAM existed, produced by other manufacturers or made by hand (without CAD design at all). Nowadays, RE is changing from a tedious manual dimensioning or tracing process to a powerful engineering tool utilizing modern digitizing equipment and CAD/CAM systems. The first step in mechanical RE of a geometric model is data acquisition from a part by using some type of Digitizer. The two most commonly used digitizers are optical and mechanical. Considering the material of the finger joint bone, the required accuracy, the bone surface complexity and the speed requirement for this project, laser optical scanning is used for the digitizing process. Reverse engineering in this study involves the scanning of bone samples to determine the geometric range in which the models should fit into and form the basic surfaces to be used for the implants. Laser scanner was used to capture surface data points to create freeform surfaces of human bone samples. This was used to

extract curve sets that could be incorporated into a generic design. Other scanning techniques such as coordinate measuring machines (CMMs) were used to compare the accuracy of the 3D scanner with other digitizing machines.
Reverse engineering is the method that reconstructs CAD models from physical models. The main process of reverse engineering consists of data acquisition, data preprocessing, surface fitting, and making a CAD model. In reverse engineering, we mainly handle point data of the Surfaces of a model acquired by measuring devices such as CMMs or 3D laser scanners. Usually a complex freeform shape model cannot be represented by a single patch; therefore, it must be divided into several less complicated surfaces. The benefit of CAD/CAM is that the existence of computer models provides opportunities for improving the quality and efficiency of a design and is convenient for manufacture [1]. Reverse engineering starts with measuring an existing object using a laser scanner, and then the measuring data is used to construct a surface or solid model. Although reverse engineering technically does not include the machining process as one of its stages, an evaluation of the part dimensional accuracy after machining was nonetheless performed. Machining provides a physical model which can be compared easily to the original part, since better visualization and measurement is possible.

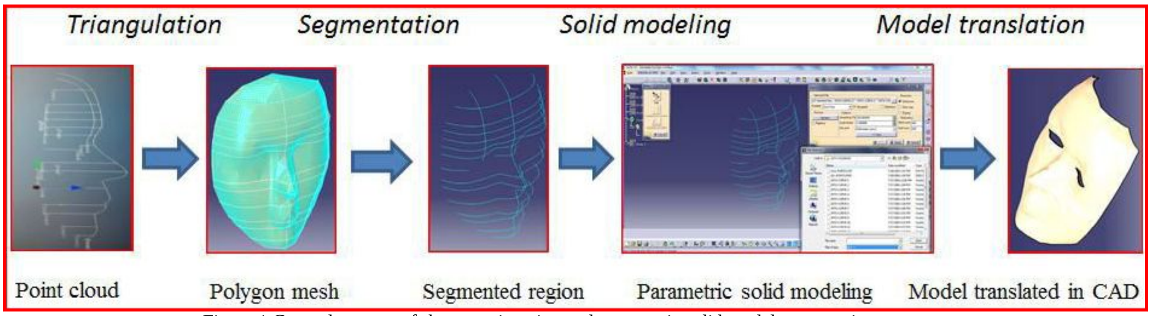

Figure 1 General process of shape engineering and parametric solid model construction

The final target of all RE processes is to obtain 3D data representing the geometries of the objects of interest from which different applications are developed. There are two types offend-use data representation that are commonly used, especially in the areas of 3D Geometrical Modeling, Engineering Design and Product Development: (i) Polygons or Triangle Mesh and (ii) Non-Uniform Rational B-Spline (NURBS). A polygon or triangle mesh includes vertices, edges and faces that define the shape of an object. The faces usually consist of triangles, quadrilaterals or other simple convex polygons. This type of data is the simplest way of representing the geometries of objects, appeared in most of the computer graphic systems; however, it is not an accurate representation of the geometries. NURBS surfaces are the ultimate output of the RE process that we would like to obtain for applications where accuracy requirements are high. NURBS are basically an accurate way to define a free-form curve and surfaces. NURBS are useful for a number of following reasons,

(i) NURBS offer one common mathematical form for both standard analytical shapes and free form shapes
(ii) NURBS provide the flexibility to design a large variety of shapes
(iii) NURBS reduce the memory consumption when storing shapes
(iv) NURBS can be evaluated reasonably fast by numerically stable and accurate algorithms
(v) NURBS are invariant under affine as well as perspective transformation and
(vi) NURBS are generalizations of non-rational B-splines and non-rational and rational Bezier curves and surfaces

Based on two types of end-use data representation, the fundamental MRE methods are presented as shown in Fig 2 in which the state of the art data processing chains for 3D geometrical reconstruction of the objects for medical application development and research are emphasized. There are 4 main phases,

(i) Phase I - MRE inputs
(ii) Phase II –Data acquisition
(iii) Phase III - Data processing and analysis, and
(iv) Phase IV – Biomedical Application Development & Research.

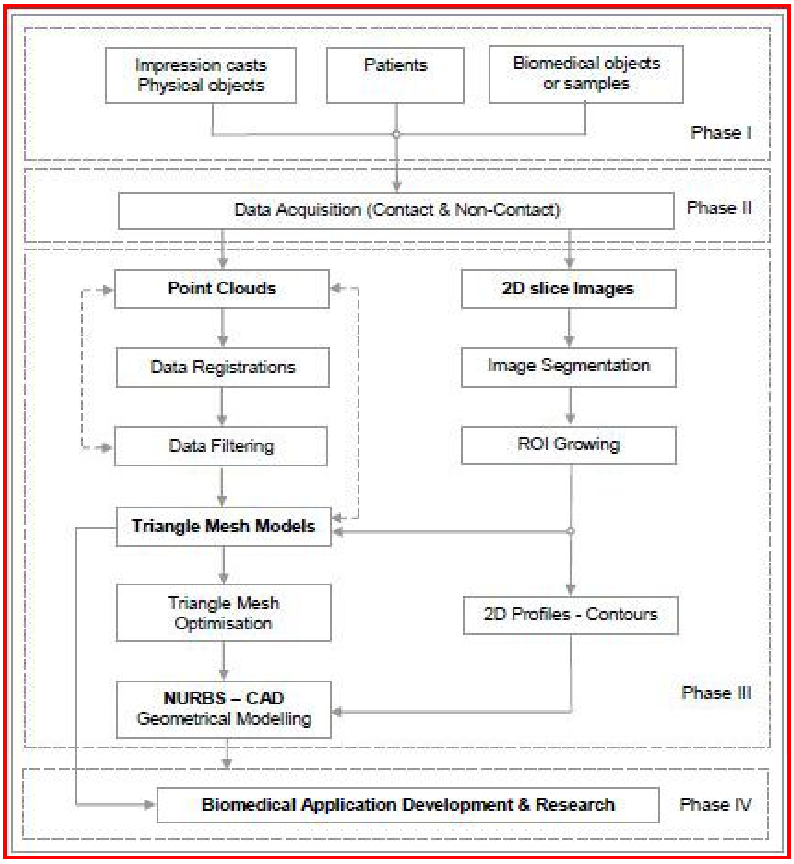

Figure 2 MRE methods- Fundamental processes and informative flow

II.EXPERIMENTAL PROCEDURE

One of the most time-consuming aspects of creating 3D virtual models is the creation of the geometric models of objects. This can be particularly frustrating when there is a real or physical version of the object. The process of 3D digitizing basically consists of a sensing phase followed by a reconstruction phase. The sensing phase collects or captures the raw data and generates the initial geometry data, usually as a 2D boundary object, or a 3D point cloud. Sensing technologies are based on tracking, imaging, range finding or their combination. The reconstruction phase is the Internal processing of the data into conventional 3D CAD and animation geometry data and generation of surface from the digital data. Once the surface is generated from cloud data the part can be processed through RPT technique by using FDM.

REVERSE ENGINEERING OF FACE MASK

In this experimental procedure of using reverse engineering with additive manufacturing of medical application we have considered of making a face mask as an example. The reverse engineering of face mask which can used in medical application has gone through below steps for collection of cloud data,

1. The object (face mask) is scanned by using CMM Prizmos series for collecting the 3D data
2. The probe moves on the object for collecting the 3D data in the form of cloud points and curves
3. The data is collected in the form of cloud points and curves in Calypso software which is integrated to CMM
4. The collected data is saved for surface generation in any of the CAD tool (Catia V5) in any of the extension files preferably .dxf of .dwg.

Figure 3 Face mask

Tracking systems digitize by positioning a probe on the object and trigger the computer to record the location. The simplest tracker is a mechanical linkage or pantograph. Coordinate measuring machines (CMMs) are robust 3D mechanical trackers for manufacturing applications. Electromagnetic, ultrasonic, optical, gyroscopic and inertial trackers are alsoused in some commercial 3D digitizers. Trackers can suffer from interference problems, either mechanical or electromagnetic. Object and environment space and materials need to be considered. Manual tracking systems require a large amount of patient, skilled labor, but they can digitize an object directly into polygonal models, eliminating the need for the reconstruction phase. Automated probe tracking systems produce point cloud data that will require reconstruction [2]. One form of automated tracker is the scanning probe microscope (SPM), which can be used to create 3D models of molecular-scale objects.

A Coordinate Measuring Machine (CMM) is utilized for collection of point cloud data. This CMM collects the data by mechanical method i.e. using touch probe. The CMM probe collects data by probes touching the surface along the complete profile of that part. A coordinate measuring machine is a device for measuring the physical geometrical characteristics of an object. This machine may be manually controlled by an operator or it may be computer controlled. The PRISMO series effectively responds to all of these demands from the production line. It incorporates the wealth of expertise nurtured by CARL ZEISS over 20 years, superior precision technology and a full host of functions in order to provide high precision, speed, stability and ease of operation. This series features outstanding quality and cost performance. The cloud data obtained is captures in CALYPSO software which is embedded with CMM.

Figure 4 Positioning of mask on CMM

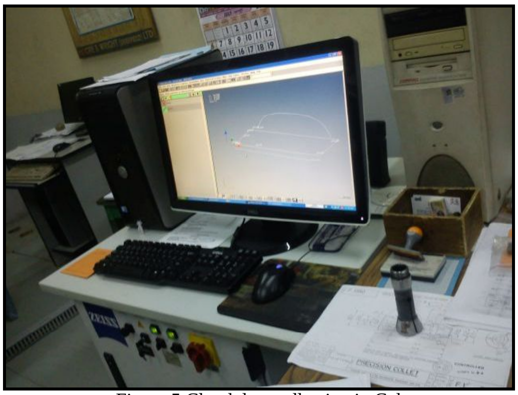

Figure 5 Cloud data collection in Calypso

The cloud points are gathered while the probe is moving on object. Calypso 3D Coordinate Measuring Machine SoftwareCalypso is an advanced software package developed by CARL ZEISS. It runs on Windows 2000/NT to provide a new measuring Environment. Some of the futures of calypso are,

- ✓ Superior graphic functions and AI functions (element auto judgment, coordinate system auto setting) are standard features.
- ✓ Captures CAD data (IGES, VDAFS, STEP, SAT, CATIA, Pro - Engineer, Unigraphics, IDEAS) to create the measuring procedure (simplified off-line teaching) on the CAD element.

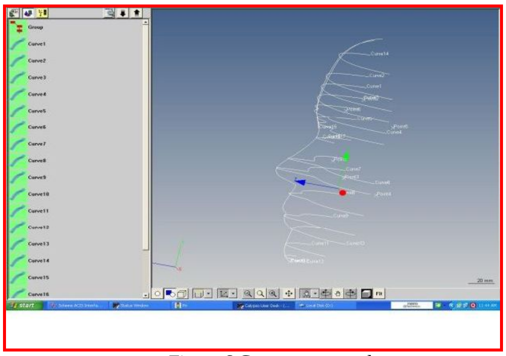

Figure 6 Curves generated

Saving these scanned data cloud points and curves in the form of CAD (.dxf or .dwg) extension formats for generating surfaces.Processing of Cloud data to generate CAD surface makes the job tougher.Importing all the generated cloud data to Catia V5 (CAD tool) for generating surface of the prostheses.

SURFACE GENERATION

Surface generation plays a major role in manufacturing the additive manufactured part. The accuracy of part depends on surface generated in CAD tool. The cloud data which was obtained from scanning of face mask is imported to CAD (Catia V5) and the process is,

1. Import cloud data to Catia V5 (CAD tool)

2. Arrange the co-ordinates of the object with respect to imported data
3. Meshing of the cloud data which are in the form of curves and points in X Y Z axis
4. Generation of surface from the meshing surface through Generative shape editor workbench

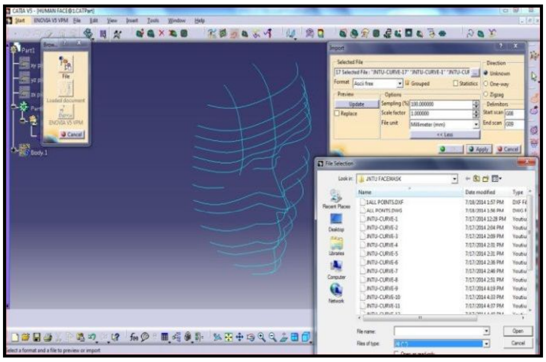

Figure 7 Importing Cloud data to Catia V5

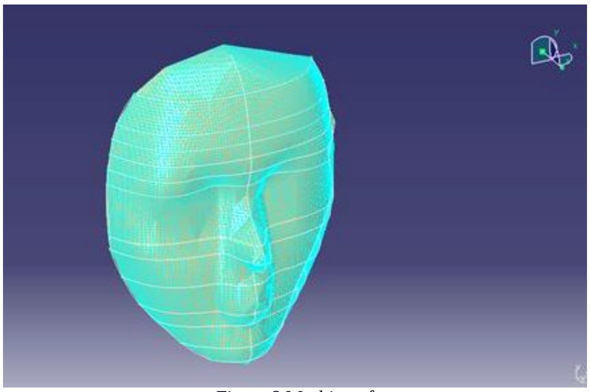

Figure 8 Meshing of part

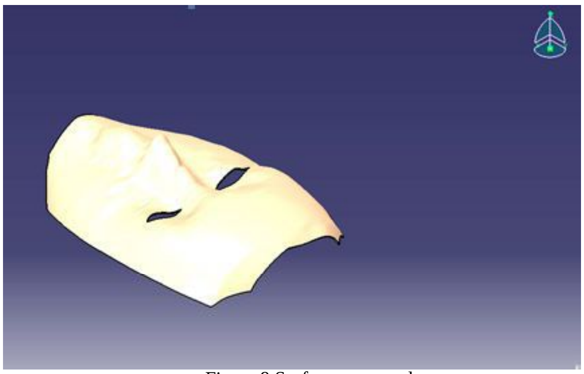

Figure 9 Surface generated

POST PROCESSING

Additive manufacturing of generated CAD model,

The CAD human face mask prostheses part model which was generated by means of reverse engineering needs to be fabricated through Additive manufacturing by one of its most used technique Fused deposition modeling (FDM).

FDM is the RP technology that forms 3-D object from CAD generated solid or surface models. FDM works on a ―additive principle by laying down material in layers. A plastic filament or metal wire is unwound from a coil and supplies material to an extrusion nozzle which can turn on and off the flow. The nozzle is heated to melt the material and can be moved in both horizontal and vertical directions by a numerically controlled mechanism, directly controlled by a CAM software package. The model or part is produced by extruding small beads of thermoplastic material to form layers as the material hardens immediately after extrusion from the nozzle as a result, the designed object emerges as a fully functional 3-D part, with the help of support material. Several materials are available with different trade-offs between strength and temperature properties. As well as ABS (Acrylonitrile Butadiene Styrene) polymer, the FDM technology can also be used with polycarbonate, polycaprolactone, Polyphenylsulfone and waxes. A water-soluble‖ material can be used for making temporary supports while manufacturing is in progress.
Specification of FDM

- ✓ Material type: Solid (Filaments)
- ✓ Material used:
- ✓ Thermoplastics such as ABS, Polycarbonate
- ✓ Polyphenylsulfone, Elastomers
- ✓ Min layer thickness 0.0050 inch.
- ✓ Tolerance0.0050 inch.
- ✓ Max. Part size:36.00x24.00x36.00 inch.
- ✓ Surface finish: Rough
- ✓ Build speed: slow

FDM segments

- ✓ Machine
- ✓ Catalyst EX. (Software)
- ✓ Smoothing and cleaning machine
- ✓ Machine-Dimension 1200es dimension 1200es printers build models from CAD STL files through computer controlled extrusion head by extruding a head of ABS plastic material.

Machine consists of two segments

- ✓ Dimension 1200es 3-D printer
- ✓ Catalyst EX preprocessing software

The build envelope measures 254 X 254 X 305 mm (10 X 10 X 12 in).
The material cartridge contains 922CC (56.3 cu in) of material.

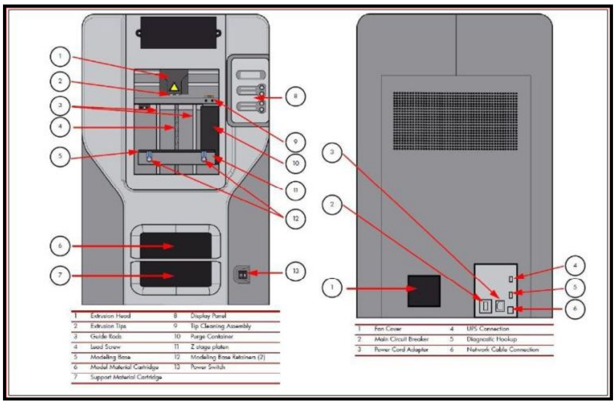

Figure 10 FDM overview

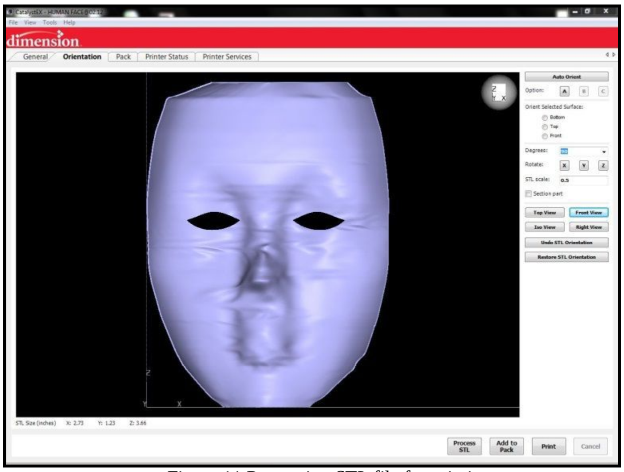

Figure 11 Processing STL file for printing

Smoothing & Cleaning Machine for removal of support material after completion of AM
Machine: Supersonic curing machine
Process: Ultrasonic process

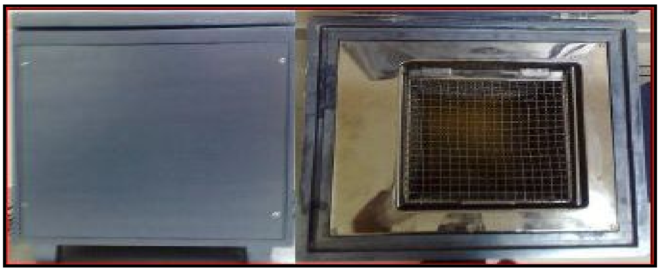

Figure 12 Ultrasonic generator

This process involves a stainless steel tanks, an ultrasonic generator, piezoelectric transducers and cleaning media. Normal electrical frequency of 50Hz 300volts converted into very high ultrasonic frequency. The electrical energy from power supply is converted into the mechanical energy through the transducers mounted bottom side of stainless steel tank and transmitted to cleaning media in the tank in the form of ultrasonic waves. This ultrasound creates high and low pressure zones in the liquid. In the low pressure phase microscopic bubbles formed and busted eventually collapsed by getting compressed. As they collapse they release a significant amount of energy creating an intense scrubbing action, which is effective on visible surfaces.There is also raise in temperature during the explosion which tends to maximum of 500 degree C. Most commonly used frequencies ranges from 20 to 50 KHz. The transducer used for the generation of ultrasonic waves is an assembly of two piezoelectric ceramics bonded between metal parts and secured by a bolt. These transducers are either bonded to the walls of tank or they are concealed in a stainless steel casing for immersion into the tank containing cleaning liquid. Once the cleaning of prostheses part is done the support material is dissolved in soluble and the final part of human face mask prostheses which is scaled down to 1/ 5 Th of the actual model is obtained.

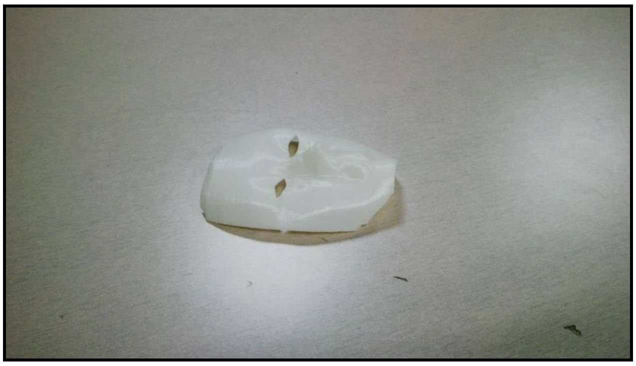

Figure 13 Additive manufactured part

III. RESULT & DISCUSSION

The results obtained by using fused deposition modeling by means of reverse engineering concept makes the most accurate and unique results for manufacturing medical applications. The result of our project shows a small example on how to make use of basic reverse engineering technology integrated together with Additive manufacturing by scaling down the model to ½ of the actual RE model. By considering the result of this where very basic level of reverse engineering techniques for collecting the cloud point through CMM was used and surface of CAD model with and the generation of RPT part for human face mask is achieved with ease.

- ✓ By using Reverse Engineering with Additive manufacturing Facemask of a scaled down model can be manufactured
- ✓ Scanning techniques used in the project work shows very good sign that CMM can be used to collect data points in medical applications
- ✓ Reverse engineering of medical applications have good potential to manufacture parts where good results can be achieved
- ✓ Generation of CAD surface form the cloud point’s data gives fine surface finish
- ✓ Surface generation is more accurate when more the cloud data is gathered
- ✓ The customization of medical applications according to the requirement can be achieved by using this techniques
- ✓ The approach using RE with CMM can be cost prohibitive
- ✓ This way of manufacturing can be an alternative of producing prototypes which require more time and efforts of skilled technicians
- ✓ If the prototype of medical applications is produced by this means the dependency levels on domain experts can be reduced

RP was not developed to solve the problems of medical modeling [3]; it is more happenstance that it is suitable for such. It therefore follows that is not an ideal solution and there are problems in using it. The most obvious problem is cost. While it is difficult specifically to allocate cost to a process when considering the potential for saving or improving the quality of life, it is clear that all technologies have associated costs. Even where there are obvious benefits in terms of improving the medical service, the approach may be cost prohibitive. Many RP machines are costly to run, particularly in terms of material costs. This is partly a consequence of the relatively low number of machines currently available. As the technology becomes more popular in all areas, operating costs will surely drop. Indeed, evidence already shows that operating costs have dropped consistently year on year over the last 15 years. In addition to cost, the properties of the materials used leave much to be desired. Most importantly, RP materials must be considerably more biocompatible than they are at present. Many materials are not even fit to be sterilized and taken into operating theatres. The mechanical properties of most RP parts are generally poor, with parts often being too weak or brittle to withstand constant use. One aim of RP research is to develop rapid manufacturing technologies that use the layer-based approach to direct manufacture of products. With the demanding environment that is associated with constant use, harsh and variable conditions and heavy physical loads, it is surely a long way off before rapid manufacture of medical devices is possible. The term refers to an alternative way of producing prototypes which required significantly more time and effort from skilled artisans. However, this is something engineers and product designers and developers can appreciate more than doctors and surgeons. As it is, RP can only be applied to applications that involve planning over periods of weeks or months rather than emergency situations. Finally, doctors and surgeons are supported by many different technical experts. It is difficult to see exactly which type of technician would be responsible for making models, but it is likely such expertise is not commonly available in a normal hospital. This may have an influence on the type of machine that would prove suitable for medical applications since the more versatile machines also require greater care, attention and expertise in order to run successfully.

IV. FUTUREWORK

As technology inevitably charges forward, applications of RDM in medicine will expand. Research in biomaterials science indicates the feasibility of direct fabrication of implantable materials using RP-like technology. This could be an important advance allowing rapid manufacture of truly custom implantable devices such as joint prostheses, complete sections of missing bone or absorbable scaffolds that provide structure while engineered tissue replacements take hold. Instead of alloplastic materials, which are merely tolerated by the body, these newer materials have the potential to stimulate growth and actually be incorporated into the body. RP-generated models and treatment aides are for the most part manufactured by specialized service bureaus. Even with modern techniques for rapid data transfer via the internet and reliable overnight shipping there inevitably is a lead time of several days for service bureaus to provide a model. As more specialties capitalize on rapid manufacturing, it may be cost effective for health care facilities to arrange for an on-site or nearby Rapid digital manufacture vendor. It is expected that, if the amount of time required to get a model or treatment device in the hands of a physician is reduced, they may find a wider acceptance, particularly in fields constrained by time urgency such as orthopedic trauma or cardiothoracic surgery Computer power has increased exponentially over the last decade. Relatively inexpensive computers are now capable of handling the large amounts of data produced in medical imaging. Off-the-shelf graphics capabilities now produce fast renderings from image data and allow the construction of composite models built from multiple image datasets.

Our research in increasing the accuracy of collecting the cloud data from which an accurate surface CAD model can be generated by means of minimum cost where every patient can afford and take the maximum credit of prostheses parts fits to their requirement. Although the cost of AM parts is high but our intension initially to work on human safety parts where the crash survivability in aircraft is very low when an unfortunate situation arises in sky.Therefore increasing the safety in aircraft with some head and neck arrangement for customized passengers who can afford the cost of the additive manufacturing parts to their own requirements.

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