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# A Comparative Study on the Dimensional Error of 3D CAD Model and SLS RP Model for Reconstruction of Cranial Defect

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***Abstract*—**Rapid Prototyping (RP) is a technology that produces models and prototype parts from 3D CAD model data, CT/MRI scan data, and model data created from 3D object digitizing systems. There are several RP process like Stereolithography (SLA), Solid Ground Curing (SGC), Selective Laser Sintering (SLS), Fused Deposition Modeling (FDM), 3D Printing (3DP) among them SLS and FDM RP processes are used to fabricate pattern of custom cranial implant. RP technology is useful in engineering and biomedical application. This is helpful in engineering for product design, tooling and manufacture etc. RP biomedical applications are design and development of medical devices, instruments, prosthetics and implantation; it is also helpful in planning complex surgical operation. The traditional approach limits the full appreciation of various bony structure movements and therefore the custom implants produced are difficult to measure the anatomy of parts and analyze the changes in facial appearances accurately. Cranioplasty surgery is a surgical correction of a defect in cranial bone by implanting a metal or plastic replacement to restore the missing part. This paper aims to do a comparative study on the dimensional error of CAD and SLS RP Models for reconstruction of cranial defect by comparing the virtual CAD with the physical RP model of a cranial defect.

***Keywords*—**Rapid Prototyping, Selective Laser Sintering, Cranial defect, Dimensional Error.

## I. Introduction

RAPID prototyping (RP) is a technology that produces models and prototype parts from 3D CAD model data, CT/MRI scan data, and model data created from 3D object digitizing systems [1]. In contrast to abrasive (or subtractive) process such as lathing, milling, drilling, grinding, eroding, and so forth in which the form is shaped by removing material, in rapid prototyping the component is formed by adding the material layer by layer. There are several RP processes like Stereolithography Apparatus (SLA), Solid Ground Curing (SGC), Selective Laser Sintering (SLS), Fused Deposition Modeling (FDM), 3D Printing (3DP). Different RP technologies have their advantages and disadvantages.

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The various steps involved in any type of RP process chain are *3D Modeling*, *Data Conversion and Transmission*, *Checking and Preparing*, *Building* and *Post processing***.** In the first step in the 3D Model of the part to be produced is modeled by using any 3D CAD modeling package like Creo, CATIA, SOLID WORKS etc or CT and MRI scan data or model data created from 3D object digitizing systems. In the next step the 3D model is converted into STL (STereoLithography) file format. The STL file format approximates the surfaces of the model using tiny triangles. In the Transmission step the STL file which resides in the workstation is transferred to the RP System's Computer. Data transmission may be through CD, email or LAN. No validation of the STL files is carried out at this stage. While in the third step, the errors in CAD Model and the non-robustness of the CAD-STL interface results in generation of unwanted shell-punctures (i.e. holes, gaps, cracks etc.). In this step these errors are eliminated by specialized software like MAGICS. Once the STL files are verified to be error-free, the 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 required part is built in the RP machine. In the final step, the various post processing operations like curing, painting, air blasting etc are applied depending on the RP technology adopted.

RP medical applications are design and development of medical devices, instruments, prosthetics and implantation; it is also helpful in pre-planning complex surgical operation [1]. The traditional approach limits the full appreciation of various bony structure movements and therefore the custom implants produced are difficult to measure the anatomy of parts and analyze the changes in facial appearances accurately. This paper aims to do a comparative study on the dimensional error of CAD and SLS RP Models for reconstruction of cranial defect by comparing the virtual CAD model with the physical RP model of a cranial defect.

## II. Literature Review

Jelena Milovanovic et al. [2] present the procedure for making medical models using Rapid Prototyping, The most interesting and challenging applications of rapid prototyping technologies are in the field of medicine. RP medical models have found application for planning treatment for complex surgery procedures, training, surgical simulation, diagnosis, design and manufacturing of implants. M. Sljivic et al. [3] the application of the two technologies: reverse engineering and rapid prototyping is emerging rapidly in the medical applications. These engineering methods have especially shown fast advancement in the following applications: in very complex preparation of computer aided surgery, computer guided implantology, non-invasive diagnostic from CT and MRI scans, design of customized implants, maxillofacial surgery, esthetic and reconstructive plastic surgery, orthopedic surgery, etc. H. Sudhoff et al. [4] present a case report of reconstructive surgery after trauma of the head and neck, which is a wide field in ENT surgery. The repair of bony defects often requires implantation of engineered prostheses. They present the case of a 48-year-old male patient who had suffered a major crush injury to his head resulting in a complex bony defect. A computer-assisted designed (CAD/CAM) Titanium implant was used for reconstruction. Direct prefabrication of the individually designed implant led to an excellent coverage of the bony defect and easy adaptation to the defect margins. The treatment plan and surgery as well as implant design and manufacturing were performed in a multidisciplinary team. Skin expander implantation prior to reconstructive surgery ensured a tension-free closure. Juan Felipe Isaza Saldarriaga et al. [5] discussed advances in medical imaging, such as CT and MRI, have allowed the 3D reconstruction of anatomical structures for several medical applications, including the design of custom-made implants and concluded that the use of 3D reconstruction techniques from medical images reduces the possibility of errors during surgery, improves fit and provides better implant stability. The use of 3D models designed and fabricated in RP processes proved to be an effective practice in the design process. Krishna et al. [6] present the application of Rapid Prototyping in development of optimum preplanning for maxillofacial surgery using selective laser sintering process.

## III. RP Process for Medical Models

The RP process chain for creating medical models is illustrated in Fig. 1. In the first step the medical image of the defect is captured by using CT/MRI scan and stored in DICOM (Digital Imaging and Communications in Medicine) format. In the next step the DICOM images obtained by CT/MRI is converted into 3D CAD Model by using imaging density segmentation software like MIMICS, 3D DOCTOR etc. For making medical prototype models the next step is to convert 3D CAD model to .STL format. A standard interface is needed to convey geometric description from 3D CAD packages to RP systems. The .STL file, as the de-facto standard has been used in many rapid prototyping systems. After the error checking and orientation is done the part is built in the RP system and in the final step the post processing operation like cleaning, curing etc is carried out depending upon the type of RP technology adopted.

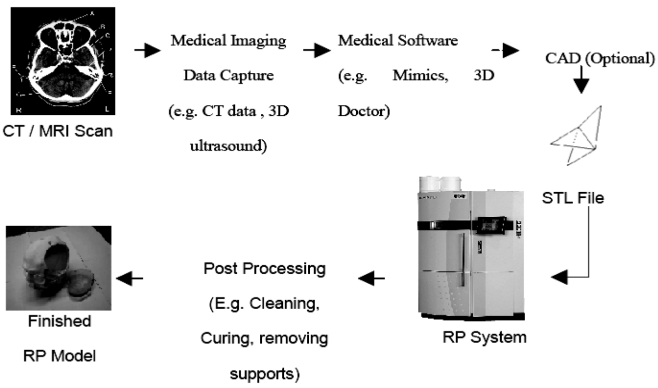


Fig. 1 RP Process chain for creating medical models

## IV. Problem Description

In this paper a comparative study on the dimensional error of virtual CAD model with SLS RP physical models for reconstruction of cranial defect in cranioplasty surgery is done. Cranioplasty surgery is a surgical correction of a defect in cranial bone by implanting a metal or plastic replacement to restore the missing part. The case study aims to reconstruct the model of the cranial defect of the patient skull by producing the physical RP model in SLS RP machine. The physical RP model of the cranial defect will serve as pattern for making the final biocompatible implant made of Polymethylmethacrylate (PMMA) during the cranioplasty surgery. Following are the objectives of the study:

- Converting the 2D DICOM images into 3D CAD Models and 3D CAD design of cranial pattern which is patient specific.
- Producing the RP Models on the SLS RP machine and.
- Compare the dimensional error of models produced by these two processes.

## V. Research Methodology

The various steps involved for solving the problem describe earlier are collection of CT scan data, creation of 3D CAD models, converting 3D CAD model in to STL file, fabricating the part in SLS RP machine, post processing and measurement of geometric dimensions of the part.

### *A. Collection of CT Scan Data*

The 2D CT scan images in the DICOM format of patient's fractured skull under consideration is obtained from Craniomaxilofacial Surgery Department, MDS Care Hospital, Hyderabad, India. Fig. 2 illustrates the CT scan data of the patient under consideration.

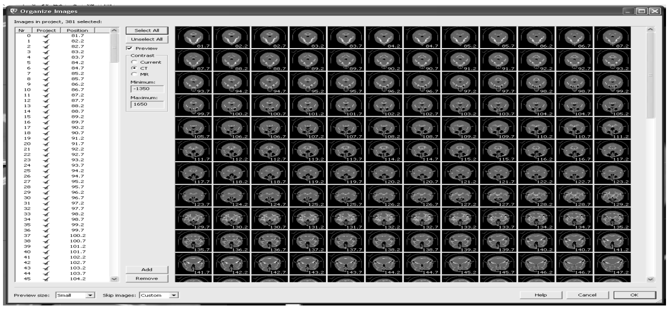

Fig. 2 2D CT Scan of fractured skull of the patient

Following are the specifications of the CT Scan machine:

- CT Manufacturer details : Philips –Ingenuity CT
- Pixel size : 0.4883
- Resolution : 512 x 512
- Field of View (FOV) : 25 $cm^2$
- Slice Thickness : 0.5 mm Axial
- Gantry tilt : $0^0$

*B. Creating a 3D CAD Model*

In this work for reconstructing the primary 3D anthropometrical model (bone structure and encapsulated soft tissues), the DICOM images obtained by CT scan are converted into 3D CAD Model by using imaging density segmentation software, MIMICS. The 2D DICOM files are imported into MIMICS software. Fig. 3 shows conversion of DICOM files to MIMICS file. After conversion into MIMCS file, the various steps involved in building the 3D model are illustrated in Fig. 4.

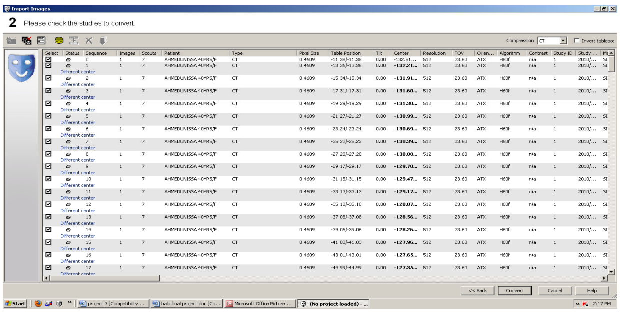

Fig. 3 The conversion of DICOM files to MIMICS file

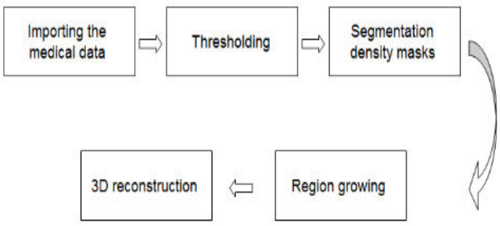


Fig. 4 Steps involved in building 3D model from CT scan Images

Thresholding is the first action performed to create a segmentation mask on a set of digital images. Thresholding based on Hounsfield Units was done to ensure that segmentation object which contains only those pixels of image with a defined value. In this work a threshold value of 226 is selected. Fig. 5 illustrates applying threshold value to the imported CT Scan Images.

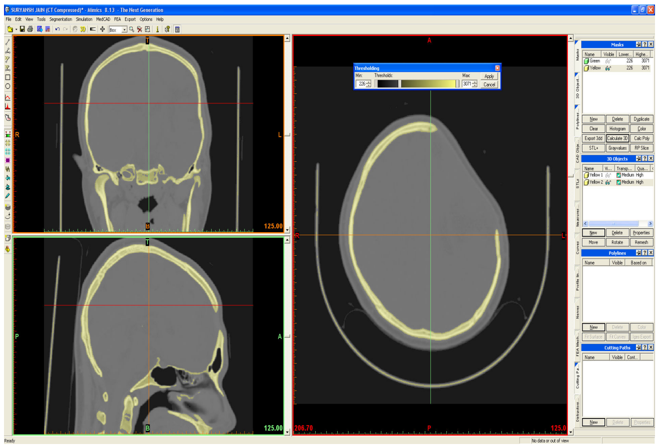

Fig. 5 Applying threshold value to the imported CT Scan Images.

The 3D CAD model of the skull and 3D CAD Model of the cranial defect obtained after performing the other steps mentioned in Fig. 4 are illustrated in Figs. 6 and 7, respectively.

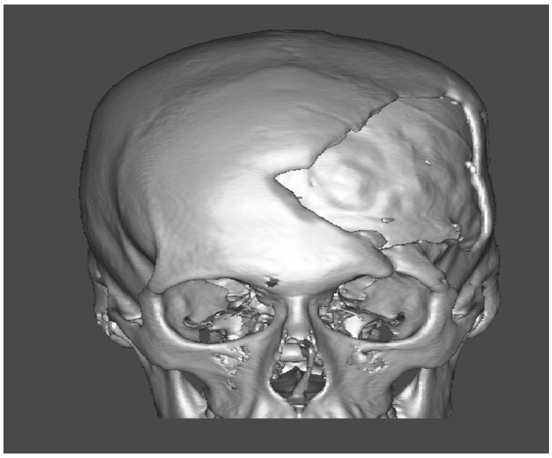

Fig. 6 3D CAD model of skull

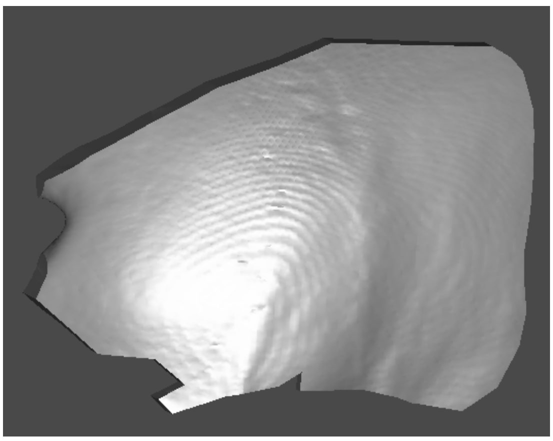

Fig. 7 3D CAD model of the cranial defect

### *C. Converting the 3D CAD Model to STL Format*

For making medical prototype models the next step is to convert 3D CAD model to .STL format. A standard interface is needed to convey geometric description from 3D CAD packages to RP systems. The .STL file, as the de-facto standard has been used in many RP systems. In this work the MIMICS, implant 3D CAD model is converted to .STL format. Fig. 8 below shows .STL file conversion in MIMICS software.

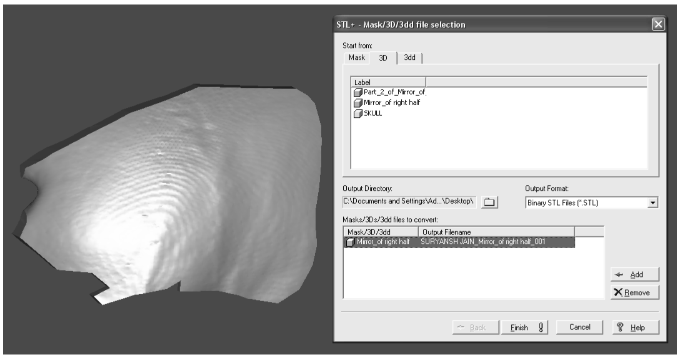


Fig. 8 Conversion of 3D CAD model to .STL file

### *D. Fabricating the Physical RP Model in SLS RP Machine*

After conversion into .STL format the next step is to build the physical RP model of the carnial defect using RP machine. In this work FORMIGA P 100 SLS RP machine available in Centre for Prototyping and Testing of Industrial Products (CPTIP) located at Department of Mechanical Engineering, University College of Engineering, Osmania University, Hyderabad is used for building the physical model. The SLS RP machine uses polyamide powder for building the model. In this process the powder is spread by a blade over the surface of a build cylinder. The piston in the cylinder moves down by one layer thickness to accommodate the new layer of powder. The powder delivery system is by two bins which move down into the process chamber by gravity. A $CO_2$ laser beam is then traced over the surface of this tightly compacted powder to selectively melt and bond it to form a layer of the object. The fabrication chamber is maintained at a temperature just below the melting point of the powder i.e. around $170^0$C, so that heat from the laser need only elevate the temperature slightly to cause sintering. This greatly speeds up the process. The process is repeated until the entire object is fabricated. A nitrogen atmosphere is also maintained in the fabrication chamber which prevents the possibility of explosion in the handling of large quantities of powder. After the object is fully formed, the piston is raised to elevate it. Excess powder is simply brushed away and final manual finishing may be carried out. No supports are required with this method since overhangs and undercuts are supported by the solid powder bed.

### *E. Post Processing Operation*

Post processing is the final step in the entire process chain. This involves removing the prototype from the machine and detaching any supports. Some photosensitive materials need to be fully cured before use. Prototypes may also require minor cleaning and surface treatment. Sanding, sealing, and painting the model will improve its appearance and durability. In this work air blasting is used for cleaning any loose powder present on the part. Fig. 9 illustrates the final physical RP model of the cranial defect produced using SLS RP machine. This will serve as pattern for making the final biocompatible implant made of Polymethylmethacrylate (PMMA).


Fig. 9 Physical model of the cranial defect produced using SLS RP machine

### *F. Measurement of dimensions of CAD and RP models*

The measurement of dimensions of the 3D CAD virtual model along X, Y and Z axes were done using Magic's software and are shown in Figs. 10-12 respectively.

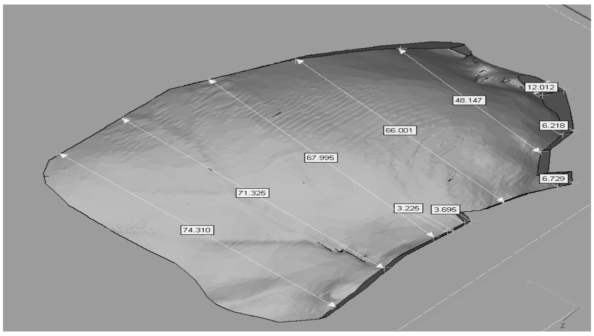


Fig. 10 Dimensions of cranial pattern along X-axis

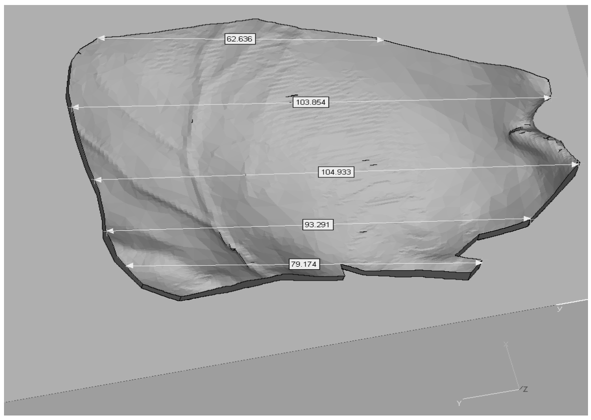


Fig. 11 Dimensions of cranial pattern along Y-axis

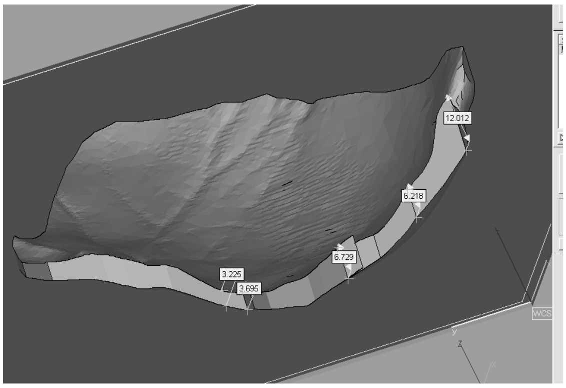


Fig. 12 Dimensions of cranial pattern along Z-axis

Using Mitutoyo vernier caliper the corresponding linear dimensions along X, Y and Z axis's of the cranial pattern produced by SLS RP process are measured. The dimensions obtained from CAD and RP Models are presented in the next section.

## VI. RESULTS AND DISCUSSIONS

Tables I, II and III shows the dimensional error of SLS RP Model with the CAD model along X, Y and Z axis's respectively.

TABLE I
MEASUREMENT ALONG X-AXIS

| S. No. | Measurement on CAD model along X-axis in mm | Measurement on SLS RP model in mm | Dimensional error between CAD and SLS models in X- Direction in mm |
|---|---|---|---|
| 1 | 48.147 | 46.047 | 2.100 |
| 2 | 66.001 | 64.011 | 1.990 |
| 3 | 67.995 | 66.015 | 1.980 |
| 4 | 71.325 | 69.325 | 2.000 |
| 5 | 74.310 | 72.260 | 2.050 |
| | | **Average** | **2.024** |

TABLE II
MEASUREMENTS ALONG Y-AXIS

| S. No. | Measurement on CAD model in mm | Measurement on SLS RP model in mm | Dimensional error between CAD and SLS models in Y – direction in mm |
|---|---|---|---|
| 1 | 62.636 | 60.62 | 2.016 |
| 2 | 79.174 | 77.08 | 2.094 |
| 3 | 93.291 | 91.29 | 2.001 |
| 4 | 103.854 | 101.86 | 1.994 |
| 5 | 104.933 | 102.88 | 2.053 |
| | | **Average** | **2.032** |

TABLE III
MEASUREMENTS ALONG Z-AXIS

| S. No. | Measurement on CAD model in mm | Measurement on SLS RP model | Dimensional error between CAD and SLS models in mm |
|---|---|---|---|
| 1 | 3.226 | 3.02 | 0.206 |
| 2 | 3.695 | 3.45 | 0.245 |
| 3 | 6.218 | 6.01 | 0.208 |
| 4 | 6.729 | 6.52 | 0.209 |
| 5 | 12.012 | 11.802 | 0.210 |
| | | **Average** | **0.215** |

From the above results it can be seen that the dimensional error is more in the Y-axis and the minimum dimensional error is in the Z-axix.

## VII. CONCLUSION

The aim of this paper is to make a comparative study on the dimensional error of virtual CAD model with SLS RP physical models for reconstruction of cranial defect in cranioplasty surgery. It is found that the dimensional error in the 3D CAD and SLS RP physical model along X, Y and Z axes are 2.024mm, 2.032mm, and 0.215mm respectively. The physical RP model of the carnial defect will serve as pattern for making the final biocompatible implant made of Polymethylmethacrylate (PMMA) during the cranioplasty surgery. The use of 3D reconstruction techniques from medical images reduces the possibility of errors during surgery, improves fit and provides better implant stability after fixation with mini screws. This also reduces the time during the surgery which results in less amount of blood loss, suffering, inflammation and postoperative pains to the patients. The scope of the present work can be further extended by comparing the dimensional error of SLS RP Process with other RP Process like Fused Deposition Modeling (FDM), Steriolithography etc.

## ACKNOWLEDGMENT

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