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Research Article

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Optimization of Computer Tomography Reconstruction Parameters using Additive Manufacturing

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Abstract

Additive Manufacturing (AM) is one of the advanced engineering manufacturing process and the application of this process is entered into each and every industry. This process best suits for production of each part uniquely. This technology best fits for medical and dental industry, where each patient has unique anatomy. Cone Beam Computed Tomography (CBCT), Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) are the major input data source for the AM medical software's. The medical data is usually stored in Digital Imaging and Communication in Medicine (DICOM) file format. In the current days the most of the CT scanners are of multi slice scanners, which help to acquire maximum data of patient anatomy with in minimum time. Once CT data acquisition is done the reconstruction of data will start. In reconstruction of CT data slice thickness, slice increment and field of view parameters play's major role. The current work is to obtain best quality of data with minimal errors by optimizing the reconstruction parameters. Considered three reconstruction parameters with three levels to conduct the experiments. The reconstruction data is analyzed using L9 orthogonal array and S/N (Signal to Noise) ratio. The paper also explains the importance of reconstruction parameters theoretically and validated by experimental analysis, also applied on few case studies. The experimental results prove that slice thickness is majorly responsible for the quality of reconstructed data. The dimensional error is reduced from 0.78 mm to 0.65 mm. The same optimal parameters are implemented in the two case studies.

Keywords: Additive manufacturing; Computed tomography; CT reconstruction; Reconstruction parameters; CT quality

Introduction

AM is one of the technology, that has been in existence for more than 30 years. This technology in the initial stage is used or Prototyping only. As per the latest advancements in the technology in current days this technology is now capable of producing final functional products [1]. This technology has been entered into almost each and every industry in the current world. Some of the most benefited industries with technology are medical, dental, automobile, construction, etc. [2]. In the medical industry no other process can produce physical bone anatomy of the patient with that accurately. The input data for medical AM is taken from Computed Tomography (CT), Cone Beam Computed Tomography (CBCT), Magnetic Resonance Imaging (MRI) and any other Reverse Engineering (RE) Techniques. The CT scan data is natively stored in the DICOM format [3].

This DICOM format is used as input data for the medical software's, which converts the DICOM data to three dimensional CAD data. The DICOM data need to be reconstructed before saving it [4]. In process of reconstruction slice Thickness, Slice increment and Field of View plays a major role [5,6]. Medical software's are capable of performing operations on reconstructed data [7]. Once after performing required operation in medical software's the data is saved in steriolithography format, which is globally accepted by all the AM machines, to fabricate the physical model of patient anatomy [8,9].

Methodology

Theoretical analysis

To reconstruction a 3D CAD model after the CT scan involves various parameters such as Slice thickness, Slice increment, Field of View, Matrix size, Voxel size, Gantry tilt and etc. By varying the above parameters the quality of the 3D CAD model varies. Even though the quality of the 3D model also depends on the scan parameters also, but the reconstruction of the scan data has significant impact on the quality of 3D model. The major advantage at this stage is that with single scan data multiple reconstructions can be made i.e., with single scan data by varying the parameters multiple 3D CAD data files can be generated. Depends on the application the quality of data becomes critical. If the 3D CAD data is used to fabricated a 3D medical model using AM only for preplanning then difference in 1 or 2 mm is acceptable, but if the data is used to design an implant, which going to be inserted to a patient the accurate model is very important. Since the beauty of AM technology is to fabricate the patient specific implants the most accurate models are required. The parameters that influence the reconstruction data are explained in detail in the below.

Pixel size: The smallest square element of the CT data is called pixel or picture element. Each of these picture elements will be assigned with the Hounsfield value. This value is assigned according to the corresponding tissue area. When scanning is performed the each soft and hard tissues are assigned appropriate HU values and these values are important to retrieve the required region of interest. The tissue will be in the free form, but whereas the pixel shape is limited to the square. Due to this some of the pixels may have chance that only partial area of

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the pixel is filled, which results as the partial volume or dumbbell effect. To avoid this effects the pixel size should be minimized. The pixel size again depends on the selection of matrix size and FOV, Which are explained in detail in below.

Matrix size: The CT image is formed with comprise of equal number of pixels to the rows and columns as a matrix. This matrix can be can only one of these sizes 256 × 256 or 512 × 512 or 1024 × 1024. The partial volume and dumb bell effect will be maximum with minimum matrix size and in the other hand due to the linear attenuation co-efficient the data loss will be more with the larger matrix size as explained in the below Equation 1. Hence, in the most of the cases 512 × 512 will give an accurate scan data and customized matrix size has been considered for the case studies explained in this work.

$$N_i = N_0 e^{-(\mu_1 + \mu_2 + \mu_3)x} \quad (1)$$

Where, No is the X-ray intensity entering the tissues, Ni is the transmitted X-ray intensity, μ is attenuation co-efficient values, x is the pixel length.

Slice thickness: The CT scan has been divided into the slices of equal thickness and by increasing the slice thickness the stair casing effect will be increased and the quality of the image data reduces. The Slice thickness is value will be dependent on the gantry rotation of the CT scanner.

Slice increment: The Slice increment means the pitch of the CT scan table movement with respect to the gantry or this is also can be referred as the distance between the two successive CT scan layers. The quality of the CT data is inversely proportional to the slice increment value.

Voxel size/volume element: The Voxel is the 3D element of pixel data whereas the pixel is only 2D view. The Voxel can be calculated using the below Equation 2.

$$\text{Voxel} = \text{Pixel size} \times \text{Slice thickness} \quad (2)$$

Field of view (FOV): The FOV is the reconstructed area of the tissue. This FOV comprises of pixel sixe and the matrix size. The FOV can be calculated using the below Equation 3.

$$\text{FOV} = \text{Matrix size} \times \text{Pixel Size} \quad (3)$$

Till now the theoretical analysis has been made for the reconstruction of the tissue and in the later sections this can be analyzed using experimental analysis.

Experimental analysis

The experimentation is conducted on a dry skull as a phantom. The Dry skull is procured from Panineeya Mahavidyalaya Institute of Dental Sciences Hyderabad for experimentation purpose. The set of experiments were conducted on 128 slice somatom CT scanner. The scanning for the phantom were conducted with following parameters of tube current as 300 mA, Tube voltage as 80 kV and pitch as 1 mm. The dimensional error was minimized using the Taguchi method [6]. The parameters considered for obtaining the best quality of CT image are as follows in Table1.

In this work considered three parameters with three levels, the total possible combinations are 27 experiments. Based on this L9 orthogonal array nine scans were conducted with different slice thickness, slice increment and field of view, the experimental design is shown in Table 2.

Dimensional error between dry skull and CAD models: Nine experiments were conducted and results from these nine experiments were analyzed to find out the optimum parameters for the final experimentation. These results were analyzed in the CAD with help of MIMICS 18.0 software [10], to identify the error between scanned CT data and dry skull. In dry skull 15 landmark points were identified, based on these15 landmarks points 9 linear measurements are identified, which are shown in Table 3. The landmark points and linear measurements were shown in the Figure 1.

Parameter	Level of parameter		
	1	2	3
Slice Thickness (mm)	0.6	0.8	1
Slice Increment (mm)	0.3	0.6	0.9
Field of View (mm)	200	250	275

Table 1: Image reconstruction parameters.

Experiment Number	Slice thickness (mm)	Slice increment (mm)	FOV (mm)
1	0.6	0.3	200
2	0.6	0.6	250
3	0.6	0.9	275
4	0.7	0.3	250
5	0.7	0.6	275
6	0.7	0.9	200
7	1	0.3	275
8	1	0.6	200
9	1	0.9	250

Table 2: L9 orthogonal array for experimentation.

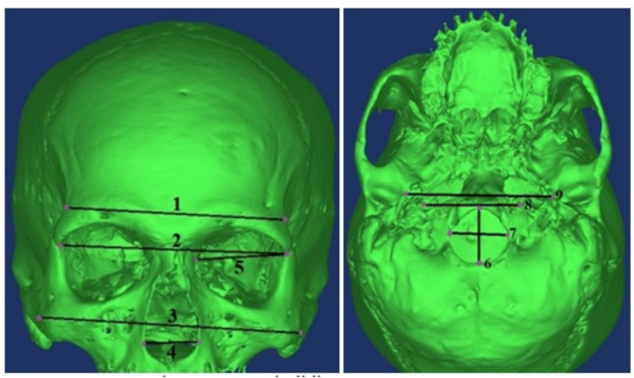

Figure 1: Dry skull linear measurements.

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Sr. No	Anatomical landmarks definitions
1	Minimum frontal breadth Distance between the two frontotemporale (ft)
2	Biorbital breadth Distance between right and left ectoconchion (ec)
3	Bizygomatic diameter Distance between most lateral points on the zygomatic arches
4	Nasal breadth Maximum breadth of the nasal aperture
5	Orbital height Distance between the superior and inferior orbital margins
6	Foramen magnum breadth Distance between the lateral margins of foramen magnum at the points of greatest lateral curvature
7	Foramen magnum length Distance from basion (ba) to opisthion (o)
8	Foramen ovale Distance between left and right of foramen ovale
9	Foramen spinosum Distance between left and right of foramen spinosum

Table 3: Anatomical landmarks definitions used for the linear measurement.

Nine similar measurements were measured on each CAD model and then compared with the manual measurements made with digital vernier calipers on the dry skull. The measurements for 3D CAD model are measured using MIMICS software with the precision of third decimal place to get the accurate measurements. Each and every measurement has measured twice to get exact dimensions. All the measurements were tabulated in the Table 4. The difference between the manual measurements to the CAD is considered as the dimensional error.

Dimensional error=Dry skull measured dimension-3D CAD Skull measured dimension (4)

Measurement Number		1 (mm)	2 (mm)	3 (mm)	4 (mm)	5 (mm)	6 (mm)	7 (mm)	8 (mm)	9 (mm)
Dry skull		**99.21**	**99.62**	**114.53**	**21.84**	**38.99**	**30.73**	**32.77**	**47.47**	**76.03**
Exp. No. 1	CAD Model	98.52	98.98	113.94	21.74	38.61	30.34	32.21	47.03	75.57
	Dimensional Error	0.69	0.64	0.59	0.1	0.38	0.39	0.56	0.44	0.46
Exp. No. 2	CAD Model	97.92	97.97	113.44	21.53	38.14	29.91	31.81	46.85	75.01
	Dimensional Error	1.29	1.65	1.09	0.31	0.85	0.82	0.96	0.62	1.02
Exp. No. 3	CAD Model	97.52	97.78	113.24	21.24	37.67	29.45	31.81	46.48	74.71
	Dimensional Error	1.69	1.84	1.29	0.6	1.32	1.28	0.96	0.99	1.32
Exp. No. 4	CAD Model	97.12	97.51	113.04	20.86	37.51	29.21	31.55	45.85	74.47
	Dimensional Error	2.09	2.11	1.49	0.98	1.48	1.52	1.22	1.62	1.56
Exp. No. 5	CAD Model	96.85	97.07	112.83	20.53	37.37	28.91	31.15	45.41	74.17
	Dimensional Error	2.36	2.55	1.7	1.31	1.62	1.82	1.62	2.06	1.86
Exp. No. 6	CAD Model	96.46	96.73	112.41	20.11	37.04	28.24	30.68	45.15	73.94
	Dimensional Error	2.75	2.89	2.12	1.73	1.95	2.49	2.09	2.32	2.09
Exp. No. 7	CAD Model	96.14	96.27	111.94	19.83	36.42	27.91	30.18	44.96	73.47
	Dimensional Error	3.07	3.35	2.59	2.01	2.57	2.82	2.59	2.51	2.56
Exp. No. 8	CAD Model	95.86	95.98	111.46	19.71	35.94	27.41	29.81	44.51	72.97
	Dimensional Error	3.35	3.64	3.07	2.13	3.05	3.32	2.96	2.96	3.06
Exp. No. 9	CAD Model	95.41	95.77	111.14	19.32	35.46	26.88	29.15	44.1	72.71
	Dimensional Error	3.8	3.85	3.39	2.52	3.53	3.85	3.62	3.37	3.32

Table 4: Dimensional measurements of dry skull and CAD models.

Statistical analysis: Taguchi is one of the commonly used and successful methods for engineering analysis, which is used in the current work. The objective behind using Taguchi is to conduct set of experiments in a controlled way. This technique not only minimizes the number of experiments but also saves lot of effort and time in obtaining results. In the current study Taguchi is used to define values that need to be conducted in the experimentation for slice thickness, slice increment and field of view in the other hand to minimize parameters like dimensional and other errors. Obtained results from the experiments are analyzed and the significant factors were identified. The dimensional error for set of L9 orthogonal array experimentation values are depicted in Table 4. In this study smaller-the-better quality characteristic is used. The signal to noise (S/N) ratio used for this type quality characteristic is defined as:

$$\frac{S}{N} = -10\log_{10}\frac{1}{n}\left(\sum_{i=0}^{i=n} y_i^2\right) \quad (5)$$

Where, n=Number of measurements in a trial/row and y=measured value in a run/row.

The S/N ratio values are calculated with average dimensional errors by using Equation 5. Mean of S/N ratio for each level of CT image acquisition parameters were calculated. In order to analyses the effect of CT image reconstruction parameters on the average dimensional error, the effects plot for S/N ratios and means of optimized parameters were generated by using Minitab software, these are shown in Figures 2 and 3. From these it was found that the optimal CT image reconstruction parameters are identified along with considerations of response table values (Table 5).

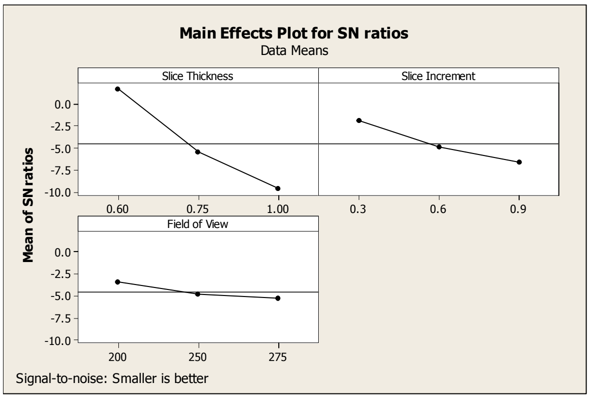

Figure 2: Mean of S/N ratio graph.

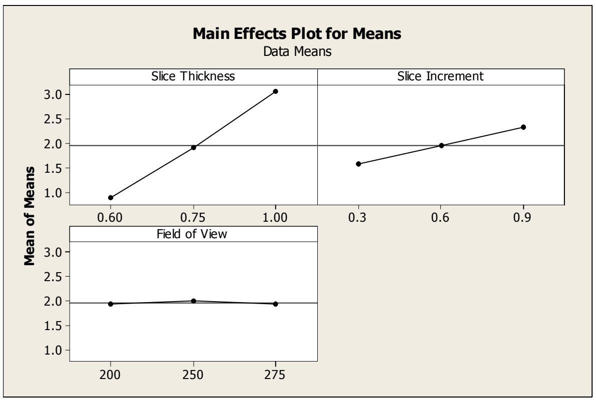

Figure 3: Mean of means graph.

From the response table values it can be observed that the slice thickness shows major contribution in obtaining quality of DICOM data. So that the smaller value provides higher accuracy which is true in most of the cases logically. The interesting point is observed in case of FOV in general scenario larger matrix size gives the smaller pixel size which should provide maximum quality, but in current scenario for matrix size of 200 is providing best quality compared to the matrix size of 275. Thus the optimal reconstruction parameters are noted as slice thickness of 0.6 mm, slice increment of 0.3 mm and FOV as 200 mm. The same parameters are applied for the following case studies. With the optimal scan parameters the dimensional error is 0.78 mm and after using optimal reconstruction parameters 0.13 was reduced and brought to 0.65 mm only.

Level	Slice thickness	Slice increment	Field of view
1	0.8933	1.5667	1.9333
2	1.9033	1.9667	1.9967
3	3.0667	2.33	1.9333
Delta	2.1733	0.7633	0.0633
Rank	1	2	3

Table 5: Response table values.

Case Studies

Case study 1

This case is regarding a 60 years male patient who lost 9 teeth and partial damage to the mandible due to the age factor. Generally in traditional way the damaged teeth will be replaced with help of dentures, but in this case even mandible got damaged so conventional dentures cannot be placed. Even though if the mandible is not damaged it is a hard job for surgeon to fix 9 teeth with help of dentures. The other problem is that the patient needs 9 teeth, which requires 9 implants as one implant for each tooth. Among 9 teeth some of them are molar teeth and some are normal teeth. All the 9 teeth have different dimensions and all the teeth require different implants with different designs. The surgeon will place all the implants on the medical model to identify whether these implants are fixing exactly. In this stage the surgeon also identifies where to drill on the mandible to fix the implant. The diameter of the teeth and implant design is also finalized by checking with the Am medical model. The CAD data for the AM medical model is generated from DICOM images using MIMICS software; images for the same are shown below in Figure 4. This medical model is used for the pre planning of actual surgery [11].

Fabrication of AM medical model: AM has flexibility of manufacturing with liquids, solids and powder as raw material with various technologies. Out of all the available techniques Fused Deposition Modelling (FDM) is readily available and economical in cost. FDM models will have good strength and very well suitable for pre planning of surgery [12,13]. For the current case studies Flash Forge Finder machine is used with layer thickness as 0.1 mm and 100% solid fill. The printing temperature is maintained at 210°C and the Poly Lactic Acid (PLA) filament is used as raw material.

Case study 2

In this case the patient has meet with a severe road accident in which the condyle got damaged. For normal persons TMJ joint is responsible for the contact between maxilla and mandible. But in this case the condyle joint got disconnected one side, due to this patient cannot open mouth properly. AM medical model is used to study the exact position of the patients TMJ joint placement, which helped in condyle reconstruction of the patient. Surgeon identified the exact length that mandible is deviated from its original position and identified the steps that need to be implemented at the time of actual surgery in advance using AM medical model so that the maxilla and mandible will gain TMJ movement again normally. The surgeon found appropriate implant, which is getting exact match with the destroyed bony anatomy of the patient in the pre planning stage with help of medical model [14,15]. The identified implant is initially fixed on the AM medical model to test the TMJ movement, after achieving expected results on the AM medical model the implant is placed to the patient in actual surgery, images for the same are shown below in Figure 5.

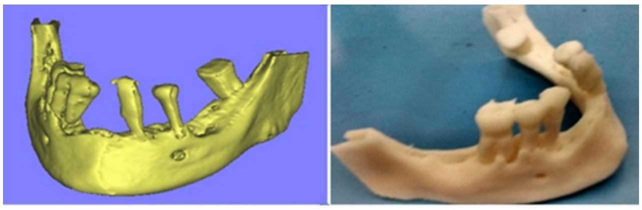

Figure 4: CAD (MIMICS) image and FDM fabricated AM medical model for teeth reconstruction.

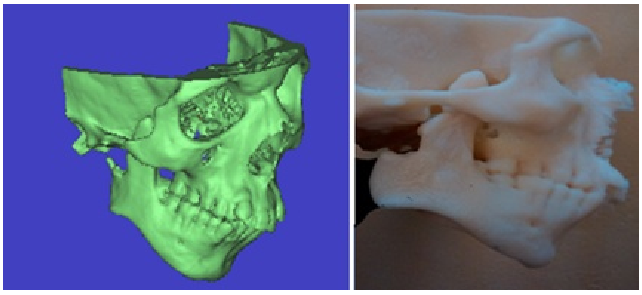

Figure 5: CAD (MIMICS) image and FDM fabricated bio-model for condyle reconstruction.

The accurate AM medical models saved surgery time and cost. In addition to that the safety to the patient is increased with help of accurate AM medical models.

Conclusion

In the current study the reconstruction parameters for CT scan were explained both theoretically along with the experimental analysis. The experimental analysis strongly supports reconstruction parameters mainly the slice thickness, slice increment and field of view are responsible for obtaining the best quality of CT data. The major advantage with these reconstruction parameters is even though the patient under go for single CT scan the same data can be used for multiple times for reconstruction with different parameters. These accurate medical models are helpful majorly to check the fitment of mesh plate or implant in prior to the actual surgery placement, if required the modification to the implant are made in prior to actual which reduces surgery time drastically. The experimental results are validated by conducting to two case studies with obtained results. Finally the patient specific accurate medical models are obtained, which helped to solve complex surgeries. The mock surgery was conducted on the medical models before going to actual surgery. In future the process of making medical models can be made more economical by streamlining the processes.

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References

1. Kai CC, Fai KL (2000) Rapid prototyping, principles and applications in manufacturing. World Scientific.
2. Gibson I, Cheung LK, Chow SP, Cheung WL, Beh SL, et al. (2004) The use of rapid prototyping to assist medical applications. 10 emes Assises Europeennes de Prototypage Rapide 14.
3. Krishna LSR, Manmadhachary A, Reddy PB, Venkatesh S (2011) Development of optimum preplanning for maxillofacial surgery using selective laser sintering. Int J Eng Sci Technol 3: 185-196.
4. Santosh Kumar M, Ravi Kumar Y (2016) Optimizing 128 slice spiral CT Scanner parameters to minimize acquisition errors. Int J Mech Eng Inf Technol 4: 1642-1648.
5. Waaijer A, Prokop M, Velthuis BK, Bakker CJG, Gerard AP, et al. (2007) Circle of Willis at CTAngiography: Dose reduction and image quality-reducing tube voltage and increasing tube current settings. Radiology 242: 832-839.
6. Nakayama Y, Awai K, Funama Y, Liu D, Nakaura T, et al. (2006) Lower tube voltage reduces contrast material and radiation doses on 16-MDCT aortography. AJR Am J Roentgenol 187: 490-497.
7. Hiller J, Reindl LM (2012) Computer simulation platform for the estimation of measurement uncertainties in dimensional X-ray computed tomography. Measurement 45: 2166-2182.
8. Santosh Kumar M, Ravi Kumar Y (2016) A review on rapid prototyping technologies in biomedical applications. Int J Recent Sci Res 7: 10783-10789.
9. Li WZ, Zhang MC, Li SP, Zhang LT, Huang Y (2009) Application of computer-aided three dimensional skull model with rapid prototyping technique in repair of zygomatico-orbito-maxillary complex fracture. Int Med Robot 5: 158-63.
10. www.materialise.com/mimics
11. Gibson I, Cheung LK, Chow SP, Cheung WL, Beh SL, et al. (2006) The use of rapid prototyping to assist medical applications. Rapid Prototyping Journal 12: 53-58.
12. Mohammed MI, Fitzpatrick AP, Malyala SK, Gibson I (2016) Customised design and development of patient specific 3D printed whole mandible implant. Annual International Solid Free Form Fabrication Symposium.
13. Alwala AM, Malyala SK, Roy L, Vasamshetty P (2016) Surgical planning in pan facial trauma using additive manufacturing medical model– Case study. Journal of Surgery [Jurnalul de chirurgie] 12: 125-128.
14. Fabris V, Bacchi A (2016) Fixation of a severely resorbed mandible for complete arch screw-retained rehabilitation: A clinical report. J Prosthet Dent 115: 537-540.
15. Ozturk AN, Usumez A, Tosun Z (2010) Implant-retained auricular prosthesis: A case report. Eur J Dent 4: 71-74.