MINIMIZATION OF VOLUMETRIC ERRORS IN CAD MEDICAL MODELS USING 64 SLICE SPIRAL CT SCANNER

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Abstract

Sixty four slice spiral Computed Tomography (CT) scanner is one of the advanced CT scanners to capture the large volume of tissues and improved longitudinal resolution. The CT images are used to develop a 3-Dimensional (3D) Computer Aided Design (CAD) medical model. While developing a 3D CAD medical model volumetric errors occur due to partial volume or volume averaging effect. In order to study, various CT image construction parameters were considered to minimize the volumetric errors in 3D CAD medical models, a human dry mandible has been selected as a phantom. A Taguchi technique was used to find optimal CT image construction parameters. A L_9 orthogonal array was used to optimize the CT image construction parameters constituting slice thickness, slice increment and Field of View (FOV) while performing CT image construction. The resultant optimal parameters are scrutinized using analysis of variance (ANOVA) method for its influence on the CT image construction. In this work, it has been found that there is a volumetric error of a 3D CAD medical model (STL file) from CT images of a dry mandible was 1978 mm^3 (6.11%).

Key words: CT, Partial volume effect, Volumetric error, CT Image construction, ANOVA.

Introduction

Rapid Prototyping (RP) is a technology that can automatically construct physical models from Computer Aided Design (CAD) data, Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) data. In this RP processes the medical models are produced by Digital Imaging and Communication in Medicine (DICOM) images which are produced by CT/MRI techniques. These DICOM images are converted into a 3-Dimensional (3D) CAD medical model by using various medical software like 3D Doctor, MIMICS etc [1]. This 3D CAD medical model converts into STL (Standard Triangle Language) file format because STL file is a neutral file format for RP processes [2]. This STL data is converted into vertical stacks of 2-Dimensional (2D) data slices by using RP software such as Catalyst, Magics etc [3]. The computer generated 2D slice is containing contour information of that slice with predetermine thickness. These 2D slices were send to the RP machine for develop a 3D RP model [4]. In this technique the main advantage is a 3D RP medical model can make by using CT, MRI and Ultra sound data etc [5-7]. This is why the RP techniques have been extensively used in the field of oral and maxillofacial surgery [8, 9], dental surgery [10], reconstructive surgery [11] and orthopedics surgery [12].

The CT/MRI images are not only used in RP, these images are applicable in cancer treatment, identification of tumor, Finite Element Analysis (FEA) of human anatomy, Computational Fluid Dynamics (CFD) analysis for blood flow problems etc [1]. For these applications image construction from the CT/MRI is the starting stage. If any error occurs in this stage these errors get propagate in the subsequent downstream processes like RP model fabrication [13,14]. So the error minimization is critically important at the DICOM image construction stage. A number of authors are working to reduce the errors during the CT image construction stage through their work on developing the algorithms for reducing errors in CT images. Very few authors have worked to reduce the volumetric error by setting the CT image construction parameters optimally. Most of experimentation was done using only two or three parameters are varied to construct the CT images. These authors have compared only linear dimensions [15, 16], but partial volume or volume averaging effect [13] much more important in RP applications. While constructing the CT image, the pixel value represents the proportional amount of X-ray energy that passes through the tissues and strikes the detector. The information contained in each pixel is averaged so that one density number (Hounsfield Unit [HU] or threshold value) is assigned to each pixel. If an object is smaller than a pixel, its density will be averaged with the information in the remaining portion of the pixel. This phenomenon is referred to as the partial volume or volume averaging effect. In this work, authors are trying to reduce the partial volume or volume averaging effect by optimally deciding the slice thickness, slice increment and Field of View (FOV).

Experimental Setup

In this study, an adult dry mandible (Fig. 1) is taken as a phantom for experimentation to find the volumetric error of the 3D CAD medical model. From the dry mandible, tooth was removed because the density of tooth and bone were different, and this work concentrated on the homogenous bony part only.

Fig. 1: Dry mandible phantom

In this work, the phantom was scanned with a 64 slice spiral CT scanner (Light Speed VCT, GE Medical Systems). The CT image acquisition was done with configuration of 64 detectors × 0.625 mm detector collimation and rotation time of the gantry was 0.4 seconds. The phantom was scanned with CT image acquisition parameters of tube voltage 80 kV, tube current 500 mA and pitch 0.984.

In the present work, the authors are trying to minimize the volumetric error of the 3D CAD, medical model by conducting the experiments on a 64 slice spiral CT scanner. The CT images were constructed with different slice thicknesses, slices increments and FOV. The acquired data set is reconstructed at a range of equal thicknesses are called slice thickness. Slice increment represents the spacing between two slices. FOV is the area of tissue that covers to construct the image of the object. These parameters with three levels are shown in the Table 1. During the CT image construction the matrix size considered is 512 × 512 for all experiments.

Table 1 CT Image construction parameters

Parameter	Level of Parameter		
	1	2	3
Slice Thickness (mm)	0.625	1.25	2.5
Slice Increment (mm)	0.3	0.6	1.5
FOV (mm)	150	200	300

Scanning of the phantom with three different parameters (slice thicknesses, slices increments and FOV) having three levels requires 3^3 (27) experiments. Taguchi method [17] uses a special design of orthogonal array to conduct the minimum number of experiments and gives the optimize parameters. The degrees of freedom for three parameters in each of three levels were calculated by following equation [17].

Degree of Freedom (DOF) of each variable is = number of levels -1 ------------------- (1)

The minimum number of experiments required based on the above Equation is 6. Because of the balancing property of the orthogonal arrays, the number of experiments for this case is 9. Based on this L_9 orthogonal array has been chosen, it has eight DOF, in which 6 were assigned to three factors (each one 2 DOF) and 2 DOF was assigned to the error. Accordingly nine scans were taken with different slice thicknesses, slices increments and FOV, it is shown in Table 2.

Table 2 L_9 orthogonal array for experimentation

Experiment Number	Slice Thickness (mm)	Slice Increment (mm)	FOV (mm)
1	0.625	0.3	150
2	0.625	0.6	200
3	0.625	1.5	250
4	1.250	0.3	200
5	1.250	0.6	250
6	1.250	1.5	150
7	2.500	0.3	250
8	2.500	0.6	150
9	2.500	1.5	200

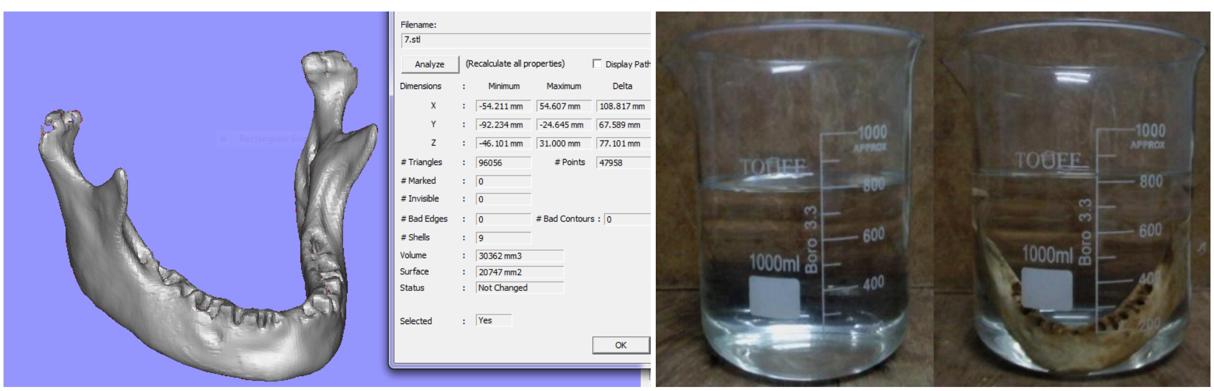
After completion of CT image construction the images were saved in a DICOM file format. From these files, a 3D CAD medical model was constructed subsequently STL file was generated from the 3D CAD medical model by using Materialize Interactive Medical Image Control System (MIMICS) software (version 14.12, Materialise NV, Leuven, Belgium) [18].This STL file is used to measure the volumetric errors between the dry mandible and 3D CAD medical model.

The 3D CAD (in a STL file format) mandible volumes were measured with MAGICS software (Fig. 2a). Dry mandible volumes were measured by using the water displacement method (Fig. 2b). In this method, the dry mandible volume is measured by calculating how much water it displaces, or pushes aside when it's placed into distilled water. Dry mandible volume is calculated by subtracting the volume of the water without the dry mandible from the new measurement with the dry mandible. The volumes were measured three times, for consistency and closest repeated value was chosen as accuracy criteria. These volumes are shown in Table 3. The measurements were measured in cubic millimeters (mm^3). In this paper the difference between dry mandible volumes to the 3D CAD mandible volume values are considered as a volumetric error. This can be written as the following mathematical relations:

Volumetric error = Dry mandible volume - 3D CAD mandible volume --------------- (2)

Table 3 Volume measurement of dry mandible and 3D CAD model

		Measured Volume (mm^3)
Dry mandible		32340
Exp. No. 1	3D CAD Model	27631
Exp. No. 2	3D CAD Model	28483
Exp. No. 3	3D CAD Model	29095
Exp. No. 4	3D CAD Model	28984
Exp. No. 5	3D CAD Model	30131
Exp. No. 6	3D CAD Model	26586
Exp. No. 7	3D CAD Model	30362
Exp. No. 8	3D CAD Model	27748
Exp. No. 9	3D CAD Model	28155



(a) (b)

Fig. 2: Volumes are measured by (a) MAGICS software (b) Water displacement method

Taguchi methods [17] have been widely utilized in engineering analysis and consist of a plan of experiments with the objective of experimental data in a controlled way. The greatest advantage of this method is the saving of effort in conducting experiments and discovering significant factors quickly. In this work Taguchi technique was used to find the optimized parameters of slice thicknesses, slices increments and FOV, with performance characteristic of volumetric error. The experimental results were analyzed by analysis of variance (ANOVA) and significant main factors are identified. Multiple regression equation was formulated for estimating predicted values of the volumetric error.

Results

As per Equation 2, the volumetric errors were calculated and these values are depicted in Table 4. In this work smaller volumetric error was chosen as the criteria for optimization. The experimental input and output results are shown in Table 4. From the Table 4 observed that at experiment number 7 gives less volumetric error.

Table 4 Volumetric Errors

S. No	Experiment Number	Input Parameters			Output Parameters	S/N ratio
		Slice Thickness (mm)	Slice Increment (mm)	Field of View (mm)	Volumetric Error (mm^3)	
1	Exp. No. 1	0.625	0.3	150	4709	-73.45
2	Exp. No. 2	0.625	0.6	200	3857	-71.72
3	Exp. No. 3	0.625	1.5	250	3245	-70.22
4	Exp. No. 4	1.250	0.3	200	3356	-70.51
5	Exp. No. 5	1.250	0.6	250	2209	-66.88
6	Exp. No. 6	1.250	1.5	150	5754	-75.19
7	Exp. No. 7	2.500	0.3	250	1978	-65.92
8	Exp. No. 8	2.500	0.6	150	4592	-73.24
9	Exp. No. 9	2.500	1.5	200	4185	-72.43

In this study smaller-the-better quality characteristic is used. The S/N ratio used for this type quality characteristic is defined as [17]:

$$\frac{S}{N} = -10\log_{10}\frac{1}{n}\left(\sum_{i=0}^{i=n} y_i^2\right) \quad (3)$$

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

The S/N ratio values are calculated by using Equation 3. These values are shown in the last column of Table 4. Mean of S/N ratio for each level of CT image construction parameters were calculated. These are shown in Table 5. The lowest value of each parameter gives the optimum values (3rd levels of slice thickness, 1st levels of slice increment and 3rd levels of FOV). The statistic delta is calculated as the difference between the highest and the lowest effect of each parameter, used as influencing parameter for CT image construction.

Table 5 Response table for S/N ratios of CT image construction

Parameter	Levels of Parameters			Delta	Rank
	1	2	3		
Slice Thickness	-71.79	-70.86	-70.53	1.26	3
Slice Increment	-69.96	-70.61	-72.61	2.65	2
FOV	-73.96	-71.82	-67.67	6.29	1

In order to analyze the effect of CT image construction parameters on the volumetric error a main effects plot for S/N ratios of optimized parameters were generated, by using Minitab software this has shown in Fig. 3. From these, it was found that the optimal CT image construction parameters are slice thickness 2.5 mm, slices increment 0.3 mm and FOV 250 mm.

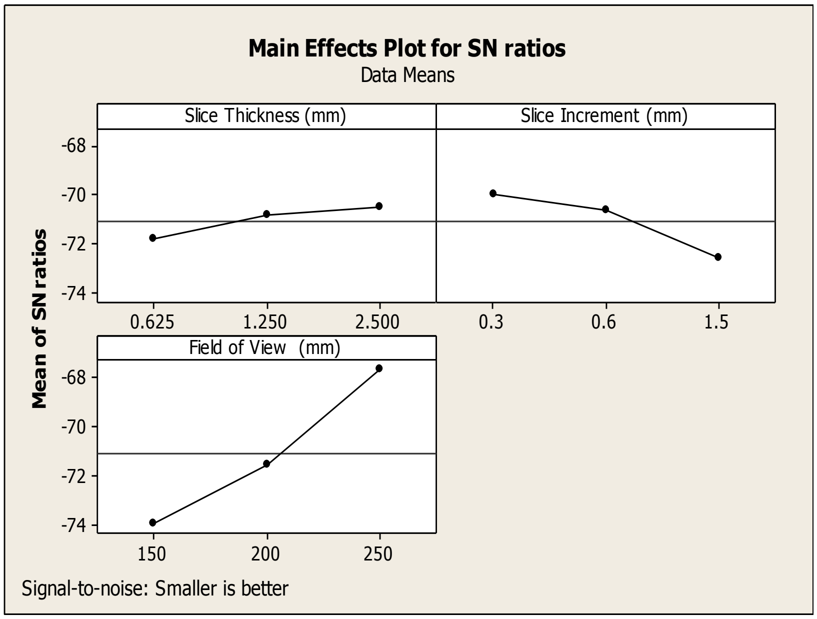


Fig. 3: Effect of CT image construction parameters on volumetric error

These optimal CT image construction parameters are selected for the CT image for confirmation tests. The confirmation experiment is a crucial step and is highly recommended by Taguchi to verify the experimental results. In the present work it has been observed that the S/N ratios, response table and main effects plot for S/N ratios were same optimized CT image construction parameters. So the confirmation experiment is not conducted to verify the experimental results.

Table 6 shows the results of ANOVA for the volumetric errors. The purpose of ANOVA is to investigate the significant factors in the CT image construction. This analysis was carried out for a level of significance of 1.5%, i.e., for 98.5% level of confidence. The purpose of ANOVA is to investigate, which the CT image construction parameter significantly affects the performance characteristics. The factor of FOV has 82.34% of contribution, is the most significant control parameter for CT image construction.

Table 6 ANOVA results of the CT image construction parameters

Parameters	Degree of freedom	Sum of squares	Mean square	F-ratio	Percent contribution
Slice Thicknesses	2	186144	93072	4.18	1.58%
Slices Increments	2	1847198	923599	41.45	15.6%
FOV	2	9690326	4845163	217.43	82.34%
Error	2	44568	22284		0.48%
Total	8	11768236			100%

A multiple linear regression models are developed in order to predict the values of volumetric error of the 3D CAD medical model. The developed models are reasonably accurate and can be used for prediction within limits. The regression equation for the volumetric error was generated with the help of Minitab software is as:

Volumetric error = 8403 - 182 slice thickness + 887 slice increment - 25.4 FOV---------------- (4)

Conclusions

In this work an effort was made to reduce the partial volume or volume averaging effect by using volumetric error of the RP medical model. As a result of these processes, the volumetric accuracy of RP medical model is improved. Further, it is applicable for manufacturing of various mandible implants and prosthetics. From this work, it has been observed that the volumetric error of a 3D CAD medical model (STL file) from CT images of a dry mandible was 1978 mm^3.These values are achieved using CT images by 64 slice spiral CT scanner with optimized CT image construction parameters of slice thickness 2.5 mm, slice increment 0.3 mm and FOV 250 mm. Even after optimization of CT image construction parameters, small volumetric errors do occur in STL file. The elimination of errors occurring during the STL construction stage is essential because it is the one of the stage for RP model fabrication. This minimization of errors in the STL file will prevent further proposition of errors in the subsequent stages like RP model fabrication.

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