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A Review on Modelling of Knee Joint Using Medical Imaging Methods

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ABSTRACT: Accuracy of the 3D CAD model of the knee joint is based on various factors like imaging method i.e CT scan, MRI data, modelling software and different algorithms for segmentation. For generating geometrical and CAD model techniques like CT scan, Co-ordinate Measuring Machine (CMM) and 3D laser scanner are used. So in this paper efforts have been made to study the different factors which affect the accuracy of a 3D CAD and additively manufactured knee model. Accuracy of the knee joint is important for anatomical study, implant modelling and pre-surgical planning. Segmentation technique is another important factor which affects the accuracy of a 3D CAD model so each segmentation technique has its pros and cons therefore evaluation of segmentation technique is also studied and compared with each other.

Keywords: Accuracy, Image segmentation, 3D printing, 3D modeling, medical imaging data.

I INTRODUCTON

The 3D model has been required for different applications like the study of various intricate shapes, implant modelling and Total - knee Replacement. The Inaccurate 3D model will lead to difficulties like implant loosening, incorrect force application and loose-fitting. A Correct measured geometrical model can also be used for simulation *i.e* studying the motion for surgery purpose. The Generated model is necessary for custom design of scaffolds and prosthesis. Image registration is the primary step in which point cloud from different orientations is registered at a common reference system. In general two types of image registration are used

a) Feature based – It is used to align the features by finding correspondence between features in the image
b) Intensity based - In this method the alignment is based on the intensity of pixels in the image [1]

In this paper Segmentation algorithm for reconstruction of the geometrical model is also compared and validated using *Manual Edge Segmentation, Sobel Operator Algorithm and Laplacian of Gaussian Operator Algorithm and Canny Edge Detection Algorithm.* Each one of the algorithm is studied and compared with each other. Nowadays , a number of software are used for 3D reconstruction and image processing so analysis of software is done using 3D Slicer (version4.9.1), InVesalius (version 3.1.1), Itk-SNAP (version 3.6.0) and VuePacs3D (version 12.1.5.0440) [2]. Models of the knee generated using these software are compared with each other. Softwares were analysed in terms of their capabilities, tools availability and complexity of handling hardware requirements

and programs functionality and also separation of different regions of interest like linear, angular and volumetric measurement. CT scan and MRI are mostly used for orthopaedic applications but from the literature, it was found out that CT scan is more appropriate for medical applications and it is also capable of removing soft tissues and ligaments in case of the knee joint. Analysis of CT scan and MRI is done on the basis of qualitative examination and statistical analysis (using the measurement of CT based and MRI based model with real bone model) Difference was calculated using [3]

Difference = Measurement from the 3D CAD model – Measurement from corresponding real bone

The purpose of this paper is to study the parameters which can affect the accuracy of 3D CAD model like modeling software, segmentation technique, an algorithm for image segmentation, input imaging technique and image reconstruction methods like slice thickness, Resolution and slice spacing. [4]

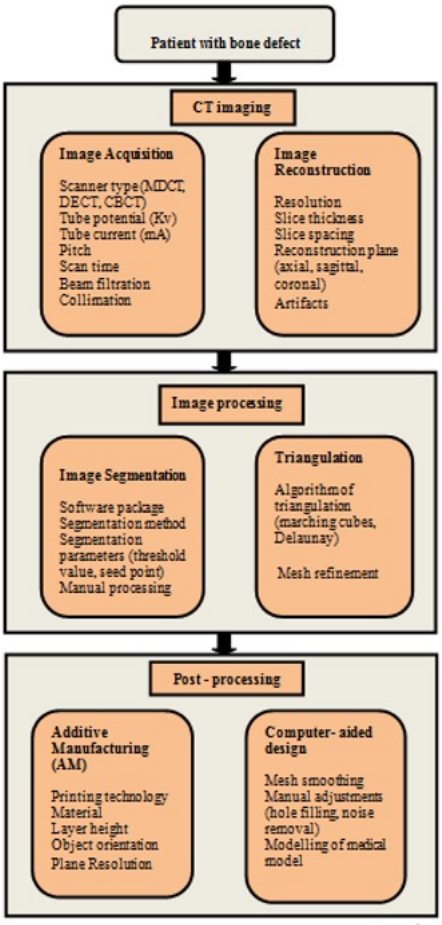

Figure 1. Overview of parameter that affects 3D CAD model of knee [6]

Comparison on the basis of a different scanning system in generating a 3d cad model of the femur bone

From comparison with respect to qualitative and quantitative analysis, it was obtained that the CT scan data has given more accurate results. Less measurement time, better editing capabilities and capturing of the complex region adds its feature in better qualitative analysis and quantitatively less number of point cloud generated in CT scanning.

As 3D models are generated using different segmentation method, comparison and analysis of most suitable segmentation algorithm is necessary for analyzing the morphological errors and stress distribution in 3D reconstruction. From literature, it was found out that in the measurement of von-mises stress, reaction force and contact stress by FE analysis it was found that *Laplacian of Gaussian Operator Algorithm and Canny Edge Detection Algorithm* had shown lower deviation. They also showed less error for femur-ACL stress & tibia-ACL stress and finally, it was concluded that the *Canny Edge Detection Algorithm* is an optimal method for reconstruction of a 3D CAD model.

The results in terms of maximum and root mean square distances calculated over five anatomical models (Ankle, Knee, shoulder, Elbow, Wrist) were found using a combination of two software. The best result was obtained between 3D slicer and Itk-SNAP (2.84 mm & 0.13 mm) while the worst results were for Itk-SNAP and InVesalius (13.14 & 2.21 mm respectively). But Despite the present abilities of freeware software, these cannot currently be used in clinical practice because of the lack of necessary certification. The software can be used for clinical practice, prosthetic design and medical education.

Table 1.1 comparison of medical image method for 3D CAD model of knee [1]

System	Measurement time	Post- processing	Outer profile	Final model
CMM(Non-contact measurement without fixture box)	4 h	Need so much processing since modelling is less no of points only	Profile was good	The Flat model obtained without surface textures
CMM(Both contact and Non-contact measurement with fixture box)	12 h	More processing steps needed than the previous method like orientation and registration due to the combination of two methods	Good but with little deviation from actual bone	Better with the above method but not accurate
3D scanner	6 h	Need rescanning rather than basic scanning due to poor lighting and insufficient memory	Due to laser, some portion was not captured	Needs polygon meshing using 3D editor tool after rescanning
Faro Arm edge	20 min	Post- processing for filling up of holes and patches is needed using Geomagic software	Good profile	Better CAD model with some patches available
CT scanning	15 min	Automatic processing and has good editing capabilities	Good profile	Complete CAD model

From the bar graph, it is concluded that CT scanning and Additive manufacturing is suitable for surgery. As the cases of Total knee Replacement (TKR) are increasing so the selection of optimum scanning technology is important for correct implantation. The increased errors associated with the MRI models (as the difference between the mean and standard deviation is more) coupled with the discontinuities, unwanted artifacts and obvious rough appearance to their surface means that accurate reconstruction of the bone surface from MRI data has not been possible.

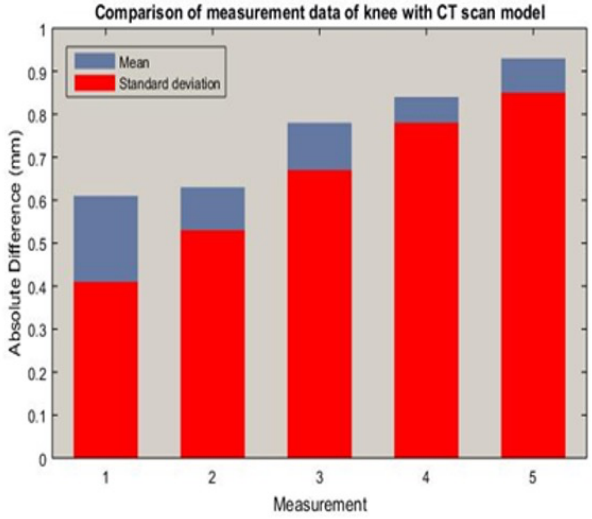

Figure 2. Comparison of measurement data of knee with CT scan model [3]

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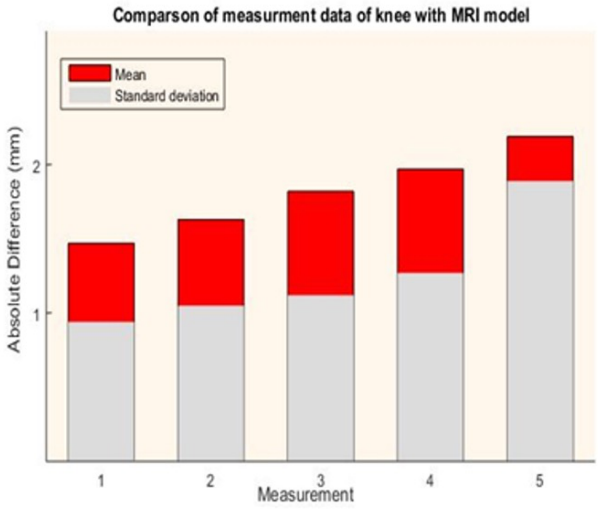

Figure3. Comparison of measurement data of knee with MRI model [4]

CT IMAGE SEGMENTATION METHODS USED FOR MEDICAL ADDITIVE MANUFACTURING (AM)

There are mainly three semiautomatic CT image segmentation method are used in medical AM

a) Global thresholding
b) Edge detection
c) Region growing [6]

Global thresholding

From literature, it was found out that global thresholding is the most commonly used bone segmentation method for medical AM. but it has a limitation that voxels reside on tissue boundaries that contain more than one tissue type and induce a blurring of grey values across boundaries. This phenomenon is referred to as the partial volume effect (PVE). As a consequence of the PVE, precise delineation of tissue boundaries using only a single threshold value remains difficult and can result in an over- or underestimation of the region of interest. These drawbacks have led to the development of more sophisticated thresholding methods such as local thresholding.

$$\begin{cases} 1 \\ 0 \end{cases} I_{x,y} \geq t, \; I_{x,y} \geq t \qquad (1)$$

Where $I_{x,y}$ in eq (1) denotes the grey value at coordinates x and y in a CT image slice and t is the threshold value for bone.

Local thresholding also referred to as multi-level thresholding, divides an image into multiple ROIs for which an individual thresholding bandwidth tk to tk+1 can be selected. All voxels with a grey value between tk and tk+1 are included in k segmented volumes using a binary mask Mx,y.

Edge detection

Edge detection, on the other hand, identifies local edges on CT images by calculating gray value gradients (derivatives). The gradients with a magnitude that is higher than a chosen threshold value are defined as edges. A range of edge detection operators are currently available that includes Sobel, Laplacian (2nd derivative) and Canny. Canny edge detection remains one of the most commonly used, fastest and most accurate operators.

Region growing

Region growing is seldom the only segmentation method used, but it is commonly combined with other methods such as (global) thresholding. An advantage of region growing is that it discards voxels that are not connected to the anatomical structure of interest, resulting in a shorter 3D printing time and material savings. A disadvantage of region growing is that each separate bony structure requires an individual, manually placed seed point. Furthermore, noise and the partial volume effect can cause voids or erroneously connected structures in a segmented image.

CONCLUSIONS

After studying and analysing different parameters it is concluded that for scanning system compared to other measurement system CT scan has given more accurate results with less scanning time and post-processing step. CT scan model also showed less standard deviation when compared with real model as shown in figure 2 and figure 3. In the case of CT image segmentation methods, Global thresholding is more appropriate but it requires manual post-processing. Image segmentation algorithm could also improve the accuracy of the patient-specific implant. Analysis of various image segmentation algorithms suggests that the canny edge detection algorithm is optimal for 3D reconstruction of the knee.

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