

Finite Element Analysis of Three Dimensional Medical Model Generated from CT Scan data.

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Abstract

Computer Tomography (CT) and magnetic resonance imaging (MRI) are the two most common techniques used to acquire detailed anatomical information in the field of medical imaging. Medical Practitioner requires skills and experience to co-relate these images for the correct diagnosis. Medical practitioner faces difficulty in accessing these images as it not platform independent, these images can be access only at platform where the scanner is attached. Hence, author has developed a program, which not only overcome these difficulty but also enhances the visualization of the CT scan images as well as facilitates to distinguish the soft tissues and bone tissues clearly thereby minimizing the ambiguity to tackle the problem during image guided surgery. Further it has been attempted to develop the actual computer aided 3 D model from the slices of CT scan images which can be analyzed by Finite Element Method to know the responses at various loading conditions. The resulted information will be helpful for the medical practitioner to suggest proper prevention and precaution to the patients. Actual physical model can be generated by Rapid prototyping technique. A precise actual physical model facilitates the pre-operative planning of an optimal surgical approach and enables selection of correct and appropriate implants. The integration of technologies such as medical imaging, Computer Aided modeling, RP and FEA is important in medical field to reduce the cost and risk to patients and strengthening the decision making capacity of medical practitioner.

Keywords: Computer Tomography, Finite Element Analysis, Rapid prototyping, Computer Aided modeling.

Introduction:

Diagnostic imaging devices such as computer Tomography and Magnetic resonance imaging are able to produce anatomical description of various features such as tissues and organs. These scan image distinguish bone tissue and soft tissue with different intensity in a computer. Doctor uses CT scan or MRI to know the exact cause and the region of the affected portion for the patient.[1] The CT scan images or MRI are stored in the Dicom form which cannot be easily decoded to visualize the actual image without the proper hardware which is normally associated with the scanner. The cost of such system is not affordable by many doctor therefore, medical practitioner faces difficulty in explaining these images to the common people. Medical practitioner also require their skill and experience to understand these images. Therefore it is needed to visualize these images in the proper form so that it can be helpful for the medical practitioner as well as common people to understand the anatomical structure or the abnormalities associated with the patient [2].

The interpretation of the dataset requires special training and depends on the experience. The platform dependency to visualize these images is overcome by introducing a variety of algorithms as well as developing a software to view extract geometric information of objects from volumetric image data. The developed software scroll or animate the CT scan images as per the requirement, this process is useful for a surgeon in image guided surgery.

The actual physical model is generated by Rapid prototyping technique concept and the developed Computer Aided model by stacking the CT scan images which is analyzed by finite element method.

The purpose of this work is to strengthening the decision making capacity medical practitioner by establishing the relation between medical imaging, Finite Element Analysis and Rapid prototyping technique.

1.1 Data Acquisition:

The CT scan data in computer processed by converting the signal from analog to digital by using an analog to digital converter. It stores the digital signal during the scan and reconstructs the images after the scan is complete. This reconstruction can be done immediately or later. Data can be manipulated to reconstruct into various planes. The formation of a CT image is a distinct three-phase process (i) The reconstruction phase, processes the acquired data and forms a digital image.

(ii)The scanning phase produces data, but not an image.(iii)The visible and displayed analog image (shades of gray)is produced by the digital-to analog conversion phase.

CT scan images are stored in DICOM forms which is required to be decoded to develop Computer aided 3 D model which is prerequisite for the analysis by FEM. The Digital Imaging and Communications in Medicine (DICOM) standard was created by the National Electrical manufacturers Association (NEMA) to aid the distribution and viewing of Medical images, such as CT scans, MRIs, and ultrasound. DICOM is comprehensive set of standards for handling, storing, printing and transmitting information in medical imaging. It includes a file format definition and a network communication protocol. The header consist of a 128 bytes file preamble, followed by a 4 byte DICOM prefix. The header may or may not be included in the file

Preamble
prefix
128bytes= ?????? 4bytes= 'D','I','C','M'

The DICOM standard does not require any structure for fixed size preamble. Where as data element is uniquely identified by data element tag. The data element in the data set shall be ordered by increasing data element tag number and shall occur at once in a data set.

1.2 Image Reconstruction

The computer receives a signal in analog form and converts it to a binary digit by using a analog to digital converter. The digital signal is stored and the image is reconstructed after the scan is over. Each picture is displayed on a matrix is called a pixel, its assigned a number based on the amount of energy reaching the detector. This number is called as Hounsfield unit. The reconstructed anatomy of an object composed of large number of tiny elongated blocks. Representing a volume of tissue called volxel (volume of pixel).

The digital value ascribed to each pixel is called the Hounsfield units, which lies on scale ,water has at is in the digital format value of 0 and air has a value of -1000. Bone has a value in order of +1000. Hu values reflect the electronic density and thus the physical composition of the volxel of tissue that the pixel represents.[3] However the scale range can be different for the different scanner which affects on the selection of thresholding value.

1.3 Windowing and Grey Scale: Technique of windowing is electronic manipulation of the data to enable the shades of grey to be used to represent a limited range of HU values so that different structures can be imaged. The value of the pixel at a specific point in the image is

converted to a grey level. However, the range of pixel values is approximately -1000(air) to+800(dense bone) but the eye can only distinguish 32 grey levels at best. The majority of the soft tissues range from -100 to +100 so a system know as windowing has been developed to allow Radiologists to dynamically view images. The developed software has a function to visualize these images and distinguish bone tissue ,soft tissue and blood clot clearly.

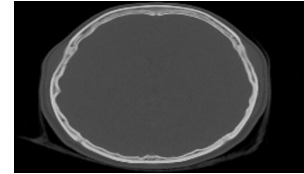


Figure 1.3(a)



Figure 1.3(b)

Figure 1.3 (a) shows bone tissue and (b) indicates bone and soft tissue

Decreasing the window width increases the contrast in the image so is good for looking at differences in soft tissues. Similarly, Increasing the window level allows the denser bones to be viewed. Windowing allows to dynamically alter the image. Both the functions are incorporated in the developed software; it allows the medical practitioner to distinguish bone tissue, soft tissue and blood clot clearly. The method is well-adopted access this images on a diagnostic console to performed the required functions.

2.0 Data Processing:

CT and MRI represent the finest resolution capability in achieving volumetric resolution. During the CT scanning process the images of the patients are taken with the increment of 1 to 1.5 mm of the infected portion. The CT scanned information from such plane are stacked together to provide a volumetric image of the structure. The virtual volume is displayed on the screen [4]. The developed computer program converts the complex data stored in the data element to the graphical form, which is illustrated by creating a virtual 3D representation. The information regarding the attributes associated with the CT scan images can also be visualized as shown in figure 2.1The program is written in Java and it's Hardware Requirements:

Pentium PC (II), 200 MHz processor,128 MB RAM, 250 MB Free Hard disk Space. Software Requirement: Java Compiler.

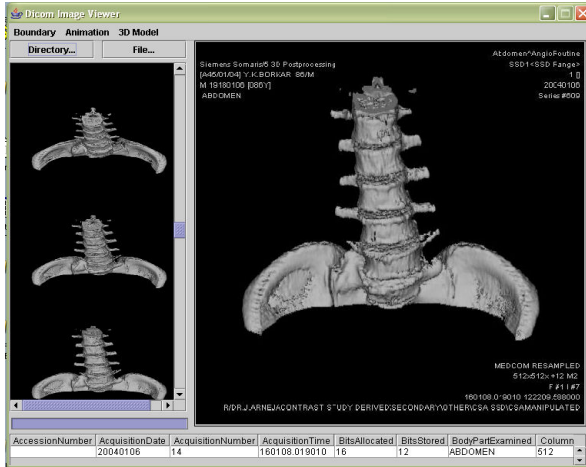


Figure 2.0 shows the surface generated model along with the attributes associated with the CT scan image.

The salient feature of the developed software shows the animated views of CT scan image from all the directions along with the boundary detection from all the sides. The slices of CT scan images as shown in figure 2.1 (a) Which are stacked to generate the 3D model. as shown in figure 2.1(b)

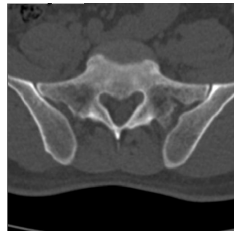


Figure 2.1 (a) view of a single CT scan image.

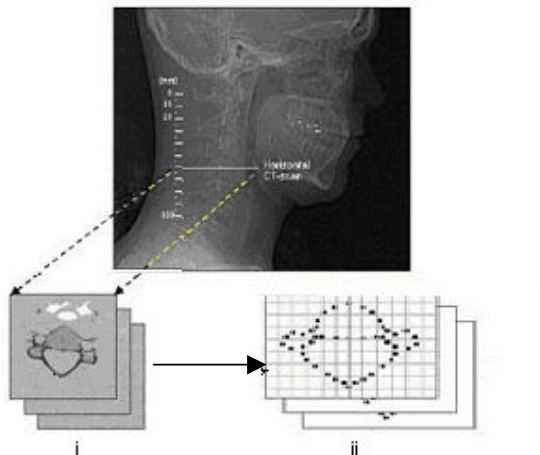


Figure 2.1(b): Schematic image that describes the generation of the model geometry.

The main Graphical user interface is developed in Mat lab, which not only used for visualization of CT images but

also developed 3D CAD model and generates the .stl file using Delaunay Triangulation algorithms for the same.

3.0 Rapid prototyping:

The CT scan slice of vertebral column was used to determine the exact geometry of the bonny portion. Points on the boundaries of the bone were determined by laying the fine grid over the images thereby focusing only on the bone portion.[5] These points were used to determine the three dimensional geometry of the vertebrae which is useful for representing 3D Image. Conventionally STL format is used in rapid prototyping technology which uses layered manufacturing technique. STL is a boundary representation that consists of simple list of triangular facets. In the geometry of triangle the vertex co-ordinate are specified explicitly for each triangle in which the vertex appears. The arrangement of vertices is in the anti clockwise direction as seen from exterior of the part. In addition, a surface normal which points to the exterior of the part is specified for each geometry of triangle.[6]

The stl files can be saved in two types ASCII and Binary. The binary format consists of only a header string, the number of triangles to follow. [5] The simplest way of writing the stl file is in the ASCII form it consists of 3-D coordinates, for each triangular facet, defining the normal and three vertices. [7]

Same technique is used for the model generation by stacking the ten consecutive CT scan images taken 1mm incremented converting it to the .stl format. The data is imported and processed by catalyst software, which is associated with RP machine to build actual physical model using additive technique. The actual flow process is shown in flow chart.

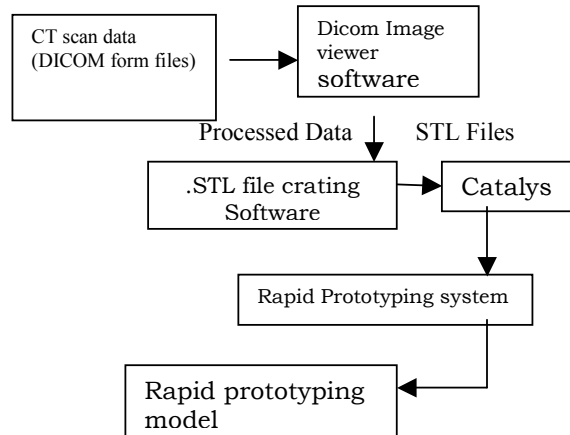


Figure 3.0-Flow chart indicating RP process for medical model

Rapid prototyping machine of 'dimension bst' uses fused deposition modeling (FDM) technique to develop model. The machine uses non laser base technique to develop physical model using ABS material. In rapid prototyping technology, physical object is produced layer by layer, each layer is 2D cross-section of the 3D mesh in STL format.[8, 9] Catalyst software preprocess the information

which is required for the RP machine to generate 3D physical model.

4.0 case studies:

The developed actual physical model from the ct scan technique has as a great significance in the field of medical sciences .The methodology and the concept of generation of actual physical model is well adopted by the orthopedic surgeon of Central Indian Institute of Medical Sciences, (CIIMS) Nagpur. The medical practioner team requires to know the status of post operated facet joint of a female patient whose Lumbosacral vertebral column region gets severely damaged in an accident.. After surgery still the patient faces a problem of the lower back pain. Hence it decided to have the actual physical model so that the post-operated statues of the surgery can be checked. A 3D physical model is generated by using the technique of rapid prototyping. To develop 3D model, the data is acquired from the transverse CT scan slices of 1.5 mm increment from the sacrum portion to the lumbar L1 portion. All the details of the CT scan reports are highlighted in table 1.

—Patient Information—			
Name: TEST --- 1		Age: 57	
ID: 00		Sex: F	
—CT scan information—			
Hospital name:			
Radiologist:			
Referring:			
Created:	2004/07/24 00:00:00	Field of view:	18.20 cm
Scanner:	Emotion Duo / SIEMENS		
Algorithm:	B30s		
Exam:	1	Voltage:	130.00 kV
Slice increment:	1.50 mm	Dose:	96.00 mAs
Slice thickness:	3.00 mm	Image res.:	512
—Reformatted Study Information—			
File:	lumbar		
Created:	25-Jan-2005 12:08 (AM)	Parallel incr.:	1.00 mm
Anatomy:	Mimics	Cross-sect. incr.:	1.00 mm
Parallel:			

The acquired CT data is processes in the developed software The actual physical model showing the detail anatomical structure is prepared by converting the CT data to CAD data The de-facto standard interface from CAD to RP is the standard triangulation language (STL). The .stl file is process in the catalyst software and the instructions are given to the RP machine to generate actual physical model as shown in figure4.0.

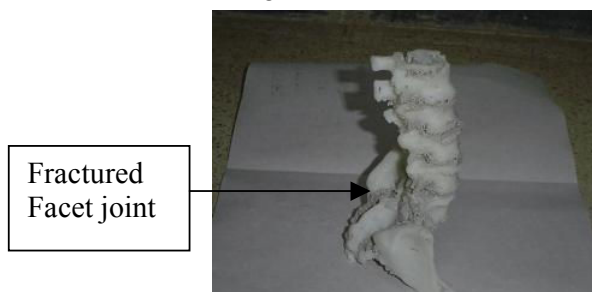


figure 4.0 shown actual physical model in R.P

In another case a patient having a problem at the chest rib, surgeon faces difficulty in tacking it. To satisfy the need of surgeon the RP model is generated by adopting the above techniques. The successful trial on the model planed the surgery in advance and rehearsal on the actual physical model of the patient overcome the difficulty of the surgeon.



Figure 4.1 shows scaled Dimensional similar model of Complete vertebral column with sacram portion.

The rehearsal drastically reduces the surgery time, because of that the side effects because of anesthesia is overcome. The successful surgery is carried out with minimum blood loss thereby helping the patient to recover soon. The same approached is rendered for a patient who had an injury in the hand. The hand bones were fractured in an accident. Surgeon decided to fix the metal plate for the support so that the healing can be proper. But locating the suitable point for nailing is a tedious and crucial job, the difficulty is over come by developed actual physical RP model

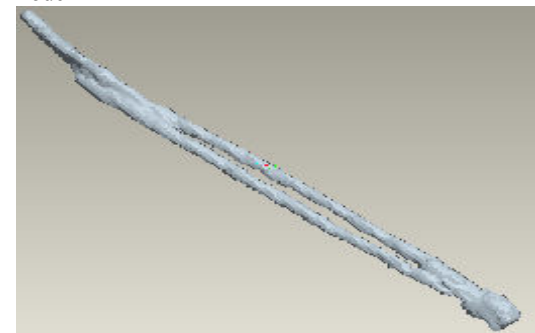


Figure 4.2 shows 3 D model of the hand bone.

The scope of the method is not limited in the medical field. It can be well applied in the mechanical industry in a situation where the CAD data is not possible to generate by using drafting software for example in case die-manufacturing, sculptures design etc. The RP model of such intricate shape feature is generated by CT based reverse engineering technique. The CT scan of the metallic funnel having the intricate shape is used to build the actual Model is visualized as shown in Figure 4.3.

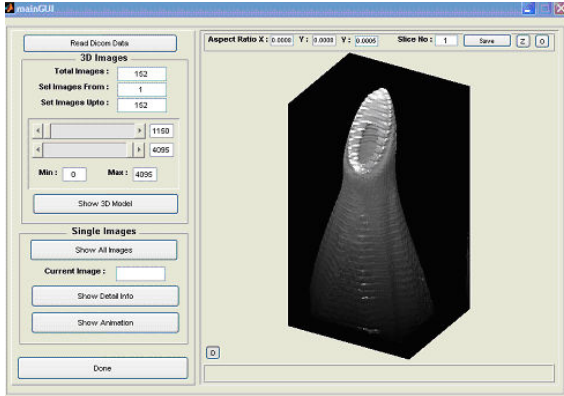


Figure 4.3. 3 D visualization of funnel

The .stl file is after process through catalyst for the RP model is shown in figure 4.4 to build the actual model.

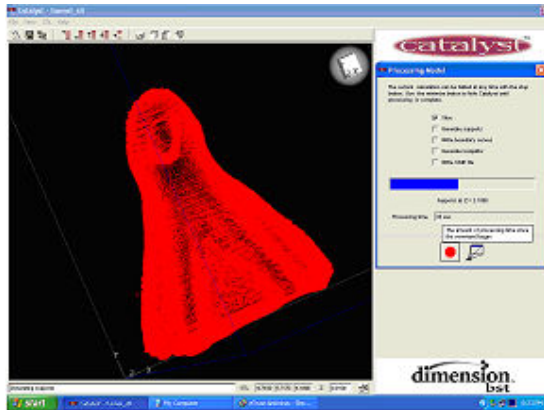


Figure 4.4. shows funnel process in Catalyst

Dimensional accuracy is poor in case of metallic model as., During the ct scan process the highly collimated X-ray beam strikes the metal surface some part of the light energy is gets reflected causing the artifacts causing the dimensional inaccuracy in the model. In the above case thickness is more as compare than the actual .The author is trying to overcome this difficulty by coating the metal surface by light absorbing material such as wet-chalk power past but complete success is not obtained.

5.0 Finite Element Approach

In recent years, the finite element method (FEM) has widely been used to simulate the mechanical deformation of tissues and organs during examinations or interventions. To build up an FEM mesh from a medical image, the contour information of segmented regions of interest need to be first extracted from a volume of data. Then, the volume is meshed into nodes and elements, and material properties are endowed to each element in accordance with the segmentation information. By further applying the boundary condition and mechanical loadings on the corresponding nodes or elements, commercial FEM software packages such as ANSYS may calculate the mechanical stress and strain, and predict the deformation and motion in the field of view.[10,11]

The .stl file of the vertebral model can be imported in pro-e, maya or solid work where the segmentation is carried out so that the peripheral unwanted structure because of noise is edited and removed. The geometry is stored in .iges formed which is then transformed to Ansys software. The wire frame model of vertebral column is as shown in figure14



Figure5.0 wire frame model of vertebral column.

The geometry is re-mesh using solid tetrahedral element in Ansys software as shown in figure 5.1(a)

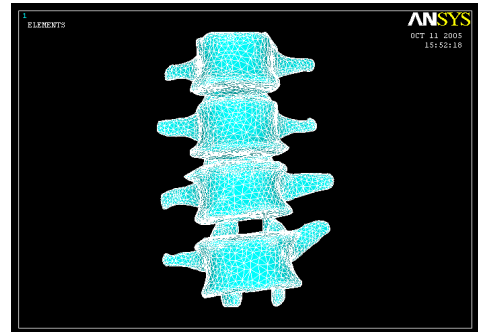


Figure 5.1 (a) Re-mesh solid model meshing figure

The outer base surface of the vertebral column was constrained to zero-displacement in all directions. A total compressive force of 2.2KN, corresponding to approximately 3 times bodyweight [12], is applied radially on the opposite top surface. The material properties of bone were assumed to be isotropic. The young's modulus and the Poisson's ratio for the bone material is consider as 50Mpa and 0.3.The stress distribution result is as shown in figure 5.1(b).

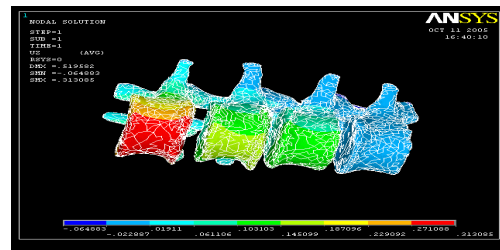


Figure 5.1(b) shows stress distribution.

The resulted information helps the Medical Practitioner to find the critical portion having the maximum stress intensity and the nodal displacement. It helps in suggesting the proper prevention and precautions to the patient. The finite element analysis result can help to decide the proper implant of the proper strength and size of when the patient

6.0 Conclusion:

The drawback of the conventional method can be overcome if the developed dicom image viewer software is used. The developed software facilitates to display all the 3D contours for visualization thereby minimizing the ambiguity to tackle the problem faced by Medical practitioner. With the aid of this software medical practitioner can easily understand the detail anatomical structure of the patient.

The additional feature of the developed software is useful in generating the actual physical model by RP technique. RP technology can make significant impact in the field of Biomedical engineering application and surgery. A physical model enables correct identification of the abnormalities, accurate understanding of the anatomical structure, it also helps in implant design of body organs. A precise model facilitates the pre-operative planning of an optimal surgical approach and enables selection of correct and appropriate implants.[13] The developed software facilitates to evaluate the stress analysis by implementing FEM technique for the developed 3D solid model.

The integration of technologies such as medical imaging, CAD modeling, RP, and FEM is important in medical field to reduce the cost and risk to the patients.

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