

# CAD MODELING USING REVERSE ENGINEERING OF HUMAN KNEE JOINT

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**Abstract**— 3D CAD modelling is the most important part for analysis Reverse engineering is one of the process by which 3D CAD model can be easily generated .Different techniques available for generating CAD models . The paper describes the methodology applied in the development of an anatomically detailed three-dimensional knee model from CT scan data. Medical imaging software is used for generating CAD model which requires CT data as a input. Step by step procedure is described in this paper.

**Keywords:** CAD model, CT data, Reverse engineering, medical imaging software, knee joint.

## I. INTRODUCTION

Geometric complexity and non-linearity of the materials of the knee make the analytical solutions of the mechanical behavior of the knee joint difficult. The knee is the most complex joint within the human body. Proper motion of the joint relies significantly on the function of the soft tissue constituents including the four ligaments of the tibiofemoral joint. These ligaments allow primarily flexion/extension and rotation of the joint by enabling the bony constituents (femur and tibia) to translate and rotate relative to each other. In addition to the ligaments, soft cartilage in the joint space permits nearly frictionless contact between the bones.

Computational modeling of the knee provides a way for better understanding the interplay between the hard and soft tissue constituents of the knee during normal and pathologic function. Additionally, properly validated models can be used in the design of knee implant systems by understanding the mechanics of the restored knee and guiding optimization of the design in order to more closely replicate the healthy knee.

This paper presents methodology to generate 3D CAD model. Medical imaging software like MIMICS is used to generate model. In this software the CT scan data is required as input.

A geometrical model for the component parts (pre-processing) were created using the software package program Mimics 10. The Mimics software is an image-processing package with 3D visualization functions that interfaces with common scanner formats. It is an interactive tool for the visualization and segmentation of CT images as well as MRI images and 3D rendering of objects.

The software enables the user to control and correct the segmentation of CT-scans and MRI-scans. For instance, image artifacts coming from metal implants can be removed. It is also a general purpose segmentation program for gray value images. It can process any number of 2D image slices (rectangular images are allowed). The interface created to process the images provides several segmentation and visualization tools.

## II. MODELING OF KNEE JOINT

A 3D anatomically detailed model of the knee was created using density segmented Computed Tomography (CT) scans

(DICOM standard images). This technique geometrically defines the knee bone structure and the encapsulated soft tissues configuration.

The geometrical complexity of the knee structure implies the use of reverse engineering tools e.g. CT scanning, in order to obtain a model that accurately simulates the biomechanical behavior of the knee, the fixation zone and the ligament.

### A. 3D modeling methodology

The complex mechanical behavior of the knee and the necessity of obtaining accurate results for Post validation with experimental values imply an adequate modeling of the knee structure in terms of 3D anthropometrical characteristics and material constitution. The anthropometrical data was obtained from a CT scan of the knee. The DICOM images generated in the CT scan were then processed with the Mimics 10 software to obtain the primary 3D model using density segmentation techniques. The generated primary 3D models were then processed and assembled as geometrical data files. Finally, the model was exported as .stl file. The model was then prepared for the analysis by definitions of loads, boundary conditions, material constitutive models, kinematic constraints and mesh discretization processes. The methodology is represented in Fig. 1.

### B. Medical image data generation

A CT scan was performed on 32 years old female using CT equipment. Scans were performed on the knee at the neutral posture where there is the least tension or pressure on tendons, muscles and bones. The scans were made up of 332 cross-sectional “cuts” with a slice distance of 0.4 mm and a field of view (FOV) of 346 mm. The images were exported from the CT equipment in the DICOM format with an image area of 1024x1024 pixels. The high image resolution associated with the reduced distance between slices assures a good geometrical definition of the primary 3D models in the future density segmentation operations. Fig. 2 shows a single slice of a gray value image (DICOM format) of the reconstructed knee.

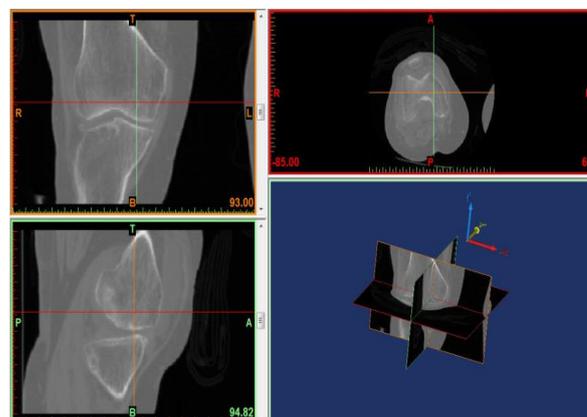


Fig. 1: A single slice of a gray value image of an knee joint of a 32 years old female using CT scan (left).

C. Density segmentation (3D reconstruction)

For the reconstruction of the primary 3D anthropo- metrical models (bone structure and encapsulated soft tissues) the Mimics10.1 medical imaging density segmentation software was used. The DICOM image files generated in the CT scan are constituted by pixels with different gray intensities. The different intensity fields correspond to different material densities in the anatomic knee structure, namely, soft tissues and bone. Note that in a CT scan it is possible to distinguish the tendon graft (ligament) structure. The separated 3D reconstruction of each bone segment was accomplished with manual editing Operations of the density masks. The reconstruction of the encapsulated soft tissues was faster and easier due to the high difference of densities between the soft tissues and the surrounding air. The spaces between bones normally occupied by cartilages and synovial liquid were not segmented. The different phases accomplished for the 3D reconstruction using density segmentation techniques with the Mimics10.1 software are presented below.

1) Importing the medical data

The Mimics software allows automatic importation of the 332 slice images generated in the CT scan. A pixel size of 0.338mm was automatically calculated accounting the present image resolution (1024x1024 pixels) and the acquisition FOV (field of view). The slice distance was correctly determined corresponding to 0.4mm. The pixel size and the slice distance guarantees the coherent dimensional reproducibility of the models generated during the segmentation process. To minimize the project size and maximize the productivity of the 3D reconstruction process, a crop operation was conducted in order to eliminate the slice images of the left knee, concentrating the modeling efforts in the right knee area.

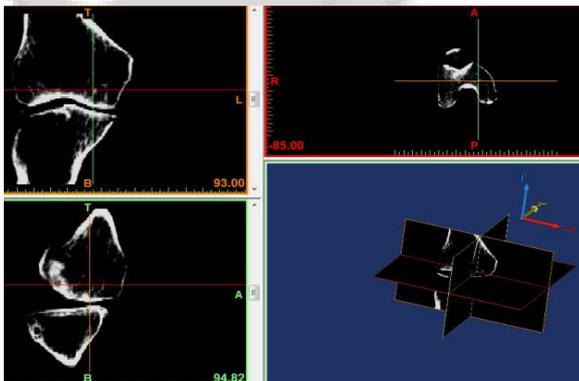


Fig. 2: Importing CT data

2) Thresholding

CT images are a pixel map of the linear X-ray attenuation coefficient of tissue. The pixel values are scaled so that the linear X-ray attenuation coefficient of air equals -1024 and that of water equals 0. This scale is called the Hounsfield (HU) scale.

Thresholding based on Hounsfield scale was used to separate each part of the knee including bones and the encapsulated soft tissues volume. In order to include all the cortical and trabecular bone at the knee bone structure and exclude the cartilage regions, a lower limit of 485HU and an

upper limit of 1467HU were defined. The soft tissues region was generated accounting a range of -188HU to 3071HU.

In the thresholding the bone structure are selected which can see with green color. In this process we select the bone structure for which we want to generate 3D model. We select only that area of the knee to generate the model. So thresholding is the selecting process of the bone structure.

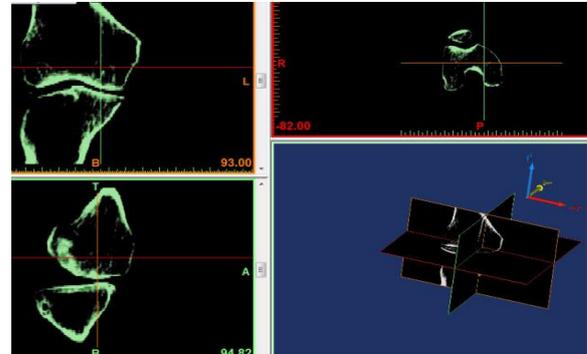


Fig. 3: Thresholding process

3) Segmentation density masks

For each bone, individual and separated masks were created. This process allows the posterior generation of independent geometrical files and 3D models. Some manual operations to eliminate residual pixels were conducted. Cavity fill operations to rule out some voids at the density masks were also realized in order to obtain independent and smoother primary 3D models. For a better visualization of the internal boundaries in the density masks, polylines were generated what allows the use of the “Cavity fill from polylines” tool, in order to eliminate in an easier way, mask’s internal voids.

4) Region growing

The region growing process allows splitting the segmentation in different and separated parts corresponding each part to one mask that can be distinguished by the different applied mask’s colors. For that geometrical separation to happen, the adjacent masks must not be connected with any residual pixel. These operations were performed in all slices generated at the CT scan. For the complete definition of the bone knee structure and soft tissues, different regions (tibia, femur, patella, fibula, tendon graft and soft tissue) were defined. Fig. 4 shows the views of an region growing process on the ligament.

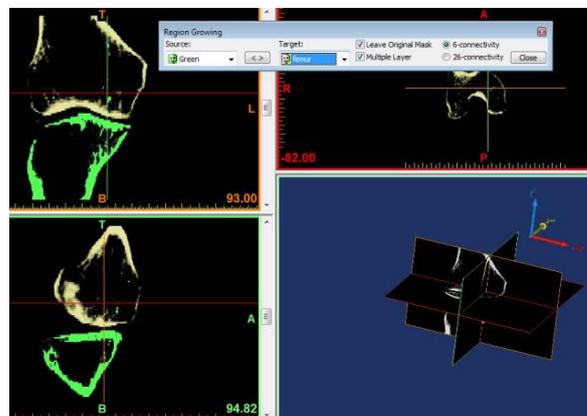


Fig. 4: Region growing process

### 5) Cavity filling

In thresholding and region growing all the bone structure cannot be selected easily so the model generated will not be accurate as only surface bones are selected. This happens due to density difference. So cavity is filled for each layer so that we can easily generate the 3D CAD model. Fig. 5 shows the cavity filling process for each layer.

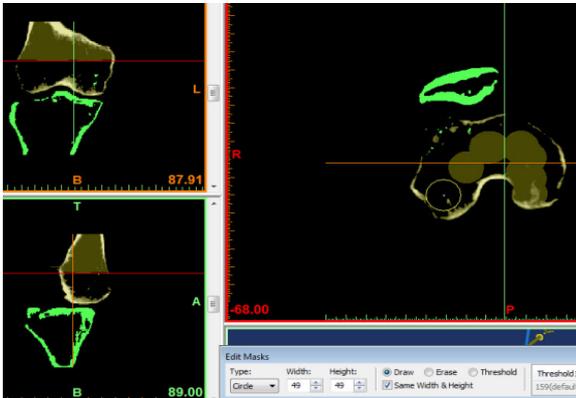


Fig. 5: cavity filling process

### 6) 3D reconstruction

The generated region masks were used to develop 3D models for each the bones and encapsulated soft tissues volume. The 3D reconstruction is based on 3D interpolation techniques that transform the 2D images (slices) in a 3D model. For this reconstruction case, gray values interpolation was used associated with the accuracy algorithm for achieving a more accurate dimensional representation of the knee structure. Shell and triangle reduction, respectively, were used for eliminating small inclusions and reducing the number of mesh elements. Each region was then reconstructed to obtain all the bones and encapsulated soft tissues volume that geometrically defines the knee structure. The relative position of the different parts constituting the primary model assembly of the knee model is shown in Fig. 6.

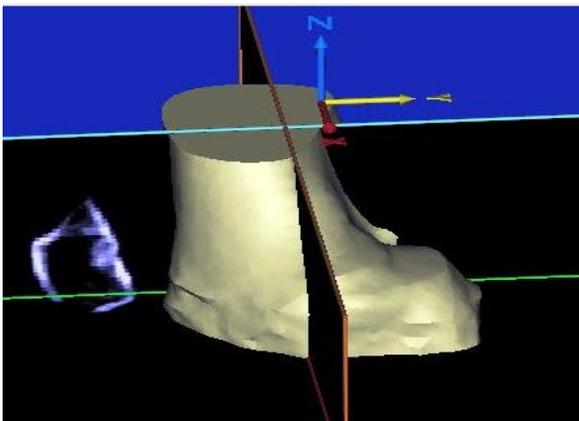


Fig. 6: 3D reconstruction of knee model

### 7) Smoothing

As the model generated by this process is not accurate. The surface of the model is rough. So to create smooth model the smoothing is done. Number of iteration is done with selecting smoothing factor between 0 to 1. Finally, the accurate 3D model is generated.

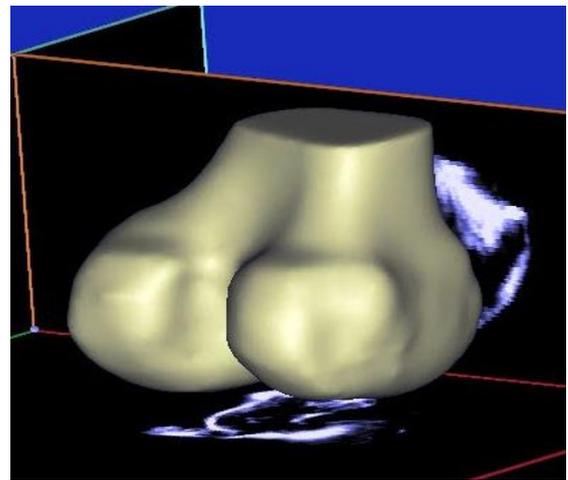


Fig. 7: smoothed 3D model

### 8) Exporting file

After creating the 3D CAD model this model must be exported for further analysis in appropriate format. In MIMICS file is generated in .stl format. In .stl format the tessellation line is generated for each layer for easy further analysis. This file is used as input for different type of analysis.

## III. MODELING RESULTS

Using the MIMICS software 3D CAD model for different bones are generated. Figures bellow show the models for femur, tibia and menisci.



Fig. 8: Femur 3D CAD model

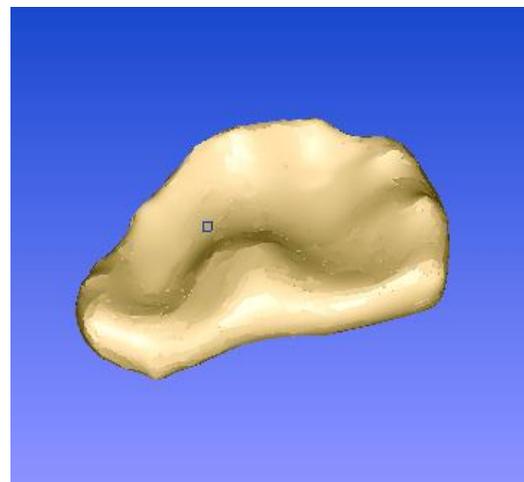


Fig. 9: 3D menisci model

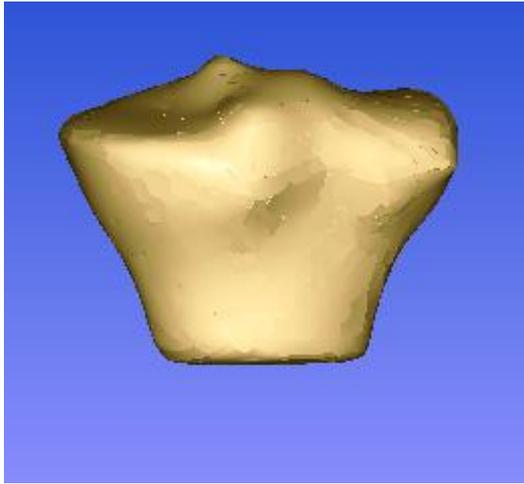


Fig. 10: 3D tibia model

#### IV. CONCLUSION

This paper presents the methodology to create the 3D CAD model of the reverse engineering process. Study shows that software based 3D modeling is easy and less time consuming. Model generated via MIMICS software is accurate to actual data. Modeling using MIMICS software requires only CT data and using simple steps we can easily generate 3D model.

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