

HUMAN UPPER LIMB 3D MODEL OBTAINED THROUGH A NEW MODELING TECHNIQUE

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Abstract: In this paper we describe an alternative for 3D virtual modeling of the human upper limb osteo-articular model. The virtual bony models were obtained by using the Lorensen's algorithm which consists in forming a cloud of points on 3D virtual environment. These clouds of points were obtained by taking in account the CT-series of a human upper limb CT-scans.

This virtual model is useful in the sight of endo-prosthetic implants finite element analysis, which was designed for human upper limb elbow disarticulation.

1. INTRODUCTION

Virtual models of different human body elements (bones, joints, ligaments, muscles of the human body) can be performed through various methods with techniques help discovered in this field, ultra modern engineering and software which are exists in present.

For reconstruction of these virtual models, the principle is always based on cross-sections obtained from some scans of human body with aid of a computer tomography.

First virtual models were developed in the International CHARM Project. The aim of this project was to model the virtual human upper limbs, based on to serial cryo-sections, which can be found in VISUAL HUMAN PROJECT, U.S. National Library Medicine [4].

Figure 1 represents the window of software, which was used to process those cryo-sections. The cryo-sections that were used are different than the other regular CT-sections series, by reason of colors existence. These colors can define certain contours of interest in the sight of the theft for virtual models reconstruction.

These cryo-sections were obtained at an interval of 1 millimeters by freezing the human subject, in the sight of conservation in good condition of human parts.

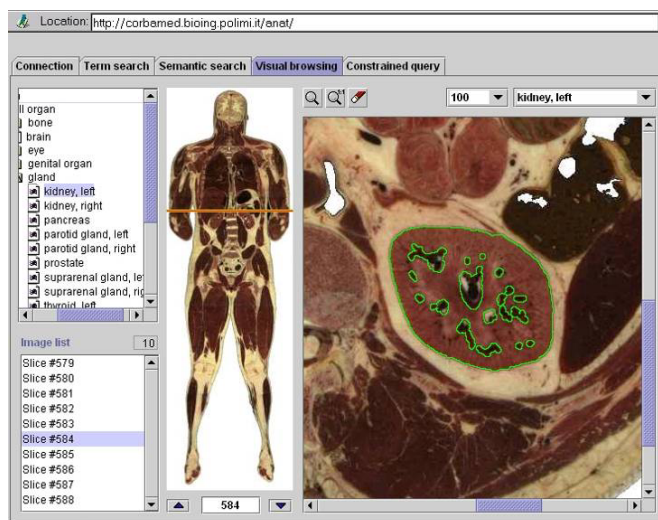


Figure 1. Cryo-section sampling

The steps for virtual reconstruction are:

1. Pre-processing - assume data conversion in special formats stored in files, that can be visualized with a special software of images, image filtering or zoom in or out the resolution in some cases, as well as image scalability. The type of software that he can do this operating functions is called ImageJ, which was created by Wayne Rasband - National Institutes of Health, USA [4].
2. The identification of interest areas, which are represented by human organ contours on the obtained images. The contours trace can be realized manual or automatic by using software capable to recognize and interpretate the contrast difference of some neighboring points.
3. 3D - Reconstruction which was created by contours unification, obtained from CT-series on to the anatomical surfaces of the human interest components (figure 2).

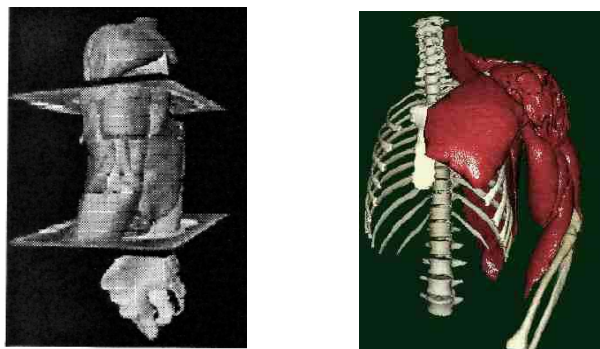


Figure 2. Virtual models sample, which was created in CHARM Project

As a first observation, for some increase contrast, the CT images are useful in the sight of osteological areas and external surfaces identification, and the anatomical cryo-sections can be specially used for virtual modeling of the soft tissues, the ones that can not be identified through other ways.

2. VIRTUAL RECONSTRUCTION METHODS

In present exists two methods for 3D reconstruction of human virtual parts, by using cross sections images obtained through various procedures (CT, MRI X-Ray). Afterwards, these methods shall be described:

- first method consists in contours identification and surface reconstruction, based on these contours, by using software of Computer Aided Design (Mechanical Desktop, CATIA, SolidWorks, Analyze, Patran), or special software developed in this purpose.
- second method, presents a different approach of volume reconstruction, based on high speed algorithms, which are create a reconstruction based on voxels (micro-volumes) of human organs, behind of contours recognition through colors and contrast differences. These virtual reconstructions were performed in the International VAKHUM Project, and this method was called Marching Cubes [7].

2.1. Development presentation of a computational model (knee articulation) by using the first method

The tridimensional procedure of geometrical reconstruction by using CT-images, contains the following steps which are represented in figure 3.

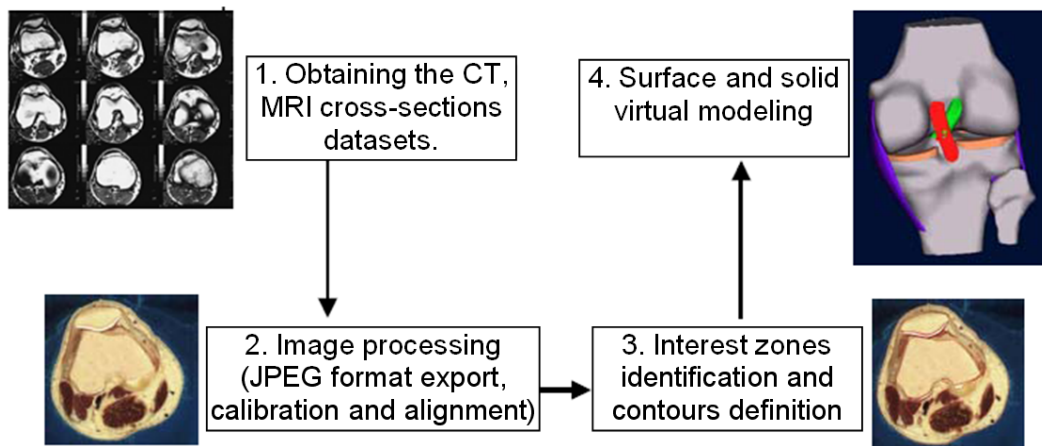


Figure 3. Reconstruction steps of a human virtual part (knee articulation) [2]

First step consists in CT-images take-off by using the CT (Computer Tomography) or MRI (Magnetic Resonance Imaging). These images (figure 4) are obtained through scans in transversal or longitudinal plans, depend of the approach method for virtual model reconstruction. The take-off images can be realized at 1 millimeter intervals in the concernment zones (human articulations, bone elements from human fingers) or at 3-5 millimeters intervals in case of bigger and longer bone elements (in the epiphyseal areas of bony elements, for example the scapula bone). These obtained images are in DICOM format, which will be translated in JPEG format, by using special software in this field (for example MRIImicro or ImageJ).

Second step is to export the graphical files in JPEG format. Thus, it is necessary to make a calibration process, which involves a dimensional scalability of images in the sight of bringing these images at 1:1 scale, to establish the image dimensions in millimeters, for example a surface resolution of 2048x1216 pixels and a pixel size of 0.33x0.33 millimeters, it results a geometrical dimension of image $A_{img} = 676 \times 401$ millimeters.

The cross – sections number is 400, and for some special areas was used cross-sections at an interval of $d_{img} = 5$ or 3 millimeters and for images obtained from articulation areas – sinovial capsule, these cross-sections were establish at 1 millimeter interval.

The cross-sections were obtained from a human male subject between talo-crural and hip articulations.

The color format was 24 bytes RGB non-interleaved with 24 bytes/pixel.

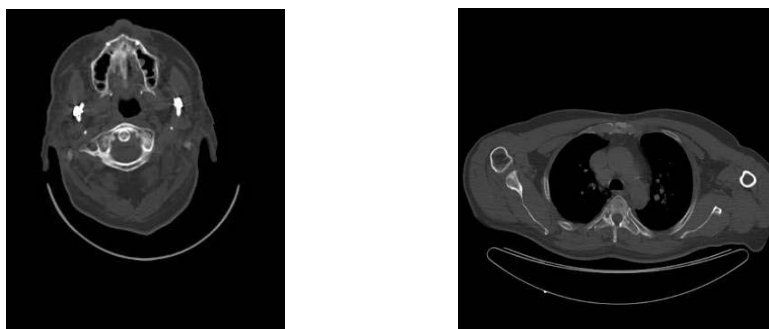


Figure 4. CT-images obtained from scans in transversal plane

Third step is the interest zone identification, this assume the recognition on each cross-section of anatomical elements represented by contours, which are involved in 3D

geometrical reconstruction. For example were recognized the suitable osteological zones of femur, tibia, patella, fibula, articular cartilage areas, lateral and lateral and cruciate ligaments. Based on the zones identification, these contours were marked through spline curves with aid of Mechanical Desktop software and saved with “.dwg” extension.

Fourth step is the virtual model elaboration, based on spline curves. These curves were imported in a special software type CAD-ProEngineer, in order to create surfaces of Aimg dimensions, and disposed on parallel plans. The distance between two plans is d_{img} .

After surface construction, these were united by calling a special command in order to generate the desirable solid of the bony virtual model (figure 5).

Finally it results a group of bones (femur, tibia, fibula and patella), and this method was applied on each bony element.

This method is too laborious, and it need a long time to obtain the bony virtual models, but the accuracy of obtained models is much higher than the other virtual models obtained in automatic mode with help of software specialized in this field. The obtained virtual models can be exported with specific extensions in the sight of virtual research with finite element method.

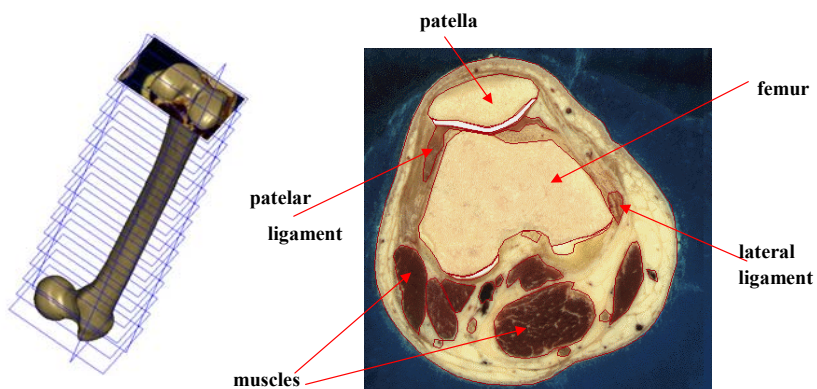


Figure 5. Femur virtual model build with aid of ProEngineering software [3]

2.2. Development presentation of a computational model by using the second method – Marching Cubes

This method was created in the International VAKHUM Project (Virtual Animation of the Kinematics of the Human for Industrial, Educational, and Research Purposes) [7], which was founded by the European Committee, Informatics Society and Technological Programming. The purpose of this project was to obtain human virtual models for cinematic and mechanical studies, in medical, educational and industrial fields.

The virtual models creation was based on CT-series.

This method consists in following steps:

- First step consists in CT-cross sections (DICOM formats) take-off by using the Computer Tomography scanner. Thus were obtained data sets, which are formed from a couple of sequences. Each sequence was made from a number of serial cross-sections in DICOM format, obtained through computer scanning in transversal plane at interval of 3 millimeters in the epiphyseal areas and in articular areas the computer scanning was performed in transversal plane at an interval of 1 millimeter (figure 6). Each DICOM format has a 512x512 pixels resolution and a pixel size: 0.84 x 0.84 millimeters. The color format was RGB – 16 bytes/pixel.
- Second step consists in image remaking for obtaining the virtual models. The base algorithm for this method was established by Lorensen in 1987 and it was applied for each

data sets in the sight of obtaining the bony virtual model, which was formed from iso-surfaces. For this method is necessary to use some special software, quite different than ones used-up in assisted design.

The algorithm consists in bony volume identification based on contrast differences from CT-series.

The algorithm principle is: if is presuming to obtain one set of CT-images of a cylindrical bodies with geometrical forms well defined, therefore he can determine the lateral area:

$$S_L = 2\pi r \cdot h \quad (1)$$

Where: - h, represents the height of cylindrical body and r, represents the base circle radius.



Figure 6. Reconstruction sample of bony virtual models developed with Marching Cubes method [7]

These images are integrated on whole cylindrical body's height at pre-established intervals.

Each CT-image has contrast variations which he limits the slash surface region of cylindrical body on the scanning is done. This region is build from voxels and each voxel has a coordinate positioning in the image plane. The principle of this special software is to identify the coordinates of each voxel and the volume reconstruction of the cylindrical body by translating these coordinates in space (figure 7).

In this way, was obtained a "cloud of points" in 3D space. With this cloud of points shall be done the volume/volumes reconstruction of cylindrical bodies (figure 8).

The principle of this type of software is to create special files. These files have special extensions (ASCII) and in those files can be found the voxels coordinates translated from each CT-image.

The cloud of points is useful to create a digitization of virtual bodies in special finite elements.

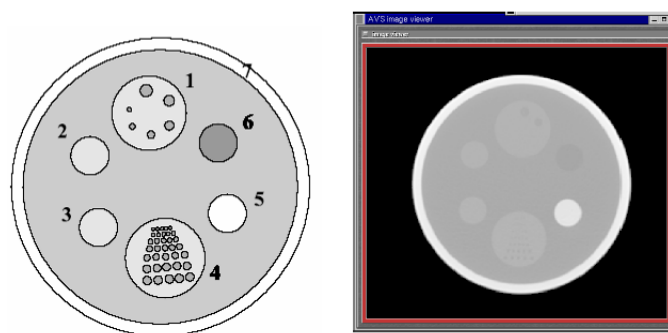


Figure 7. Reconstructive sample by using Lorensen's algorithm [7]

In figure 9 is presented an example of Marching Cubes reconstruction algorithm for a femur diaphysis.

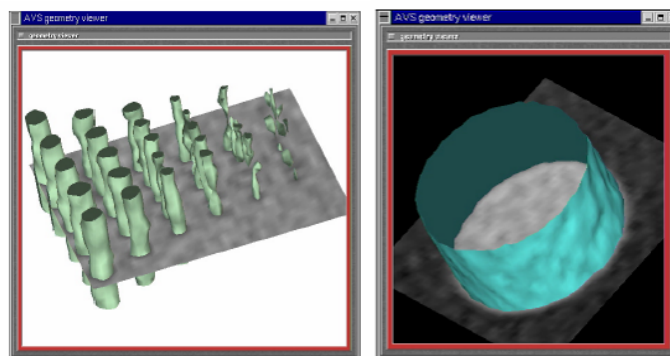


Figure 8. Virtual reconstruction of cylindrical bodies with the aid of Lorensen's algorithm [7]

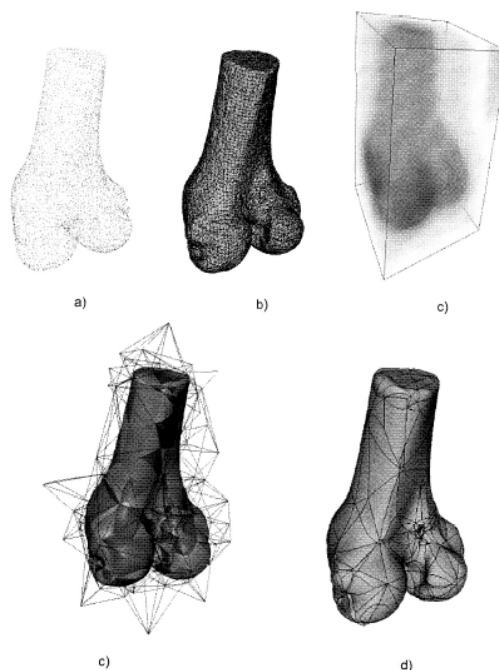


Figure 9. Reconstruction algorithm steps: a – points extracted from volume's iso-surfaces, that was rebuild from CT-series; b – construction solid through points; c – volume determination of engaged solid; d – tetrahedral support network of surfaces which estimate the solid exterior; e – final surface [3].

3. HUMAN UPPER LIMB MODELING OBTAINING THROUGH AN ALTERNATIVE BASED ON MARCHING CUBES METHOD

This alternative use the Lorensen's algorithm and some engineering software of Computer Aided Design, with relative good results.

The softs which were used in virtual models reconstruction are:

- CATIA V5 software, commercialized by Dassault Systemes Company;
- UltraEdit V 1.3 software, produced by IDM Computer Solutions ();
- ImageJ software, created by The National Institutes of Health, USA.

All of these software versions were obtained through a direct contact for acquest them in DEMO version.

The elaboration procedure of human upper limb bony virtual models is constituted from three stages:

- First stage is to process the CT-images for obtaining the points coordinates which are circumstantiate the voxels position. Thus they were obtained CT-cross sections of human left upper limb from a 17 years old male subject. First of all, was made the image scalability and special adjustments, with ImageJ software help, these images were in DICOM format. Then through contrast differences where retained only surfaces which can be serve to virtual bony model reconstruction. A retained surface was constituted from a number of voxels, each voxel was automatically identified his position in the surface plane. Through coordinates identification of each voxel in 2D – XY plane and by taking account the bony element length and the distance which the cross-sections where scanned, with the UltraEdit (figure 10) software's help, these voxels values where transposed into a file which was saved with .cgo extension (a specific extension to data reading and identification by the CATIA V5 software).

This stage is very laborious, but she can be made automatically with special software, the voxels filtering accuracy has a small error.

- Second stage is to perform the bony virtual model by using CATIA software and the necessary information for this stage were obtained with aid of UltraEdit software. Thus, by calling the CATIA V5 software, it is perform the points import, obtained from the first stage. By these imported points, it is realized a "cloud of points", which describes the bony virtual model form used in the sight of reconstruction, for example the scapula bone represented in figure 11.

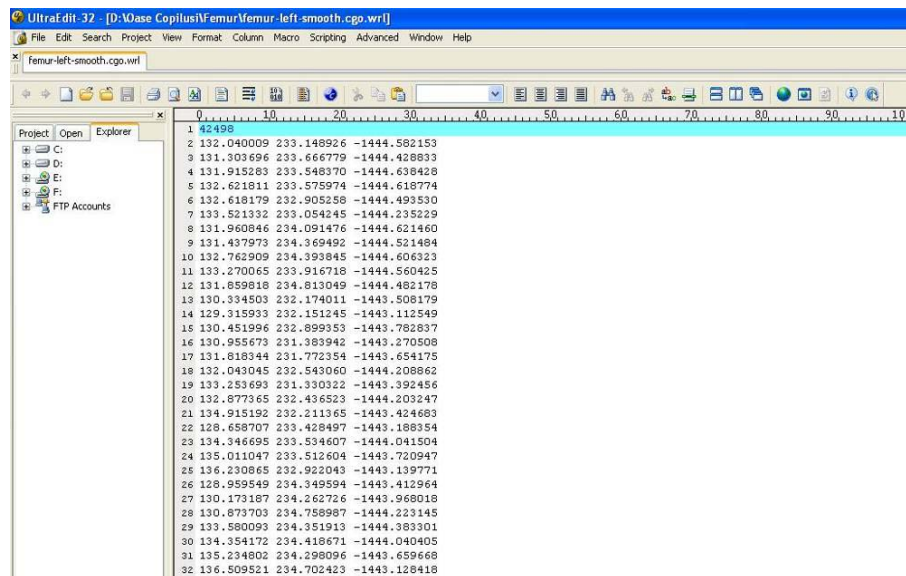


Figure 10. Window of the UltraEdit 3.3 software. The 3 columns represent the voxels values in xyz coordinates

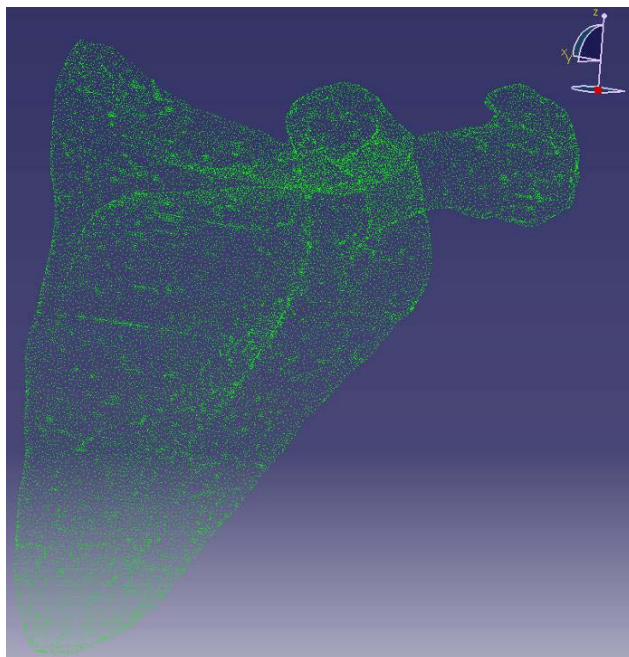


Figure 11. Scapula's cloud of points which are imported in CATIA software

- Third stage is to generate the digitized shape of bony virtual model in specific finite elements, for surface reconstruction from the next stage. This digitized shape will cover up the bony virtual model represented in figure 12.
 - Fourth stage is to generate the volume form of virtual bone, by surface generation based on digitized virtual model (figure 13).
 - The final stage is to generate the bony virtual model as a solid object (figure 14).
- In this way, there were rebuild all the virtual bony elements of human upper limb, which are represented in figure 14.

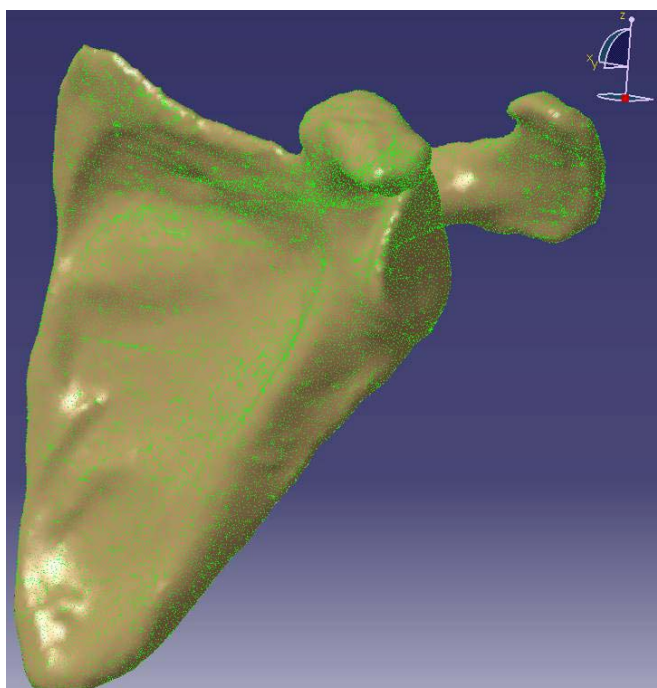


Figure 12. Scapula reconstruction by digitizing the cloud of points in specific finite elements

The modules used from CATIA V5 structure were:

- Mechanical Design/ Part Design;
- Shape Design/ Digitized Shape Editor.

As an observation, the estimated time for obtaining the bony virtual models was relatively short comparative with a classical method (12 hours), and the accuracy was much better, because it doesn't need to make an interpolation for the spline curves.

Based on this alternative there where virtually created all of the human upper limb bony elements (figure 15).

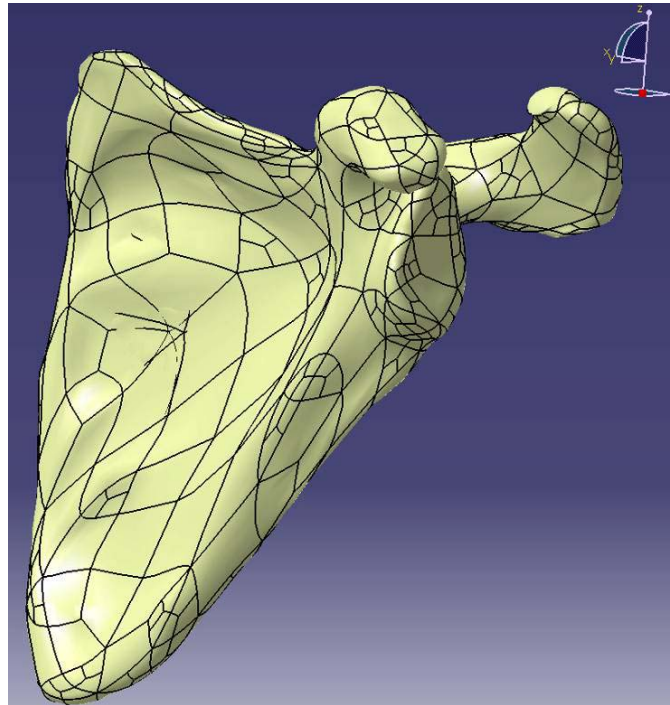


Figure 13. Volumic form generation of scapula with surfaces help

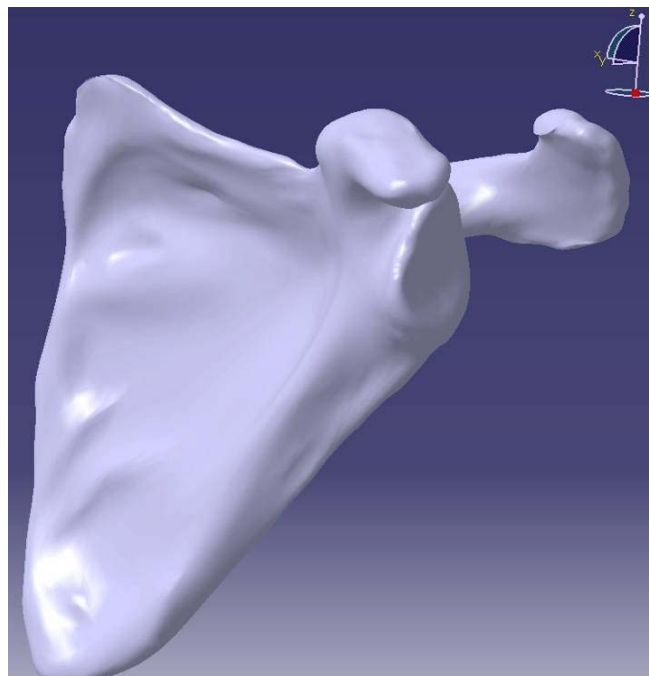


Figure 14. The scapula solid model obtained by using CATIA software



Figure 15. Virtual human upper limb reconstructive aspect

4. CONCLUSIONS

Through this paper were obtained the virtual model of the human upper limb, and the main objective for this model reconstruction is to implement virtual prosthetic models.

The obtaining procedure is relatively heavy, but, through this application, it can result the CAD software utilization which posses an engineering character, and allow the mechanical systems integration. This aspect can explain the motivation for not using the specialty software which can be realized the automated modeling of some elements or organs from the human structure based on CT-sections.

Through study of the virtual bony models obtaining procedures, was established a proper alternative for modeling the bony elements, and it can be useful in other CAD applications with a high level of complexity.

6. REFERENCES

- [1] Copilusi C., Cercetari privind sisteme mecanice aplicabile in medicina. Teza de doctorat. 2009.
- [2] Gruionu, L., Analiza geometrica si funcționala a articulației genunchiului, in vederea modelării cu elemente finite, in Referatul de doctorat. Facultatea de Ingineria si Managementul Sistemelor Tehnologice, UPB: București. 2001
- [3] Gruionu L., Modelare si simulare numerica in biomecanica Editura Universitaria 2004.
- [4] ImageJ software documentations. Accessed at: <http://rsb.info.nih.gov/ij>. 2008.
- [5] Schiemann, T., J. Nuthmann, U. Tiede, and K.H. Hohne. Segmentation of the Visible Human for High Quality Volume based Visualization. in Visualization in Biomedical Computing. Springer-Verlag. 1996.
- [6] UltraEdit documentation manual. Accessed at: <http://www.ultraedit.com>. 2008.
- [7] VAKHUM Project, Virtual Animation of the Kinematics of the Human for Industrial, Educational and Research Purposes: Technical Report on Data Collection Procedure. ISTP. 2002.