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REVERSE ENGINEERING OF THE HUMAN FIBULA BY THE ANATOMICAL FEATURES METHOD

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Abstract. *This paper describes reverse engineering (RE) of the human fibula, on the right male bone, by using the method of anatomical features (MAF) with the aim to obtain a 3D surface model. The first step in the process of reverse engineering is CT scanning and digitalization of data. CT data are obtained with the Toshiba MSCT scanner Aquillion 64 and saved in the DICOM format. They are subjected to further processing and imported in the Computer Aided Design (CAD) program as a STL file. The process continues in the CAD program with identification and determination of the Referential Geometrical Entities (RGEs) which are crucial for RE process. The RGEs are the basis for defining the axis and planes of intersection. The intersecting polygonal model of the human fibula, namely upper and lower extremities and the body with these planes, results in a set of curves used for determining points on the given planes. Through these points the splines are pulled, and with loft function surface models of extremities and the body of fibula is built. Joining and merging of these models leads to 3D shape model of fibula. The model accuracy is confirmed by conducting distance and deviation analysis. The model is suitable for rapid prototyping, reconstruction of the missing parts of fibula, orthopedic training and simulation.*

Key Words: *Reverse Engineering, Geometrical Model Human Fibula, 3D Surface Model*

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1. INTRODUCTION

Production of geometrical models of the existing objects is necessary in many industrial areas. Unlike the traditional forward engineering (also called "direct engineering"), in which products are manufactured on the basis of the previously prepared technical documentation, RE can provide a computer-based reproduction of an object or a product without design [1, 2].

The application of RE in the field of medicine and dentistry is resulting in biomedical objects or implants with adequate properties for the biomedical needs. The examples are: different types of implants (personalized, dental, artificial hip joints), external orthopedic prostheses, bony tissue scaffolds, [3]. Another field of application of RE in medicine includes visualization, diagnostic (diagnosis), surgery planning, surgical templates, production of the artificial organs, training and teaching [4, 5].

The objective of this paper is to present a RE process of the human fibula, based on the anatomical features method (MAF), described in [5]. The activities involved in our modelling approach are:

1) CT scanning,
2) Polygonal model building and healing,
3) Determination of RGEs,
4) Creation of a 3D surface model of fibula extremities and body,
5) 3D surface model assembling, and,
6) Verification of obtained model.

These activities are presented at Fig. 1. This process is the result of the improvement of the earlier process presented in [6].

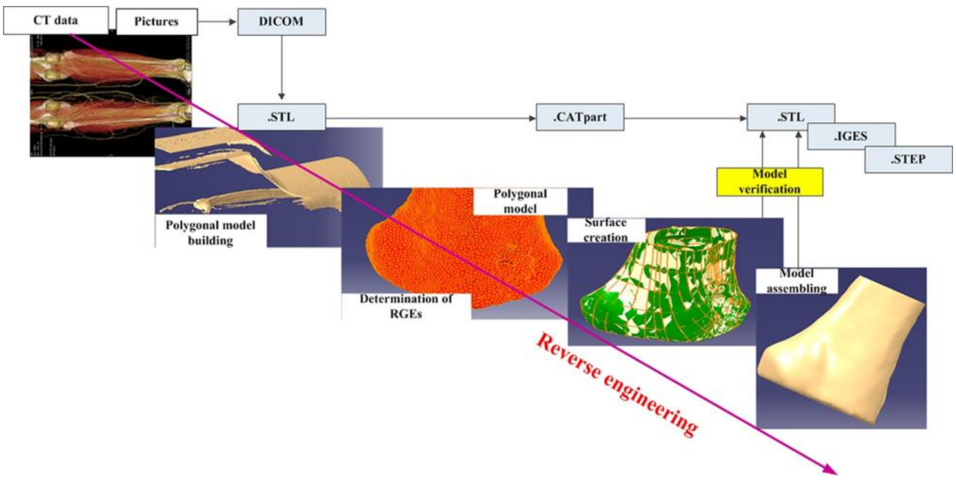

Fig. 1 Activities in RE of the human fibula

2. MATERIAL AND METHODS

2.1. CT scanning

RE process starts with the acquisition of three dimensional shape data of the human body structures. The common systems used in medical imaging to obtain anatomical information are: X-ray, Computer Tomography (CT), Magnetic Resonance Imaging (MRI), Ultrasound System (US), Mammography, Radiography (Plain X-Ray), Laser Digitizer and digital fluoroscopy, as discussed elsewhere [4, 7, 8, 9, 10, 11, 12].

In this case we present RE of a 61-year-old healthy male fibula. Input data are a series of traverse CT images, obtained on the Toshiba MSCT scanner Aquillion 64 (120kV, 150 mAs), with the following parameters: thickness 1 mm, in-plane resolution 0.781 × 0.781 (pixel size), acquisition matrix 512 × 512; field of view (FOV) 400 × 400 mm. All CT data are saved in the DICOM format.

2.2. Polygonal model building and healing

The initial 3D fibula point cloud is established via masks creating, region growing, calculation, and remeshing of 3D objects [13]. This model is imported in RE software in the form of STL (STereoLitography) format and subjected to specific operations for eliminating the model errors (isolated triangles, nonmanifold vertices or edges, etc.). After removing all unnecessary entities, polygonal model was created. Operations such as healing, optimization and mesh smoothing are conducted with the aim of improving the polygonal model. This model is suitable for determination of RGEs in the CAD program.

2.3. Determination of RGEs

3D shape model of the human fibula is created by using RGEs described in [14, 15] as the basis for definition of the bone 3D geometry (curves, polygons, surfaces). RGEs represent the geometrical entities (points, lines, axes and planes) created in accordance to the anatomical landmarks, [5].

Fibula is a paired long bone and, and like all long bones, has two extremities (upper and lower) and the body. It is placed on the lateral side of the leg. Its upper extremity is articulated with the tibia, and its lower extremity with malleolar surface on the lateral side of the talus.

For the purpose of our research, at the fibula we have defined the following RGEs described in [6]:

1) at the upper extremity (lat. epiphysis proximalis s. extremitas proximalis):
- **ACF** (lat.apex capitis fibulae) – apex of the fibular head,
- **FACF** (lat.facies articularis capitis fibulae) – articular surface for the articulation with the lateral condyle of tibia;

2) at the lower extremity (lat.epiphysis distalis s. extremitas distalis):
- **FAML** (lat.facies articularis malleoli lateralis) – articular surface for the articulation with the talar lateral malleolar surface;
- **AML** (lat.apex malleoli lateralis[1]) – top of the lateral malleolus, as the most distal point on the lateral malleolus.

[1] It is not official term from Terminologia anatomica.

On the basis of the previously defined RGEs we have constructed:

- the mechanical axis of the fibula - which connects the centers on the articular surfaces of the upper (FACF) and the lower extremity (FAML) of the fibula, and,
- A-P (anterior-posterior) plane - defined by mechanical axis and ACF.

2.4. Creating 3D surface model of the human fibula

The polygonal model of upper extremity of the fibula is intersected with the planes obtained by rotation of the plane passing through the mechanical axis of the bone and ACF. The mechanical axis is taken for the axis of rotation, while the rotation angles are variable. In these intersections a set of curves is obtained and points on them are defined. Through these points we have constructed the splines. Using the loft function we have got a surface model of the upper extremity, as shown at Fig. 2.

The same methodology is used for generating a model of lower extremity of the fibula, but the polygonal model of the lower extremity is intersected with the plane which passes through mechanical axis and AML. For the rotation axis, the axis that connects ACF and AML is taken, as the most distant points at the fibula. The lower extremity model is presented at Fig. 3.

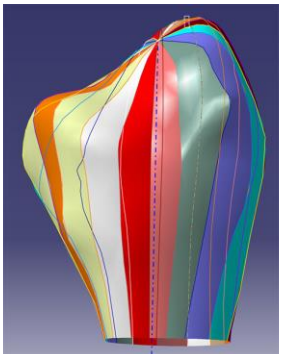

Fig. 2 Surface model of the upper extremity (with splines)

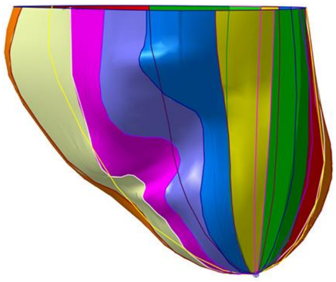

Fig. 3 Surface model of the lower extremity (with splines)

For the body of fibula we have used 30 cross-sections perpendicular to the mechanical axis. We have obtained 30 curves of intersections and defined points on them. These points are used for constructing the splines. By loft function we have obtained surface model of the fibular body, presented at Fig. 4.

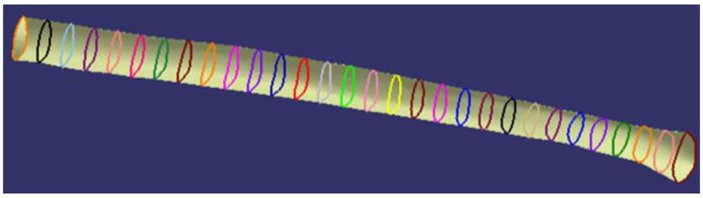

Fig. 4 Surface model of the fibular body

3. RESULTS AND DISCUSSION

All surface models are joined and merged (merging distance of 0.001mm) and 3D surface model of the right fibula is obtained. This model is shown at Fig. 5.

Fig. 5 3D surface model of the fibula

We have created a polygonal model at 3D surface model with the aim of analyzing the differences between the RE model and the initial STL polygonal model. The full distance analysis is computed in 3D, with discretization of 50, based on the chosen color range, and shown in selected color range at Fig. 6. The obtained statistical results indicate that the most of the area is in the range of 0 – 0.083 mm, and we consider this result as very good.

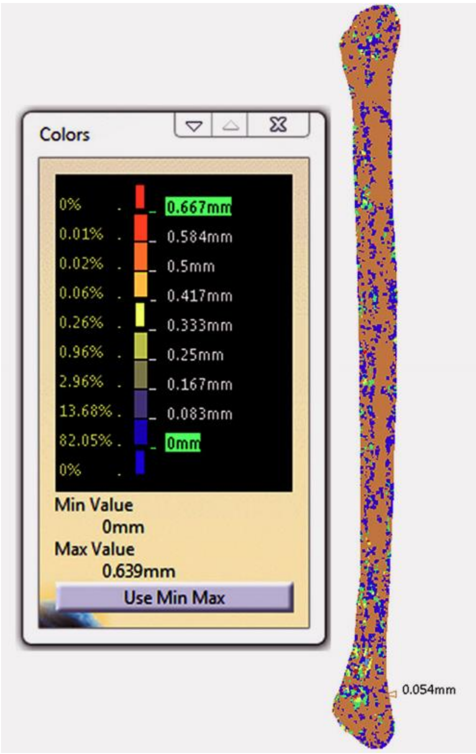

Fig. 6 Distance analysis between final initial polygonal model

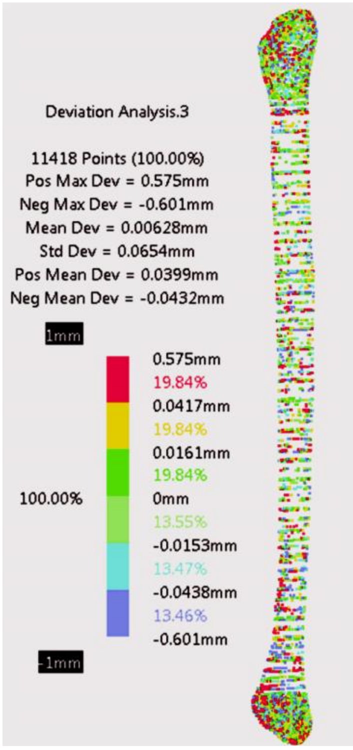

Fig. 7 Deviation analysis between and initial and final point of cloud

For the purpose of deviation analysis we have exported our final surface model as a STL file. This model is suitable for rapid prototyping. The mean deviation is 0.00628 mm, standard deviation is 0.0654 mm. The range of mean deviation values is from −0.0432 mm to 0.0399 mm, while the range of maximum deviation is from −0.601 mm till 0.575 mm, which is another proof that our surface model is satisfactory. These results are presented at Fig. 7.

4. CONCLUSION

Judging by the results of verification which is conducted through distance and deviation analysis, we can conclude that the presented approach provides a 3D surface model of the human fibula with high accuracy and precision. As expected, the MAF has proved to be suitable for reverse engineering of the human fibula. The resulting model is convenient for building of the solid model as well as for rapid prototyping of the bone.

RGEs which are defined on the human fibula are important for development of the predictive parametric model, which represents the next step in our further research.

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REVERZNI INŽENJERING LJUDSKE FIBULE METODOM ANATOMSKIH KARAKTERSTIKA

U radu je prikazan reverzni inženjering (RI) ljudske fibule, na primeru desne muške fibule, pomoću metode anatomskih karakteristika u cilju dobijanja 3D površinskog modela. Skeniranje kompjuterskom tomografijom i digitalizacija podataka predstavljaju prvi korak u procesu RI. Za dobijanje podataka kompjuterskom tomografijom korišćen je Toshiba MSCT scanner Aquillion 64, a podaci su sačuvani u DICOM formatu. Podaci su obrađeni i uveženi u CAD program u obliku STL datoteke. Proces se nastavlja identifikacijom i određivanjem Referentnih Geometrijskih Entiteta (RGE) u CAD programu. RGE predstavljaju osnovu za definisanje osa i ravni preseka. Presecanje gornjeg i donjeg okrajka, kao i tela poligonalnog modela fibule ovim ravnima ima za rezultat skupove krivih, na kojima su definisane tačke. Kroz ove tačke provučene su prostorne krive, te su pomoću loft funkcije dobijeni površinski modeli okrajaka i tela fibule. Spajanjem i stapanjem ovih modela dobijen je 3D površinski model fibule. Tačnost modela je potvrđena analizama rastojanja i devijacija. Model je podesan za brzu izradu prototipova, kreiranje delova fibula koji nedostaju, obuku i simulaciju u ortopediji.

Ključne reči: *reverzni inženjering, RGE, fibula, 3D površinski model*