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SIMPLIFIED CAD MODEL OF HUMAN METACARPAL FOR IMPLANTATION

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Abstract: Due to the increasing availability of additive manufacturing technologies, the need for individualized medical implants also increases. Among the development steps of this type of implant, image processing and CAD modeling have a huge influence on the usability of implants. The possibilities of CAD modeling using image processing methods are analyzed in our present work.

Keywords: *CT scan, stl, CAD model, bones, Finite Element Analysis*

1. INTRODUCTION

Due to the extremely fast development and cost reduction of additive manufacturing technologies, the so-called 3D printing methods generally used in the engineering industry for the production of prototypes are increasingly becoming available in all areas of life [1]. Thus, the need for utilization in medical science has been also emerged [2].

Bone replacement may be required for a number of surgical interventions due to their serious defect. Nowadays, typically, series-made implants are used, which are only made in a certain series of sizes. Optionally, the patient or doctor selects and implants with the most appropriate size.

However, in extreme cases due to the patient's anatomy or facial features, these series-manufactured implants are difficult to use or ineffective at all. Here comes the need to deviate from serial production and create unique implants.

These unique implants are more representative of the original bone geometries, and the design can optionally be modified to make the final implant appropriate in all respects [3].

Traditional implants are mainly made of biocompatible corrosion-resistant steel or titanium alloys. The mechanical properties of such bone substitutes can largely differ from human bone due to the material and geometric demands.

With the time, this results in damage of the bones connected to the implant, and lead to the loosening of the implant and finally it should be replaced.

From this it can be seen that the individual implants are not only necessary due to the nature of the defects, the additive manufacturing technologies also offer much more favorable mechanical property.

Thus, the implants of which material characteristics are close to the original bone can be manufactured. [4], [5] Therefore, the 3D model of these implants should be designed to be suitable for finite element analysis after modeling and based on the simulation result, the model can be modified, if there is too much different in the mechanical behavior compared to the original bone [6].

In most cases, we can only estimate the material properties of the original bone as they depend on age, health and type of bone. [7], [8]

2. Process

The design and manufacture of individual implants consists of several stages. This article deals with the creation and then the simplification of the 3D model of the reproductive bone, namely the implant design.

3. 3D MODELING

3.1. CT scan of the defect

The input information for 3D modeling is given in our case by a CT (Computed Tomography) scan.

The subject of the study is a high osteoporotic human metacarpale removed from one of the hands of an elderly lady. We can use DICOM files made by CT equipment of the examined bone to construct a 3-dimensional model.



Figure 1. Location of human metacarpale in the hand

These files can be displayed as grayscale layers, where each pixel stores the weakening value associated with a particular segment of the scanned object. These files

contain other data that refer to the patient, the distance of the layers, and the size of the objects on the pictures.

Most tissue types represent different weakening range. [9] Thus, after converting DICOM files to a picture file format, using image processing methods allow us to separate the examined tissue – in this case the bone – from its environment and to create a model.

3.2. Image processing in MATLAB

The image files from the CT recordings were processed using MATLAB, which is one of the most versatile software in engineering field. [10]

MATLAB is able to automatically load and process the image layers in accordance with code without any action. It is possible to run the program automatically because the images are derived from one record and their sizes are the same in pixels and the distance of each pixel – in the specified directions – is the same.

Their names have been also sorted and the distance between the layers is the same. This also means that in almost all cases, if you want to start processing a new CT record, the input parameters listed above have to be given in the program.

The program reads and processes the images file one by one in the right order. After reading, each image is stored as a 2-dimensional matrix, where each element of the matrix corresponds to one pixel. From here, the processing operations use these matrices.

The first step in processing is masking: removing parts with greater intensity around the bone. For this, a polygon is defined around the bone, which forms a mask and the intensity of the pixels outside the mask is reduced.

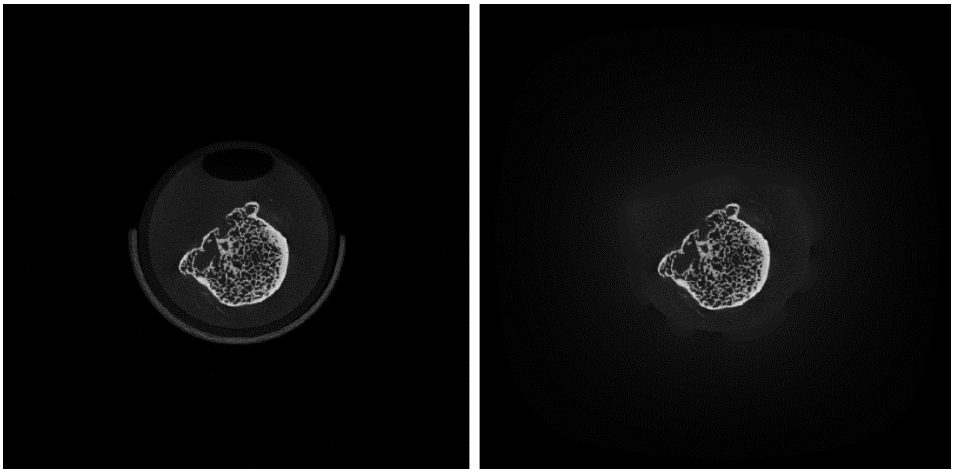


Figure 2. Original image on the left, after masking on the right

In the next step, the image was binarized, whereby the 2-dimensional matrix will contain only ones and zeroes, where the threshold is set according to the particular intensity limit for each pixel.

Many small spots can be seen on the left image of *Figure 3* right after binarization. These tiny spots are removed (right image) so the 3-dimensional model does not have any small floating particles in the bone model.



Figure 3. The image right after binarization (left), the image after elimination the small object (right)

Although the best approach of the original geometry is right image of *Figure 3*, the created model from these images could be difficult to produce even with the best 3D printers, and the finite-element simulations of this model would not be possible at all. [8], [11]

Thus, its strength properties could not be predetermined. Therefore, the next step is to simplify the inner part by filling the so-called holes, while retaining the outer geometry. The result of the 'filling' is shown on the left side of *Figure 4.*

Finally, the outer contour of the bone was modified to be smoother, the circumference of the bone slices is more uniform.



Figure 4. Image after the holes are filled (left), with the 'smoothed' circumference (right)

3.3. Preparation of surface model in MATLAB

The result of smoothing process can be seen on the right picture in *Figure 4*. The picture can be displayed as an image, but this is still a binary two-dimensional matrix.

The two-dimensional matrices resulting from the processing of all images are stacked together to form a three-dimensional matrix. In addition to the three-dimensional matrices, there are also three special vectors that define the normal distance between the layers of the matrix in the x, y, z directions from an arbitrarily selected base point.

After this, everything is done to make the surface model from bone. Another MATLAB function can generate a surface model from the loaded data as an output, which is an STL file.

The generated surface model is shown on the left picture of *Figure 5*.

4. MODEL TRANSFORMATION

4.1. Improvements in the model

The created model may still contain many errors in this form. This can be:

- slight angularity of the layered structure,
- floating objects separated from the bone, which have not been eliminated during image processing because of their larger size,
- protrusions (that are not belong to the original bone) resulting from the errors of image processing,
- surface openness,
- inclusions inside the bone.

These failures will be corrected.

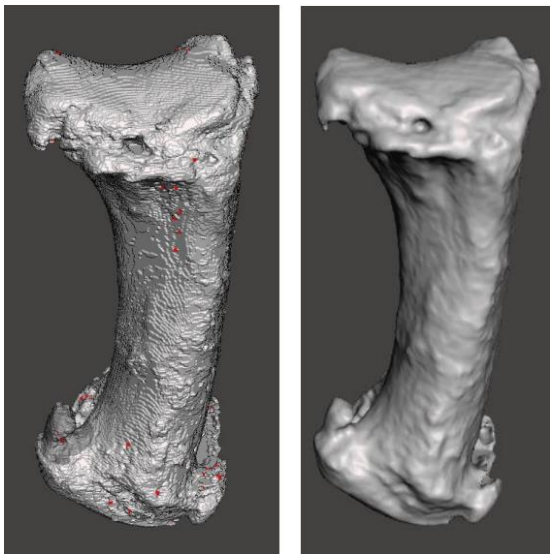


Figure 5. Original (left) and improved surface model (right)

4.2. Construction of solid model

In general, surface models are not suitable for finite element simulations, so they have to be converted to a solid model. The generated model is a solid model with triangular surface mesh corresponding to the mesh of the surface model.

This model could already be suitable for finite element modeling, but since the triangles that covers the surface are very small, the element size would be also very small in the finite element software.

Further, this would cause many calculations for the software, which requires a lot of time and computer resources. To avoid this, we simplify the model.

4.3. Simplification of the model

It is possible to simplify the model by cutting it at the appropriate spaces and replace the intersections with NURBS curve. Through the created curves, we perform a so-called swept extrusion. Thus, we re-create a part of the model that has no triangular surface [3].

However, the swept extrusion is not suitable to fork off in two or more directions. To eliminate this, the part of the model is simplified, and where this occurs the small surface triangles are merged and redefined and finally the swept extrusion method can be re-applied on the forks.

It is easier to perform a finite element analysis on this models with their much simpler surface geometry.

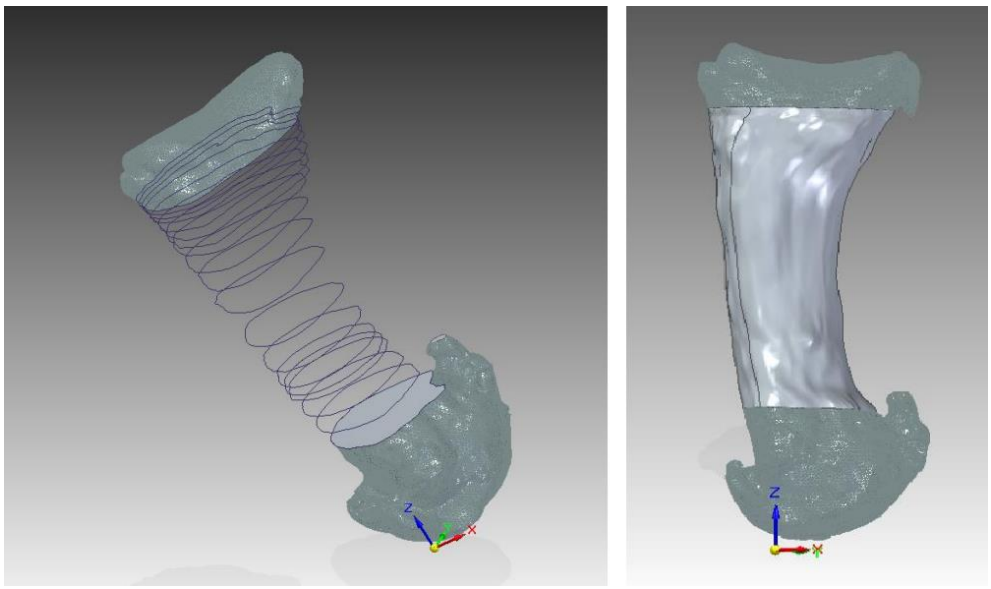


Figure 6. The curves drawn one by one (left), the rebuilt model by the curves (right)

The geometry obtained after the simplification is virtually unchanged from the original geometry after the manufacturing, as it is shown in *Figure 7*. This means that the handling of the simplified geometry has improved significantly, while the loss of information during the simplifications (formal deviation from the original geometry) is almost neglible.



Figure 7. Original and simplified geometry after printing

5. SUMMARY

At an early stage in the design of a personalized bone replacement implant, image processing allows us to freely adjust the geometry before modeling, while retaining the outer contour. The reconstruction of solid model with NURBS curves can be a good solution to simplify it.

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