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3D Mesh Model Generation from CT and MRI data

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Abstract—With the image processing techniques, nowadays it is possible to obtain 3D X-ray tomography which is used in medical diagnosis. Such systems require a reconstruction of an object - a human body in this case- in 3D from a set of its 2D projections. The reconstruction volume is usually discretized on a regular grid of isotropic voxels which implies an increase in their number to achieve good spatial resolution. In this work, we propose a process to obtain 3D mesh generation method allowing to discretize the 3D reconstruction space in a relevant way directly from the structural information contained in the projection data. The idea is to obtain a representation adapted to the studied object. here we have recourse to a tetrahedral mesh matching the structure of the object: the mesh density adapts according to the interfaces and homogeneous regions. To build such a mesh, the first step of the method consists in detecting the edges in the 2D projection data. The structural information thus obtained is then merged in the reconstruction space in order to construct a point cloud sampling the 3D interfaces of the imaged object.

Index Terms—visualisation, image processing, tomography reconstruction, 3D mesh generation

I. INTRODUCTION

Human anatomy is one of the most crucial subjects at medical schools. One must learn the body to identify what is wrong with it. Medical students are obliged to memorize not only the way how an internal organ works but also the Latin titles of certain positions of internal organs' tissues. They learn these titles by studying either on heavy and expensive books' illustrations, on a cadaver, or 3D printed models. Students can't access a cadaver without the supervision of their professor. Therefore they can only inspect one during class. 3D printed models are hard to carry around and occupy some space. So they are not practical to use and not preferable. Considering all this, the students' first choice of study resource is books. They are easier to use than other resources and have detailed illustrations of every internal organ. But their problem is that they are expensive and heavy. They also include only drawings but not actual body images. Even if they do, they can only include 2D pictures [1]–[4].

This study aims to solve the problems of the anatomy books. Firstly the details on anatomy must be stored on a computer. So students can access the information they need without carrying heavy books. Computers also give us the ability to use various 3D visualization techniques. Thanks to that, internal

organs can be inspected in 3D via computer. Also, with the CT (Computed Tomography) and MRI (Magnetic resonance Imaging) methods, images of the interior of the human body can be acquired. Therefore students can study images of real internal organs and not just drawings, and this project aim that.

The study is an application that uses 2D segmentation images of an internal organ to create a 3D model of said organ and display it with Latin names of points of tissues. The first step of the project is to find a way to create a 3D model of an internal organ on demand. For an accurate 3D model that resembles a real organ, CT scans and MRI images are used. These 2D images display series of segmentation of an organ.

The second step of the study is to find a way to display the titles of points of the organ's tissues. The application has to identify these points. To achieve that, an artificial intelligence model such as CNN (Convolutional Neural Network) approach is planned.

The third step of the study is creating an environment to control the model of the organ. This environment must have several tools like cutting or painting the model. The application 3D Slicer has such an environment. Besides that, an open-source game engine is an alternative solution that can be used to develop such an environment. The application 3D Slicer can accomplish the first and the third step. Therefore the study is planned as an extension of 3D Slicer.

The rest of the paper is divided as follows. Research domain is presented in Section II. In Section III, related works are presented. Sections IV and V introduce the adaptation of the data to create 3D mesh and creation of 3D tomographic mesh. Besides the implementations of each steps are introduced in these sections. Finally, conclusion and discussion are given in Section VI.

II. PROCESSING DATA

With the high improvement in computer vision, pattern recognition, and image processing techniques, computer based healthcare applications have become a hot topic in research domain. Such systems gained a crucial role by clinical data acquisition and post-processing. Health research is increasingly oriented towards the use of numerical simulations. It is therefore now necessary to have reliable mathematical and numerical models of the human body [5], [6].

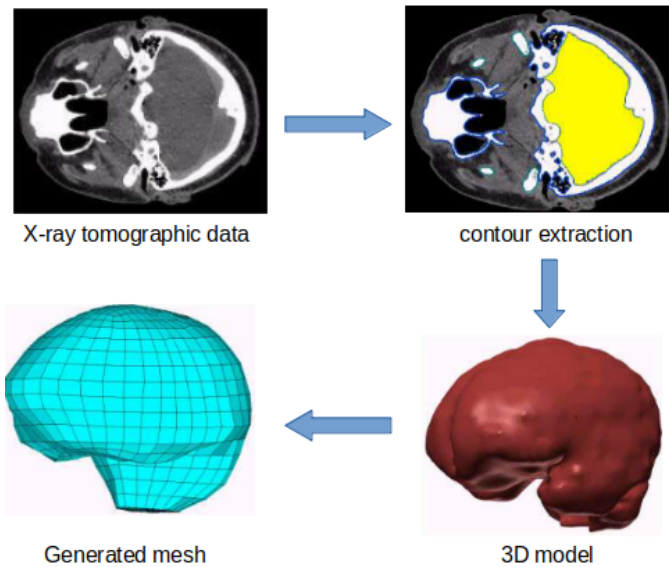


Fig. 1: Steps for Generating mesh model from raw X-ray tomographic data

This ability to be able to observe the interior of a body or an object through its projections, or x-rays, very quickly aroused interest in the body medical. The reconstruction of the three-dimensional object from these, however, had to await the advent of computer science, alone to even provide a sufficiently powerful tool to perform the associated calculations. Mathematically speaking, this problem of reconstructing a signal of dimension N from observations of dimension $N-1$ corresponds to a problem of the inverse type: tomography [7], [8].

Nowadays, CT (Computed Tomography) imaging is a very popular method. The images obtained are representative of the attenuation of an X-ray beam passing through the various tissues of the human body. This attenuation is proportional to the thickness and density of the tissues passed through. A black section is obtained when no attenuation of the beam is observed. A white section testifies to a fabric that is difficult to cross by the rays. This happens for high density tissue or tissue containing large atomic number atoms.

In the framework of tomographic reconstruction by X-rays, we try to calculate, at each point of the space of interest to us, the density of the material crossed by the radiation. The resulting cartography corresponds theoretically to the interior of the observed object. The first solution to this problem was provided by the mathematician Johann Radon in 1917 by means of an eponymous transform operator. The first applications of this method, however, had to wait until the 1970s and the founding works of Hounsfield and Cormack. Since this decade, the field of X-ray tomography has been in constant evolution: improvement of acquisition systems, introduction of new reconstruction methods or even diversification of application frameworks. Nowadays, mainly due to its strength as a non-invasive / destructive observation method,

it is one of the diagnostic tools most used by the medical body and has become a staple of NDT (Nondestructive testing) processes.

On the other side, Magnetic Resonance Imaging (MRI) is also a widely used method. The image obtained is the reflection of the variation in the orientation of the hydrogen atoms. The patient is subjected to a constant magnetic field which directs the spins of all the protons (hydrogen atoms) in the same direction. A second antenna intermittently generates another magnetic field which allows protons to move away from their initial direction. At each pause of this second emission, the protons, by resuming their initial position, emit an energy that is measured. This energy can be broken down along axes parallel or perpendicular to the magnetic field, and therefore generates two images [9].

These are functional images of the human body and not a true anatomical representation of it. The organs are there quite easily visually differentiable. However, MRI images are generally of lower resolution than scanner images. Functionally, the big advantage of this process is that it is non-invasive. Despite its definite advantages in terms of the possible distinction of contours, we have hardly worked on this type of imagery. Indeed our work was carried out using frozen anatomy subjects. However, MRI tends to heat the tissues, causing rapid thawing.

III. RELATED WORKS

Radio-frequency electromagnetic waves or microwaves are used in many applications, as well in the medical field, industrial, or in our daily life. Their use is increasing in our society, raising questions about their effects on health. The effects of electromagnetic fields on humans, particularly at the thermal level, remain unknown. Electromagnetic field and temperature measurements are found to be difficult in the human body. On the one hand, direct measurements, by introducing probes into the human body, are impossible with sufficient spatial resolution, or even to reach areas that are difficult to access. In addition, the probes disturb the temperature distribution. On the other hand, non-intrusive measuring devices do not have sufficient resolution for the time being. Whether in order to improve treatments based on exposure to these waves, as in the case of therapeutic hyperthermia in oncology, or to allow us to assess the effects induced in the human body of electromagnetic fields, the scientific community is turning to simulation and model calculation. These models are based on the calculation of the power absorbed and heat transfer phenomena in the human body. When simulating electromagnetic and thermal phenomena, it is necessary to have reliable models of the human body. Thus, one of the essential criteria of digital modeling resides in the quality of the geometric modeling. We briefly enumerate, in the following paragraph, the various processes allowing to obtain a geometrical representation. The geometric reconstruction process can be broken down into three stages:

- a first step is the acquisition of geometric data on the human body and their analysis;

- a second step is the 2D / 3D segmentation of the various anatomical elements that one wishes to model;
- a third step discretizes the field of study for the numerical simulations.

The three-dimensional reconstruction methods and the surface mesh methods are closely related. Indeed the representation in triangles of a surface (general form of a three-dimensional reconstruction) can be considered as a mesh, even if the quality of this one is not necessarily adapted to simulations by finite element. A structured mesh is a mesh whose connectivity is of finite difference type (the mesh is then called grid). Connectivity is of type (i, j, k) i.e. for a point (i, j, k) its neighbor on the left is the point $(i-1, j, k)$, its neighbor on the right is the point $(i + 1, j, k)$, This kind of mesh can hardly be applied to domains with complex geometries. An unstructured mesh is any connectivity mesh. It is an effective alternative to structured meshes when dealing with complex domains. A mixed mesh is a mesh comprising elements of different geometrical type (mixing for example triangles and quadrangles). A hybrid mesh is a mesh comprising elements of different degree (mixing for example triangles and tetrahedra). A uniform variety mesh, or manifold mesh, is a surface or boundary mesh such that its internal edges are common to exactly two elements (except for boundary edges). A control space is a tool used to govern a mesh construction or optimization process. Ideally this is a function defined at any point in space which specifies the size and the directional properties to be respected by the elements of the mesh. Usually this function is only known discretely [10].

IV. CREATION OF THE 3D MESH ADAPTED TO THE OBJECT

By definition, a mesh is a discretization of the 2D or 3D Euclidean space by means of geometric-type basis functions. Usually, we use triangular, tetrahedral or quadrangular meshes. To be able to best describe certain curved shapes, it is possible to go up in order of complexity and use Bezier meshes similar to the previous shapes but for which each of the faces is replaced by a curved patch of spline type [11], [12].

By using a uniquely shaped mesh to discretize the space, we obtain a regular representation that may be suitable for certain applications - space limited to a simple object for example. However, since the space of interest is composed of several different domains, whether it has complex boundaries or contains singularities, it is no longer reasonable to use a regular representation. To answer this problem, it is common to use irregular meshes allowing to vary the shapes - or even the types - of meshes used in order to better describe the set of the space of interest. The so-called adapted meshes belong to this category and aim to obtain a good discretization of space for the most reasonable possible number of cells [13], [14].

Consider the general case of a space comprising a set of domains of various sizes and shape factors. A mesh making it possible to obtain an adapted discretization of the space will present, at the interfaces between domains, a high density of

meshes of small dimensions and with the anisotropy in adequacy with them. . Conversely, within each domain, the density should be very low and the meshes large - the anisotropy remaining in agreement with the shape of the domain under consideration. In our context, we can consider the volume of reconstruction as the global space and the set of imaged objects as its different domains.

Thus, in order to obtain an adapted discretization it is necessary to arrive at a good localization of the interfaces separating the different domains of space. In many application contexts - finite element simulation for example - these interfaces are known, the objects making up the simulation scenario often being written in a surface way - CAD files. In tomographic reconstruction, this knowledge is either unavailable - medical imaging - or difficult to implement. Indeed, for industrial control applications, knowledge of the CAD of the part could provide a strong a priori but would require a realignment of the 3D mesh according to the acquisition geometry to be in coherence during the step reconstruction. This adjustment would not be trivial and the method not very versatile. Two possibilities are therefore offered to obtain a mesh adapted to the objects in reconstruction: iteratively improve a regular discretization or manage to find the useful interfaces from the acquired projections.

V. IMPLEMENTATION AND RECONSTRUCTION OF 3D MESH MODELS

Due to the use of a non-regular discretization, it is necessary to adapt the projection / re-projection operators in order to be able to implement the usual iterative schemes . First, we consider the possibility offered by the mesh of storing the reconstructed attenuation coefficient in a nodal or cellular manner. The second section presents the implementation of a Siddon-type projector for these two types of information encoding. We conclude by comparing the different types of headlamps and their respective performances.

A. 3D Mesh Generation via 3D Slicer

In this study, for the first choice, a free and open source software package for image analysis and scientific visualization is used. 3D Slicer is a free open source software (BSD-style license) that is a flexible, modular platform for image analysis and visualization. 3D Slicer is extended to enable development of both interactive and batch processing tools for a variety of applications. 3D Slicer provides image registration, processing of DTI (diffusion tractography), an interface to external devices for image guidance support, and GPU-enabled volume rendering, among other capabilities. 3D Slicer has a modular organization that allows the addition of new functionality and provides a number of generic features not available in competing tools. The interactive visualization capabilities of 3D Slicer include the ability to display arbitrarily oriented image slices, build surface models from image labels, and hardware accelerated volume rendering. 3D Slicer also supports a rich set of annotation features (fidu-

cial and measurement widgets, customized color maps) [15]–[17].

The data used in this part is the sample human body provided from the platform. A real human data will be used once an agreement is signed with a hospital for a research collaboration. Figure 2 illustrates the generated 3D mesh models by using 3DSlicer tool.

B. 3D Mesh Generation via Matlab

In the second step, Iso2Mesh tool is used. Iso2Mesh is a MATLAB/Octave-based mesh generation toolbox, designed for easy creation of high quality surface and tetrahedral meshes from 3D volumetric images. The image stack was imported into Matlab as a 3D image array. Iso2Mesh was used to convert the 3D image array into an all-tetrahedron mesh. Simpleware meshes were generated using its proprietary mesh algorithm and graphical user interface [18]–[21]. Figure 3 presents the generated 3D mesh models by using Iso2Mesh tool of Matlab.

C. 3D Mesh Generation via Dicom2Mesh

Our third option was using a specialized command tool such as Dicom2Mesh. Dicom2Mesh is a handy command line tool, which enables the user to automatically create a 3D mesh from a set of 2D DICOM images, a common image format used in medicine. For instance, in this study only CT images are performed on this tool. In our future steps, MRI images will be performed as well.

The 3D surface mesh is computed by the marching cubes algorithm. As an input, this algorithm requires a threshold which indicates what range of voxel values should be considered. This threshold is also known as iso-value. In CT scans, the iso-value depends on the tissue (density). In Dicom2Mesh you can specify the iso-value with the parameter -t X, where X is an integer. Since the mesh of a medical DICOM images commonly exceed 1 GB of data, data reduction has a critical role. Besides, acquired medical images contain often heavy noise. This is visible in the extracted 3D surface. Smoothing the mesh leads often to a better result. Moreover, the resulting 3D mesh contains often parts which are not of interest, such as for example the screws of the table on which a CT scan of a patient was acquired. On Dicom2Mesh tool, we remove objects below a certain size [22], [23]. Figure 4 illustrates the generated 3D mesh models obtained by Dicom2Mesh tool.

VI. CONCLUSION

In this paper, we mention one of the crucial subjects at medical schools: learning and identifying human body. In such schools, it is mandatory to memorize only the way how an internal organ works but also the Latin titles of certain positions of internal organs' tissues. Existing solutions such as 3D printed human organ models are far away from practical. To facilitate this study, we propose a detailed digital inspection of human anatomy and 3D visualization techniques using CT (Computed Tomography) and MRI (Magnetic resonance Imaging) methods.

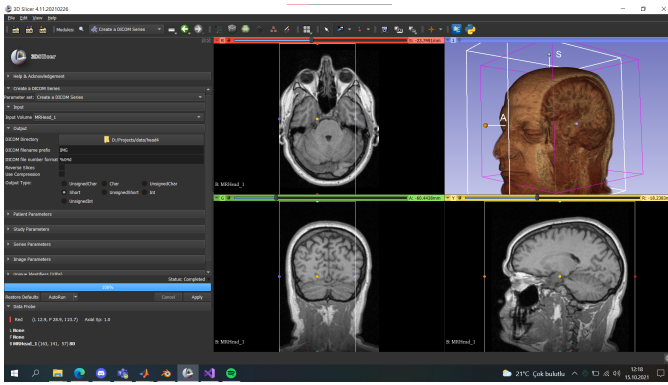
In the future part of this study, we focus on finding a way to display the titles of points of the organ's tissues by applying artificial intelligence model such as CNN (Convolutional Neural Network) approach.

ACKNOWLEDGMENTS

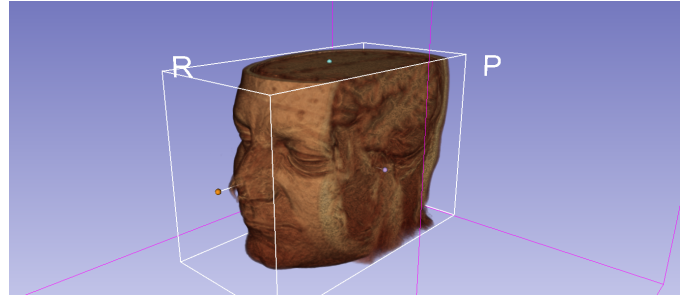
This work is supported by Galatasaray University Research Foundation under the Grant No. FBA-2021-1041.

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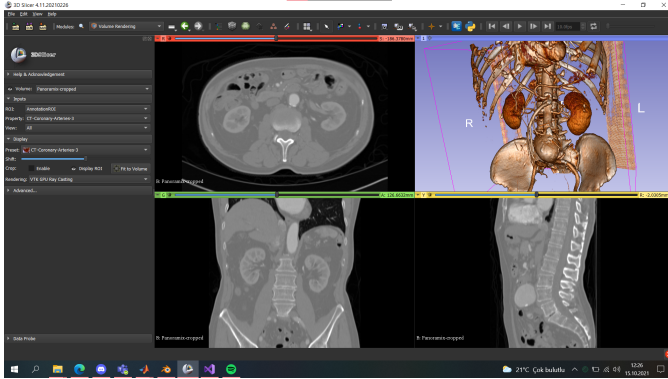
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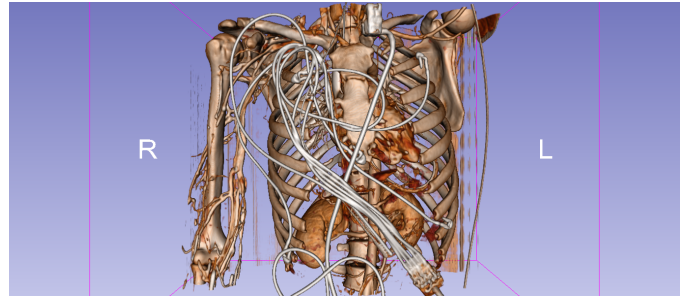
(a) Generating 3D for Model-1



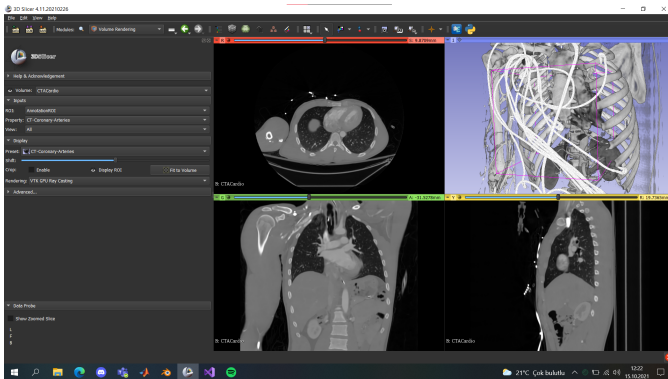
(b) Mesh View of Model-1



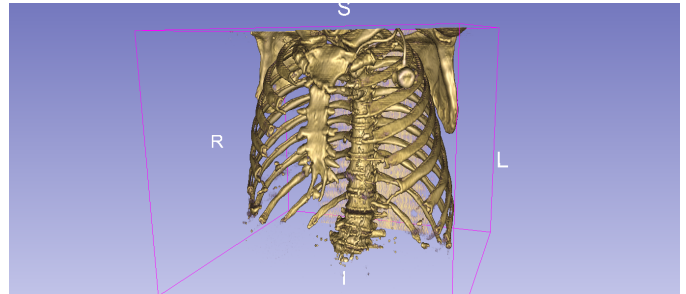
(c) Generating 3D for Model-2



(d) Mesh View of Model-2



(e) Generating 3D for Model-3



(f) Mesh View of Model-3

Fig. 2: Generated 3D Mesh Models via 3D Slicer Tool

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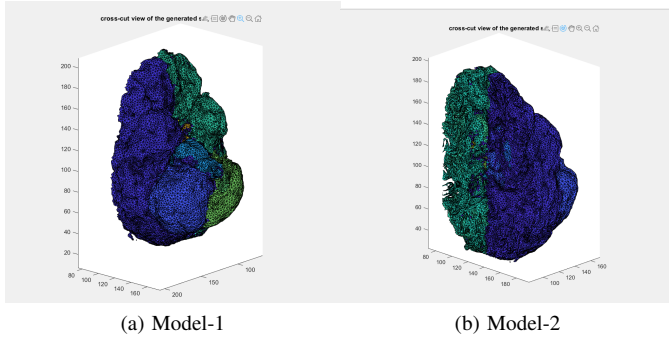


Fig. 3: Generated 3D Mesh Models via Iso2Mesh Tool

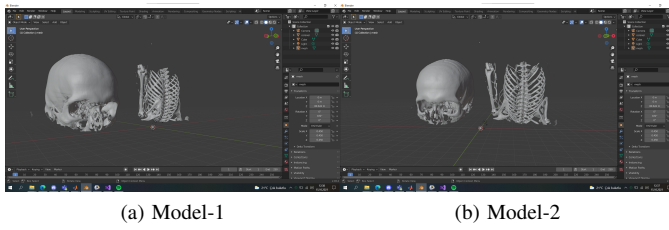


Fig. 4: Generated 3D Mesh Models via DiCom2Mesh Tool