An Improved Method for Building A 3D Model from 2D DICOM

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***Abstract*—The development of images processing techniques in recent years brings us a lot of useful application in practice. In the field of medical image processing, several researches and their application have been widely applied in practice such as diagnostics, treatment, training and education. This paper presents an improved method for reconstructing the shape of 3D objects from 2D DICOM datasets. We first focus on DICOM data processing based on techniques of digital image processing to get a 3D point cloud. This step includes extracting features, boundary of the shape, removing noisy data and inserting new pixels to obtain a regular dataset on each 2D DICOM slice. In the next step, we reconstruct the 3D object based on triangulation of 3D point clouds. In the last step, we build an application for rendering and visualizing the 3D medical image objects. Comparing to the existing methods, the proposed method is very fast for creating a 3D object from DICOM images. The application can be used to support medical staffs and doctors in diagnostic, treatment and training.**

Keyworks: Medical images processing, DICOM datasets, Contour extraction, 3D Reconstruction.

I. Introduction

Digital image processing is also a researched field in computer science. It is performed by using algorithms directly on digital images to deal with the problem of image analysis and enhancement of image quality. Geometric modeling is a part of applied mathematics and computational geometry that study the methods and algorithms for mathematical description of shapes. The combination between them in many computer graphic applications can help us to obtain an optimal model in reconstructing, simulating, rendering or visualizing the 3D objects.

In the field of medical image processing, the problem is how to check and see clearly the parts inside of human body such as brain or organs. They are very important and needed to check regularly and periodically for health caring. Indeed, they are difficult to observe without supporting from computer aided application. Although, the development of medical devices and their techniques in endoscopic surgery, images diagnostic or ultrasound, etc., bring us a lot of successful in medical treatment. There are several applications developed to support doctors and their teams in diagnostic and decision making. They are performed based on combination of medical images processing and computer graphics [1], [2]. The rapid development of the high-tech devices and new scientific studied methods can help a lot in medical software products [3]–[5]. However, the method for building 3D objects from 2D medical images has still existed some drawbacks of time processing. For example, the existing methods are processed based on indirect volume rendering like marching cubes [6]. Especially, where the input are very big data containing too many slices generated from MRI, CT scanner or tomographic.

As presented in the previous work [1], we constructed an application for rendering and viewing DICOM images. In this application, we can view a series of DICOM slices in 2D and its model in 3D. Besides, we can also handle the 3D object like rotation, zoom-in/out for visualization. However, the obstacle of this application is time processing for 3D object creation. In this research work, we proposed a new method for data processing and reconstructing the 3D objects from DICOM dataset to overcome the drawback of previous work. We first focus on data processing of the DICOM images. Then, we apply the methods of geometric modeling to triangulate the surface of 3D object for a better visualization and time saving.

The rest of paper is organized as follows: the structure of DICOM images, related works and many software products for 3D modeling from 2D medical image slices are presented in section II. Section III describes our proposed method. Section IV presents the Implementation and Results. Discussion and evaluation are presented in section V. The last section (section VI) is our conclusion.

II. Literature review

In this section, we first study the structure and format of DICOM images generated from the medical devices (i.e. CT scanner machine). The existing methods for data processing and building 3D objects from 2D DICOM are then reviewed. We have also explored many current software products for processing the medical images in recent years. The knowledge in the state-of-the-art are background for us to research and propose a new method with an expectation to contribute in this field.

A. *Structure of DICOM images*

Following the description in the researches [7]–[9], DICOM is a standard for handling, storing, viewing, and transmitting

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information of all medical images. It contains the information of patients and theirs diseases. They can be viewed by using a special computer software that designed for DICOM images. The DICOM standard is structured into two parts (Header and Dataset) following the PS3.10 specification (Media Storage and File Format for Media Interchange). The characteristics of DICOM data are also detailed in the previous work [1]. They are including ultrasound (US), positron emission tomography (PET), computed tomography (CT), Magnetic Resonance Imaging (MRI), endoscopy (ES), mammograms (MG), digital radiography (DR), computed radiography (CR), etc (see Fig.1).

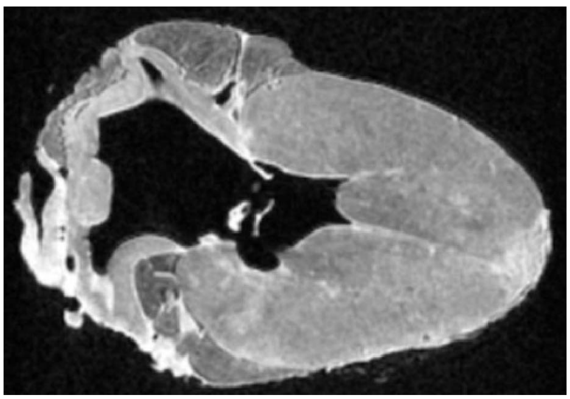

Fig. 1: The 2D Dicom slice obtained from CT Scanner [10]

B. Related works

Nowadays, the demand of using 3D medical models based on computer aided design has been reported very high and necessary [11]. Especially, in endoscopic surgery, images diagnostic or ultrasound, etc. The researched work in the field of medical image processing are very interested in the last few years. Normally, they are classified into two categories. One of them is analyzing the medical images to find abnormal signals or assumption of the diseases. The other one is focusing on building or reconstructing the 3D models from medical images. Ali et. al. [12], presented a review of existing methods for medical image segmentation using deep learning methods. Comparing to the normal methods (i.e. based on manual segmentation), it proved the efficiency of time processing. Farzama et. al. [6] introduced techniques to reconstruct 3D model from a list of Brain MRI slices. These methods are also detailed in the previous work [1]. Z.Hu [13] presented a method to extract any angle virtual slice on 3D CT image. This method can help to provide more information for building a completed 3D model. Chen et. al. [14] presented a research to convert a series of 2D CT slices into 3D model based on Marching cube algorithm. Many recent survey studies [15]–[18] have been presented an overview of medical images analysis, application and compression techniques. Vimala et.al. [15] presented an analysis, discussion and evaluation of medical images taken from different imaging tools such as X-Rays, CT, MRI, Ultrasound, etc. The advantages, drawbacks and comparison between them have also been discussed. Alagendran et.al. [17] focused on research the various types of medical image compression techniques. This research shown us the difference between techniques with their performed results that serve in medical image transmission or storage process. In the application of medical images processing, Ioan et.al. [16] studied most of software companies all over the world where produced software products for viewing and handling medical images. This research is a great practical value supporting to medical staffs in their work. Serveral algorithms for 3D modeling from 2D medical slices have been implemented and tested. Most of them based on the techniques of digital image processing, medical processing and computational geometry [19]–[23]. Each of these methods has its own advantages but also containing some difficulties. For this reason, building a method for 3D modeling from medical images that can overcome the disadvantages of the previous work is still an interested topic in this researched field. In the previous work [1], we introduced three popular algorithms, which are implemented successfully to render and handle 3D objects from 2D DICOM images. That research work are also considered as background for the next improving step and experiential sharing to overcome the obstacles of these algorithms. The last and most important point of the researched work is that we focus on studying serveral existing methods, both in theoretical research and implementation of 3D model from 2D medical images [24]–[28].

C. Several applications

With the support of new techniques and devices in medical image processing, the obtained results can help doctors a lot in their professional work. However, the quality of the output images in some medical divices like CT scanner or MRI are not always obtained the best information for doctors. Besides, the CT scanner machine and its devices are normally very expensive and difficult to equip for all hospitals. While the traditional device like MRI is cheaper but the quality of the output images is not good enough. That are the reasons why some various types of medical image processing (MIP) techniques have been introduced by many software companies [2]–[5]. We now present several application for rendering and handling the 2D and 3D objects from DICOM dataset. For each of them, we explore which functions it has, the method or solution it used, how does it works, and what are the advantages as well as the disadvantages. The software products are well known and have been provided by many companies [2]–[5]. They have developed the applications for 3D model creation from a set of medical image data. Most of these applications are implemented based on the visualization toolkit libraries VTK and ITK [29], [30] and updated every year. They are open source libraries used in computer graphics and MIP [30]. They are written in C++ using library classes and also supporting other programming language like Java or Python. They provides a huge amount of geometric and images processing algorithms that can be developed for visualization and 3D modeling. These libraries are very useful for researchers

in the field of medical image processing.
The first one is named “Radiant DICOM Vierwer” [3]; it is a tool designed for viewing medical images. It is developed by Medixant, a small and private company, in 2009. This software can process well with the input data like CT, MRI, PET, etc. All basic functions (i.e. rotate the volume, change zoom-level and position, adjust color and opacity, etc) are worked well. The latest version has also supported to visualize a large volume of data generated by modern CT/MRI scanners in 3D space. The next software is assigned with a name “Santesoft” [5] and developed by Santesoft LTD company. It contains most of necessary functions: read DICOM files, view images in a series to compare, multiplanar reconstruction, measurement tools, etc. Using this software, users can handle and manage their input and output DICOM files. It has also supported to create a 3D model based on geometric algorithms and image processing. The last application is built for visualizing medical images and is knew with the name “Medical Imaging ToolKit” (MITK) [4]. It is an open source application, developed by Dr.Tian and his team to use in medical field. The main aspects of the application are implemented based on some geometrical algorithms such as segmentation, reconstruction, visualization, and registration of medical data. It can support the function to export the volume mesh from DICOM data. This application has also studied and compared detaily in the research of I.Bitter et.al. [31].

Most of above applications are adapted to the needs of users. However, we must pay for a business license if we wish to acquire the full version including superior features. In addition, processing time for 3D model creating are not always working stable in every computer. In the next section, we will describe in detail our proposed method.

III. Proposed method

A. Overview

Visualizing DICOM images by reconstructing a 3D model allows medical staffs or doctors obtaining insight knowledge of the patient’s disease. Therefore, an appropriate treatment can be provided in time of need. The methods of early treatment are very important in some cases of illness such as cancer, hepatitis, tuberculosis, etc. Moreover, the obtained results of DICOM standard machines, patient’s information in DICOM format are easily accessed in the hospitals. They are considered as input data for reconstructing a 3D object.
In this section, we present the whole picture of our proposed method for DICOM image processing and reconstructing its 3D object. The input data are set of DICOM images. We process on each 2D slice based on combination of image processing techniques and computational geometry to get exactly the shape’s boundary. In the next step, we remove the noise based on digital image processing. After inserting new pixels on the boundary, the output is a regular boundary of point cloud. We combine all 2D slices to obtain a 3D point cloud of the 3D object. The last step is triangulating this 3D object for rendering and visualizing medical entities. The description of each step is presented as follows:

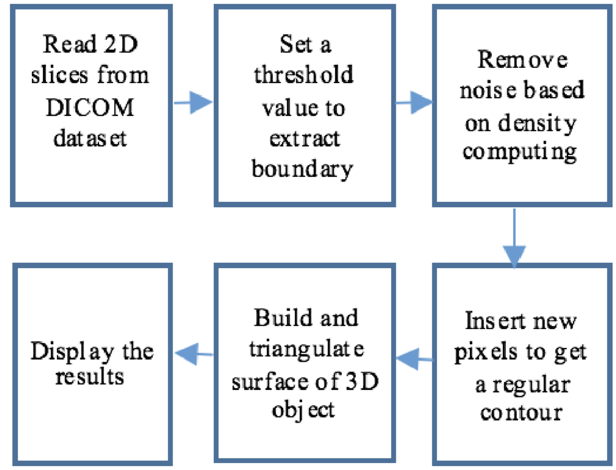

Fig. 2: A proposed method for 3D model from DICOM Images

B. Boundary extracting and noise removing

As we knew, the proposed methods are available for boundary detection of 2D shapes based on segmentation, clustering, region growing or data splitting. They are widely applied in the researched field of geometric modeling. However, in the medical images processing, a little bit difficulty is noisy data. They come from data acquisition techniques based on a threshold of grey value on each pixel. To solve the problem of noisy data, Convolution can help us in such field [32]–[34]. In this research, concept of contour (or called exterior boundary) is an outline of a shape on each 2D slice, as defined in [35]. This method can extract the 2D exterior boundary even in the case of discrete (unclosed) boundary. In order to determine an outline of shape on each 2D slice, we first identify all pixels that formed the shape based on the intensity of grey value on each pixel. In the next step, we apply the method in [35] to extract the exterior boundary of the shape. We combine with some functions existing in the libraries of VTK [30] to process, the result of this step is presented as follows:

Fig. 3: The 2D boundary of shape after extracting from Fig.1

After determining the exterior boundary of the shape, we need to compute and remove all noisy points inside of that shape. As mentioned above, the goal of our research is to build a 3D object from a set of 2D image boundary slices and triangulate its surface. Therefore, the points inside of its boundary are considered as noisy data points. They are removed easily to save processing time for the next surface triangulating step.

C. Pixels inserting

As mentioned in the related work, the techniques to get DICOM images are not always obtaining completed information of the objects. Depending on the techniques, characteristics, position of object in the human body, that can lead to lack of some detailed information on several parts of the object. For this reason, after extracting the boundary on each 2D slice, it is updated by inserting new pixels on the boundary to obtain a regular boundary. In order to insert new points on the boundary, we compute based on the interpolation of neighboring boundary points. Following the characteristics of medical DICOM images, the density of points on the boundary are well regularly, and the local shape on the boundary is not too complex. It means that some missing points on the boundary can be filled easily based on the formula of linear interpolation. However, to preserve the local shape on the boundary, we use the formula of Bezier curve, with degree 2 (Eq. 1, where: $0 \leq t \leq 1$, $t = 0$ at p_0 and $t = 1$ at p_2). An example in Fig.4, the way to compute and fill new points p_i on the boundary is described as follows:

$$p_i = (1-t)^2 p_0 + 2(1-t)tp_1 + t^2 p_2 \quad (1)$$

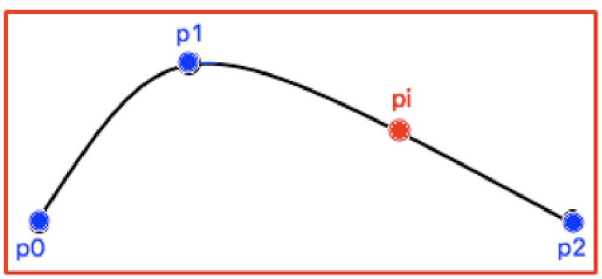

Fig. 4: Insert new point p_i on the boundary based on (1)

We use formula (1) to compute and insert p_i. The process is repeated on each inserted point, located on the boundary until the boundary is full-fill updated (see Fig.5).

Fig. 5: Inserting new points (red color) on the 2D boundary

D. Triangulating 3D object

After processing the boundary of each slice, we have a set of regular boundary points (i.e. the distance between the boundary points on each slice approximates the distance between the slices). We apply the method in [36] to triangulate the surface of 3D point clouds generated from a set of points on the adjacent slices. An example in Fig.6, with three consecutive adjacent slices. They are slice 7, slice 8 and slice 9 (..., s7, s8, s9, ...) in a sequence.

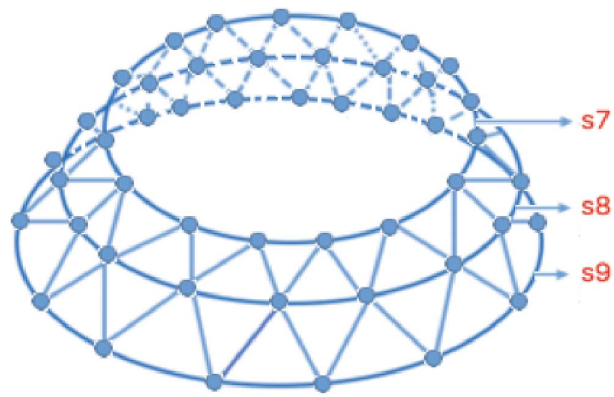

Fig. 6: Triangulation on the surface of a series of slices

The corresponding algorithm (Algorithm 1) for the whole processing steps is implemented, as follows:

Algorithm 1 3DMeshFrom2DSlices(DICOM Dataset)

```
for each 2D slice do
    Extract exterior boundary of shape.
    Remove noisy points inside of the boundary.
    Update the boundary by inserting new points.
    Generate 3D point clouds from set of slices.
end for
for all 3D points of the object do
    Meshing its surface.
end for
```

IV. Implementation and Results

In this section, we perform our proposed method and build an application to visualize the 3D objects obtained from DICOM images. We use C++ programming language based on Qt platform and combined with the VTK (Visualization toolkit) libraries [30]. We have also implemented some existing algorithms [19], [21], [22] integrated in the previous work [1] for reconstructing the 3D objects with the same context to compare. The interface of the application is designed simple, useful and easy to manipulate. The input data to test in the proposed method are donwloaded from the open source websites [37], [38]. The application allows loading a series of DICOM images slices; adjusting the colors and choosing one algorithm in the list (marching cube, ray casting, texture-based or proposed method) to build and visualize in both 2D and 3D. The 2D medical slices can be loaded and viewed with multiple slices as the same time. While the 3D object (built from a set of Dicom data slices) is displayed and also handled by transforming its status (see Fig.7).

Fig.8 is the final obtained result, after triangulating the surface of 3D model that is built from the 256 Dicom data slices based on the proposed method. Fig.9a is the result of a 3D model (from the 233 Dicom data slices) using the marching cube algorithm. Fig.9b (3D point clouds of the surface) and 9c (after triangulating the 3D point clouds) shows the results of using the proposed method algorithm to build from the 233 Dicom data slices. Fig.10 is an additional example to illustrate the obtained results with different rotations. To measure processing time between the methods, for each input Dicom dataset, we test three times to get its average value of running time. The obtained results have been shown in Table 1.

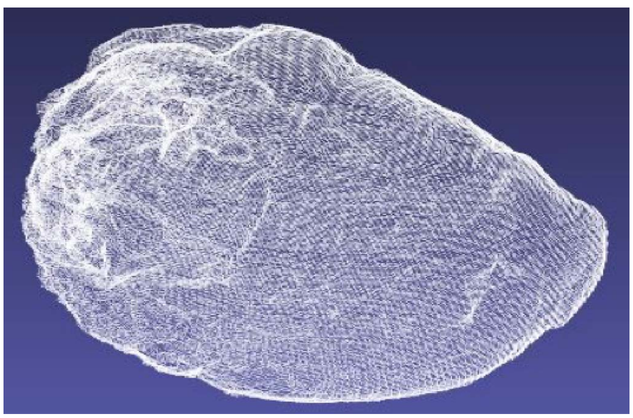

Fig. 7: The surface of 3D point clouds obtained from 256 boundaries of Dicom data slices of the heart

V. Discussion and evaluation

In this section, we give some discussion and evaluation between the proposed method and existing methods. Most of discussed methods in the related work can build a 3D object that are close to their shapes. However, the processing time in each of these methods is still considered as a drawback. Comparing to the existing methods, the processing time of our proposed method is faster (see Table 1).

Number of DICOM slices	Processing Time (Milliseconds)			
	TB	MC	RC	Our method
Brain Head (233 slices)	39005	33524	8312	4357
Sheep Heart (256 slices)	32844	14962	6616	5297
Marching Man (93 slices)	4240	2307	1330	956
Breast (88 slices)	18559	16925	3738	674
Head Shoulder (137 slices)	31658	16254	5693	621

TABLE I: Comparing the processing time of building 3D model from DICOM images (MC: Marching cube; TB: Texture-based; RC: Ray casting and Our proposed method)

The Marching cube (MC) is an indirect volume rendering algorithm, using the iso-value as a threshold value for obtaining the object's shapes. This method did not require the transfer function to process colors. While the Ray casting (RC) and Texture-based (TB) are direct volume rendering algorithms. They are required the transfer function to process colors but did not using the iso-value as in MC. During the research and implementation of these algorithms, we have seen that each method has its own advantages and disadvantages. MC has some advantages such as: it is flexible for modification; it can extract necessary surface; it have no limitation in memory. In most cases of our implementation, the processing time for each input data of TB and MC is higher the RC to reconstruct a completed 3D model.

The RC algorithm provides a high quality image, flexible extension and an easy implementation. Besides, this algorithm need to access the whole video memory; and it significantly increases the quality of the images after generating a 3D model. However, the processing time of this method is higher comparing to our method. The third algorithm is the TB volume rendering algorithm. The processing time of this method is highest comparing to all methods; the quality of the image is very sustainable. However, the limitation (in texture memory) is one of the most restrained traits of this algorithm that makes it rarer to be used in practice with a huge amount of medical data slices.

In our proposed method, we process the DICOM images based on combination of algorithms between MIP and geometric modeling. The obtained results are adapted our expectation. The processing time is very fast and the shapes of 3D objects are preserved. In order to compare the quality and accuracy of the final 3D object between the methods, we need to set up and implement them in the same context. For example, if we use the same iso-values to get the object's shape on each 2D slice; the 3D model is then constructed and measured the geometrical characteristics of its shape, our method obtained exactly initial shape of the real object (see Figs.9 and 10).

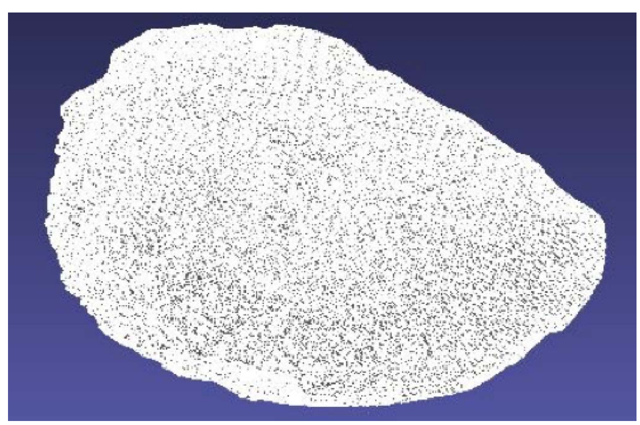

Fig. 8: Triangular surface of the 3D model creation from Fig.7

VI. Conclusion

In this paper, we have presented an improved method for 3D modeling and reconstructing the surface of 3D point clouds

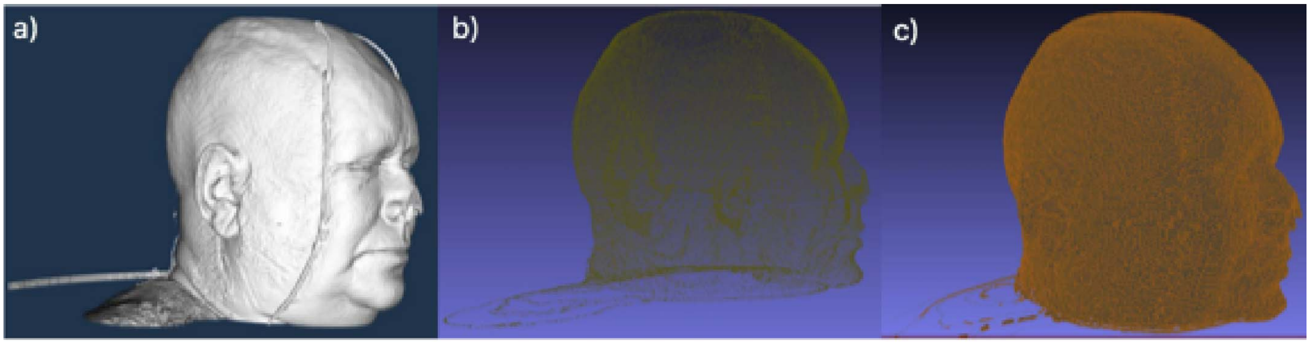

Fig. 9: The 3D model of BrainHead that is created by 233 Dicom data slices: (a) the 3D model created by the marching cube algorithm; (b) and (c) are the results of our method: (b) 3D model of point clouds after after extracting and updating the exterior boundary for each slice; (c) after triangulating the surface of 3D model.

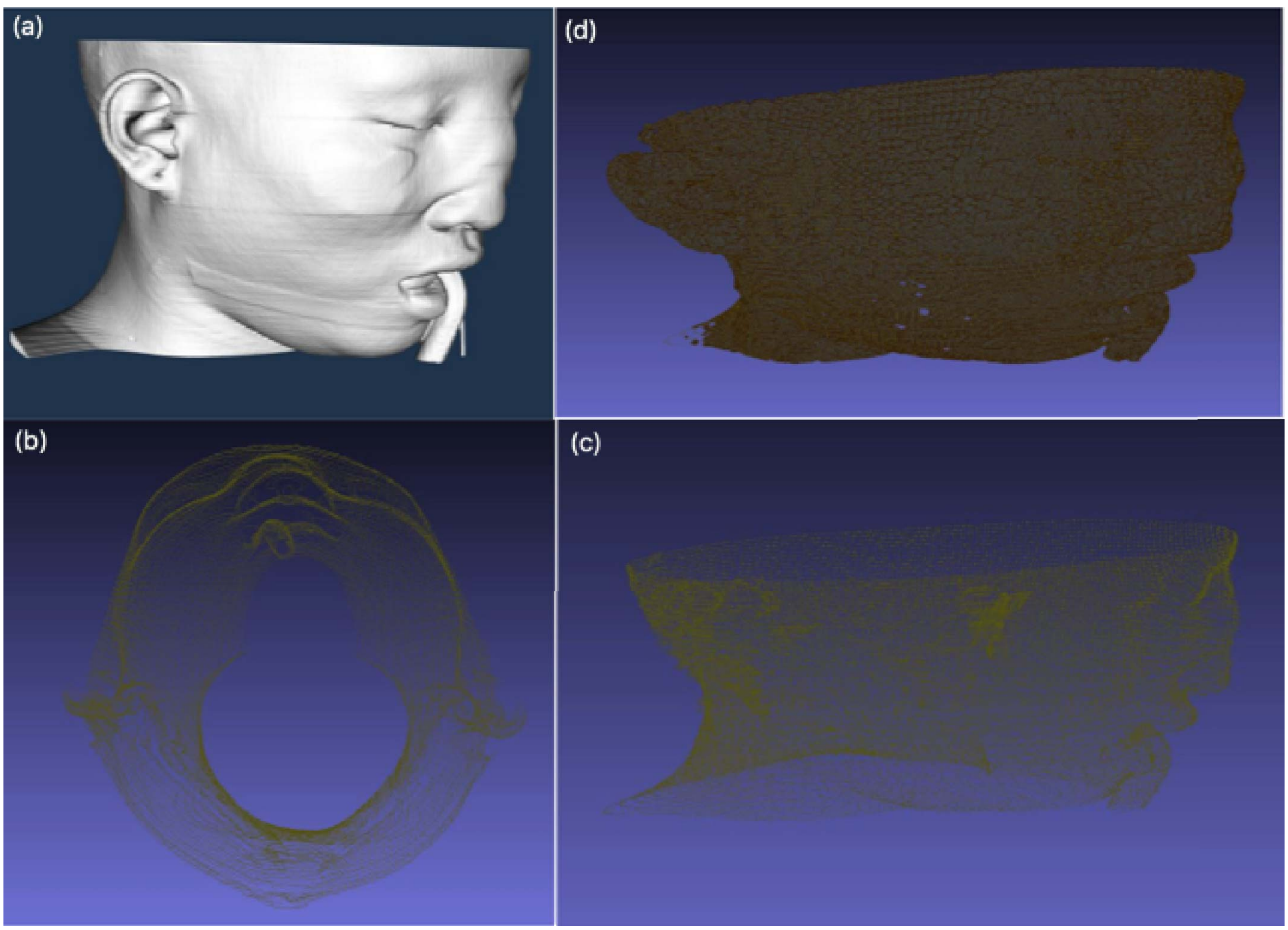

Fig. 10: The 3D model of MarchingMan that is created by 93 Dicom data slices: (a) the 3D model created by the marching cube algorithm; (b), (c) and (d) are the results of our method: (b) and (c) 3D model of point clouds after extracting and updating the exterior boundary for each slice; (c) after triangulating the surface of 3D model.

from a set of 2D DICOM images. We first studied in detail the existing methods for modeling a 3D object from medical images slices. Some software products in this field have also explored and revised. Among many methods for building a 3D object from DICOM images slices, we have interested and focused on both direct and indirect volume rendering techniques. However, the limitation of these methods have been analyzed and that is also the reason why for us to propose an improved method. Thereafter, we developed an application for visualization of the medical data slices based on VTK library. All of methods (Marching cube, Ray casting, Texture-based rendering and our proposed method) are implemented. They are run fine and the obtained results shown that the 3D model very close to the initial shapes of the real object. This application can support medical staffs and doctors in their work for diagnostics and treatments on the patients. It will also be an application that can freely use not only in hospitals, but also in academic research and training. Studying and processing the shapes inside its boundary of the Dicom objects are our continuous research work in the future.

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