3D Heart Image Reconstruction and Visualization

with Marching Cubes Algorithm

Pratomo Adhi Nugroho, Dwi Kurnia Basuki, Riyanto Sigit
Computer Engineering
Electronic Engineering Polytechnic Institute of Surabaya
Surabaya, Indonesia
Email: adhinugroho0@gmail.com, dwiki@pens.ac.id, riyanto@pens.ac.id

***Abstract*—Heart image taken using a CT-scan or MRI is a two-dimensional image. Information obtained from these images is very limited and it takes a lot of pictures from various sides to be able to determine the condition of the heart as a whole. This may slow the process of diagnosis of the heart condition of a patient. This study aims to solve these problems by developing a 3D reconstruction system. Some 2D images taken from different sides, and then go through the filtering to remove noise and sharpen images. The result of filtering is reconstructed using surface rendering technique and implementation of Marching Cubes (MC) algorithm. The MC algorithm used is a standard MC with 15 combinations of the cube. The use of 64 images is sufficient provided that it has an average error of 1%. Preprocessing is essential to obtain segmented part of heart from the original cardiac CT-scan images.**

Keywords—Heart image; 3D Reconstruction; Filtering; Marching Cubes

I. INTRODUCTION

The heart is one of the most important organs of the body and plays a role in the circulatory system. Therefore, abnormalities in the heart are very dangerous and even can cause death. Heart problems are generally divided into two: heart attacks and heart disease. A heart attack is a condition when the heart is not working at all and often occurs suddenly. Meanwhile, heart disease is a condition that causes the heart cannot function properly.

Heart inspection usually performed by a doctor using a diagnosis tool called CT-scan [4]. CT-scan generally use X-rays, and the resulting image is processed by a computer to produce two-dimensional slice images [4], [9], as shown in Fig. 1 which shows an image of heart CT-scan. Two-dimensional image have a limited amount of information, because it can only show information from one point of view [4], [11]. While an accurate diagnosis requires examinations from various viewpoints with a lot of images. It takes a long time and precision. So we need a 3D reconstruction to visualize the heart model from 2D CT-scan images.

3D reconstruction is a process to capture the shape and appearance of real objects. The reconstruction process can determine the 3D profile of each object and determine the coordinates of each point on the object's profile. 3D reconstruction has been developed and implemented in various fields such as Computer Graphics, Animation, and Medical Imaging and might be the first step towards the Virtual Reality [6].

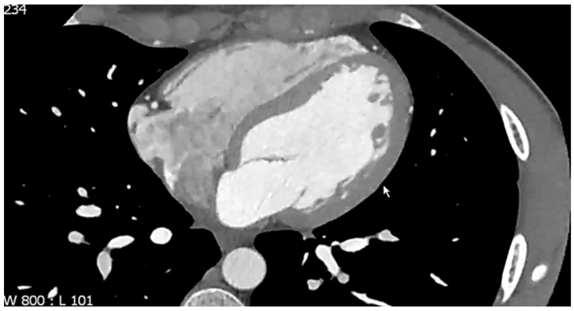


Fig. 1. A slice of heart CT-scan image

Visualization is the process to understand the structure of an object [8]. This research use surface rendering which is a technique of object's surface modeling from 3D data [10]. Data sets interpretation developed by generating polygons that represent the surface and display the 3D model [8], [11]. Surface composed of dots with the same intensity. One of the most popular surface rendering techniques is Marching Cubes [2], [3], [8], [11], [12].

The reconstruction process use Marching Cubes algorithm proposed by Lorensen and Cline [11]. This method is used because of its simplicity, robustness, and efficiency. Also, the availability of input images, which are 64-slice CT-Scan images, make this method more suitable.

Marching Cube algorithm is isosurface approximation algorithm that produces a triangulated mesh surface from vertices derived on the edges of the rectilinear lattices [1], [7]. Marching Squares, which is the 2D equivalent of Marching Cubes, generates contours in order to choose the threshold in the 3D reconstruction. Marching Cubes is using divide-and-conquer approach to generate connectivity between slices, then create a table of cases which defines the topology of the triangle [11]. Furthermore, the algorithm would process the 3D medical data in scan-line order and determines triangle vertices using linear interpolation between adjacent slices [9]. Image generated from a surface model is a result of the stabilization of inter-slice connectivity, surface data and gradient information in the original 3D data.

II. RELATED WORKS

There were several ideas of how to reconstruct 2D images into a 3D model and visualize it. According to [10], there are three types of 3D rendering techniques which are multiplanar rendering, surface rendering, and volume rendering. The most commonly used techniques are belong the category of surface rendering, because it produces better result than multiplanar rendering using some calculations but doesn't requires enormous amount of them as in volume rendering.

Surface rendering technique visualizes a 3D object as a set of surfaces called iso-surfaces. Each surface contains point which have the same intensity (called iso-value) on all slices. This technique is used when we want to see the surfaces of a structure separately from near structure. Two main methods for reconstructing iso-surfaces are contour and voxel based reconstructions [10]. Fig. 2 shows the basic rule of the algorithm.

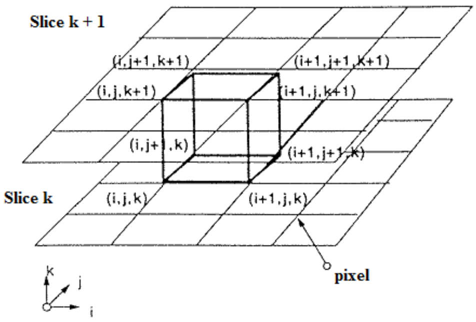


Fig. 2. Marching Cube [11]

Lorensen and Cline [11] proposed a 3D voxel-based surface reconstruction method called Marching Cubes. This algorithm creates a polygonal representation of constant density surfaces from 3D array of data. Compared to the existing 3D algorithms at the time, Marching Cubes produces more detailed result and is noted for its simplicity, efficiency and robustness [3].

Several studies have successfully reconstructed 3D model of certain objects using Marching Cubes (MC) algorithm. Hafizah et al [8], used the standard MC (15 cases) with unfiltered ultrasound images as shown in Figure 3. They concluded that image processing need to be performed thoroughly by adding other detailed processing techniques so that noises can be fully removed.

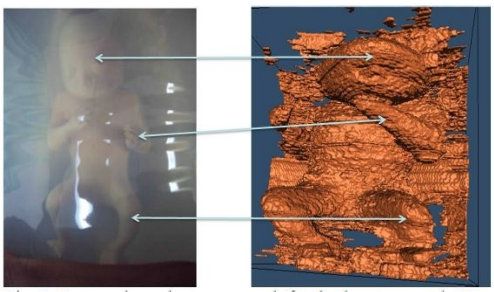


Fig. 3. Comparison between real fetal phantom and 3D fetus image [8]

Another research by Delibasis et al [6], proposed an improved Marching Cubes with additional cases. This study stated that standard MC algorithm has the occasional 'hole problem', as well as great number of produced triangles and computational overhead imposed by the cube rotations. Its use of 15 predefined cube configurations that reduces the number of original configurations (256) can produce topologically incoherent surfaces, or 'holes' in certain cases of two adjacent cubes.

Dietrich et al [3] suggested the use of edge transformations to improve the mesh quality of Marching Cubes. One of the key shortcomings of standard Marching Cubes is the quality of the resulting meshes, which tend to have many poorly shaped and degenerate triangles. This research proposed a method to modify the grid on which Marching Cubes operates which greatly increases the quality of the extracted mesh. The result of the experiment didn't create any degenerated triangles and the modification itself can be readily integrated in existing Marching Cubes implementations.

III. METHODOLOGY

In the proposed system there are five steps including Data Acquisition, Preprocessing, Feature Extraction, Model Creation and Display as shown in Fig. 4.

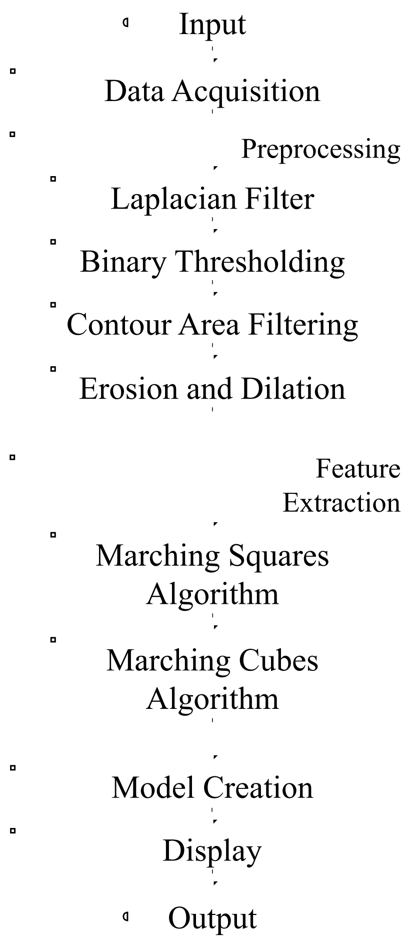


Fig. 4. 3D Reconstruction System

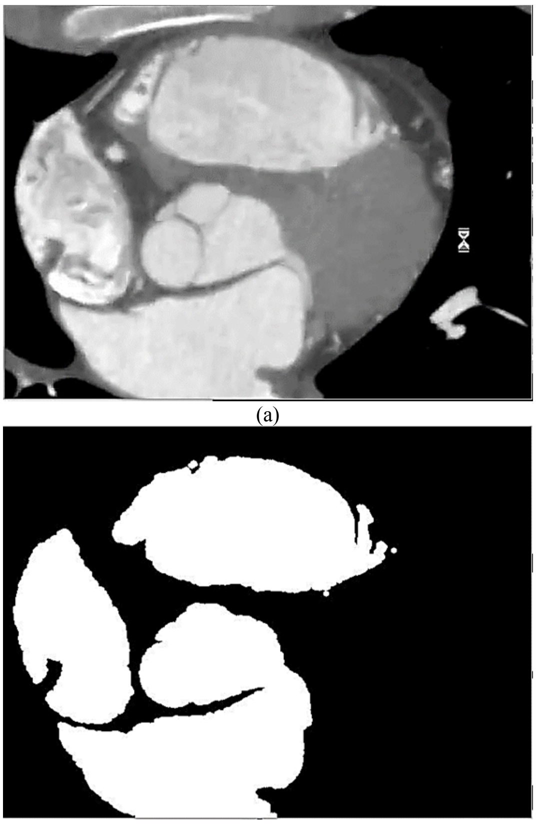
A. Data Acquisition

This first stage, performed by the medical imaging hardware which is CT-Scan, samples some property in a patient and produces multiple 2D slices of information [11]. The data sampled depends on the data acquisition technique. CT-Scan is able to produce up to 64 image slices of the heart. Each slice representing each side of the object, for example the very top, middle and bottom part of the heart. The difference between the three sets of the image: the more the number of images in the set, the more the object area that can be covered. However, because the images are obtained using this method, the error by lighting affection, which is common problem on 3D image reconstruction will be ignored.

B. Preprocessing

CT-scan images not only show heart, but also the other objects in the vicinity such as ribs (Fig. 5.a). Such objects are not needed in the reconstruction process, so that should be eliminated or minimalized. Stage of preprocessing used to improve and refine the image [3], [12], as well as removing unneeded parts of the image or can be referred as noise [13], before going through the process of 3D reconstruction.

Preprocessing steps includes Smoothing, Filtering, Enhancement and Reduction to minimize the noise so as to produce finer images and accurate [8], [13]. Some image processing functions used in the preprocessing stage includes a Laplacian filter, Binary thresholding, Contour Area Filtering, as well as Erosion and Dilation.



(a)

(b)

Fig. 5. (a) The original CT-scan image (b) Preprocessing result

Filter Laplacian serves to sharpen the image, so that the boundaries between the parts of the heart in the picture seems clearer. Binary thresholding utilize grayscale color composition to remove parts of the image that are not needed [7]. This thresholding step use clustering-based method where the gray-level samples are clustered in two parts as background and foreground (object). The foreground is the heart image, while the background is the parts other than heart. Contour Area Filtering as well as Erosion and Dilation also eliminate part of the image, but refers to the size of the pixel area of the section. Fig. 5.b shows the preprocessing result of Fig. 5.a.

C. Feature Extraction

The fourth stage, Feature Extraction, aiming to extract information from each image. This stage uses Marching Squares and Marching Cubes algorithms. Marching Squares used to retrieve information from each of the 2D images by dividing the images into smaller ones (Fig. 6). Each image then is identified by its shape using Marching Squares lookup table shown in Fig. 7.

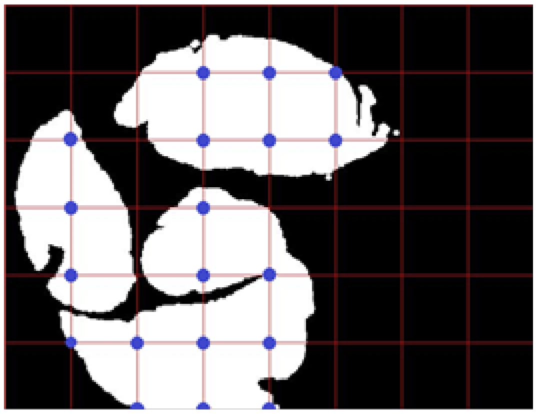


Fig. 6. Image division using Marching Squares

The size of each square affects the reconstructed image, where the size is determined by the number of image slices used. This happens because regardless of the number of image slices, heart height must always be the same, thus affecting the horizontal size (the size of the squares). Extraction and visualization result is shown in Fig. 8.

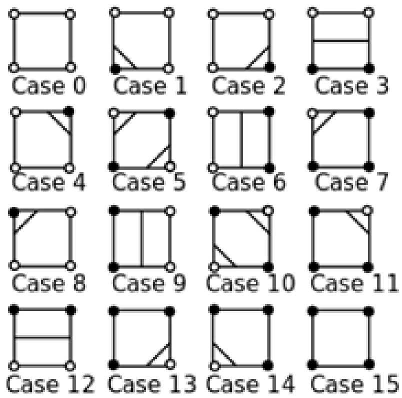
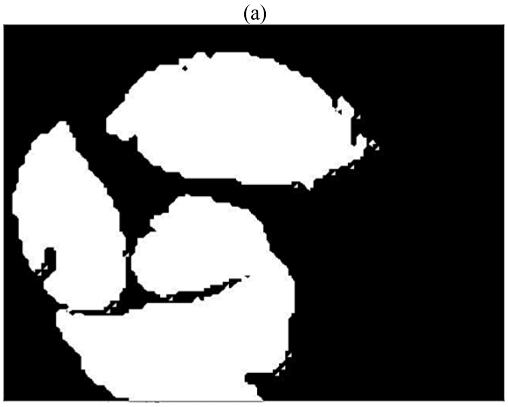


Fig. 7. Marching Squares lookup table

0	0	2	3	3	1	0	0
2	1	6	15	15	9	0	0
6	9	6	13	12	8	0	0
6	9	6	11	1	0	0	0
6	11	7	15	9	0	0	0
4	12	15	15	9	0	0	0

(a)



(b)

Fig. 8. Marching Squares data visualization

The extraction of 2D images are then processed to obtain a single slice of 3D by combining two 2D image slices [4] using the Marching Cubes algorithm. The basic concept of the Marching Cubes algorithm is a linear interpolation process along the edge of the grid to calculate the vertices of the isosurface approximation [1]. Vertices are then connected to form a valid triangulation.

As shown in Fig. 2 [11], in the process of merging the first slice (k) serves as the bottom side of the sliced 3D, while the second slice (k + 1) acts as the upper side, or it could be otherwise. Then, based on the shape identified in each side (top and bottom), then the shape of the object between the two sides are generated using Marching Cubes algorithm.

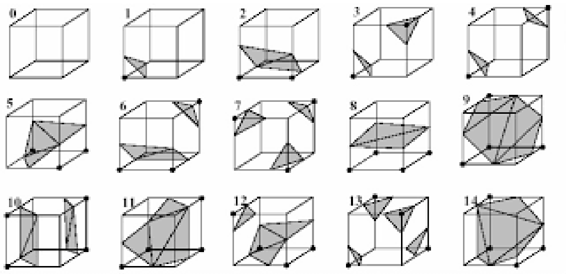


Fig. 9. 15 Unique Cube Configurations generated by Marching Cubes Algorithm [11]

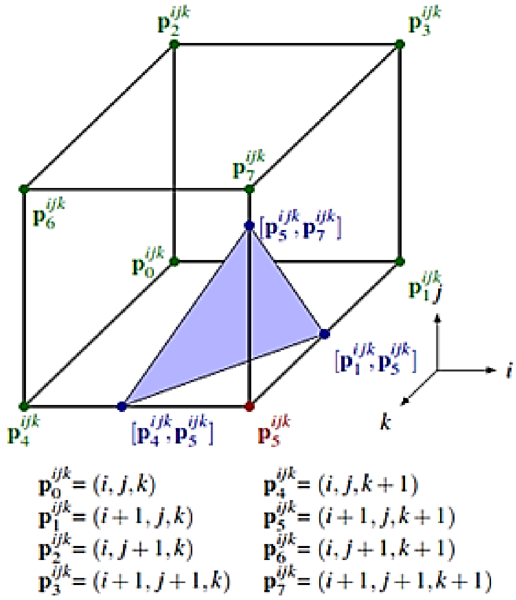


Fig. 10. Construction of a cube in Marching Cubes

Each side has four vertices, so the total number is eight knot, as shown in Fig. 10, that produces 256 combinations (2 8 = 256) [11]. Marching Cubes standard lookup table containing 256 combinations, which then simplified to 15 cases (Fig. 9). This simplification can be done thanks to the concept of rotation and mirroring.

Marching Cubes algorithm can be represented by the following pseudo code [6]:

```
FOR each image voxel
    a cube of length 1 is placed on eight adjacent voxels of
    the image
    FOR each of the cube's edge {
        IF (the one of the node voxels has value greater than
        or equal to t
        AND the other voxel has value less than t) THEN {
            calculate the position of a point on the cube's
            edge that belongs to the isosurface, using linear
            interpolation
        }
    }
    FOR each of the predefined cube configurations {
        FOR each of the eight possible rotations {
            FOR the configuration's complement {
                compare the produced cube configuration of
                the above calculated isopoints to the set of
                predefined cube configurations and produce
                the corresponding triangles
            }
        }
    }
}
```

D. Model Creation

The next stage is to develop the data that has been found to be a description of a 3D model of the heart using the lookup table of Marching Cubes (Fig. 9). Fig. 11 shows the 3D object formed by two images using formula as shown in Fig. 2. The 3D model of the heart as a whole will be formed with 64 images.

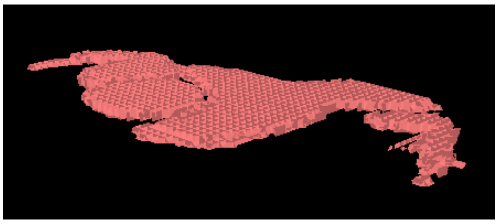


Fig. 11. A reconstruction result of two slices

E. Display

The data compiled into a 3D model descriptions of the heart then visualized using OpenGL-based graphical tools [5]. The 3D visualization of heart must be able to show the entire surface of the heart with the help of the rotation function, as well as the inner wall by display partial reconstruction of the whole image.

IV. RESULT

The experiment is done using 64 images of heart from CT-Scan. The algorithm used is standard MC with 15 predefined cube configurations. This experiment consists of four stages. The first stage is reconstructing the heart images with only Laplacian Filter in the preprocessing step. This means that the parts of the images other than the heart are also reconstructed.

Fig. 12 shows the result of the first stage. With the whole images being reconstructed, makes the heart part hardly recognizable. One of the purposes of this system is to display the heart clearly. So we have to extract the heart part from the whole image. The second stage use binary thresholding as an addition in preprocessing step.

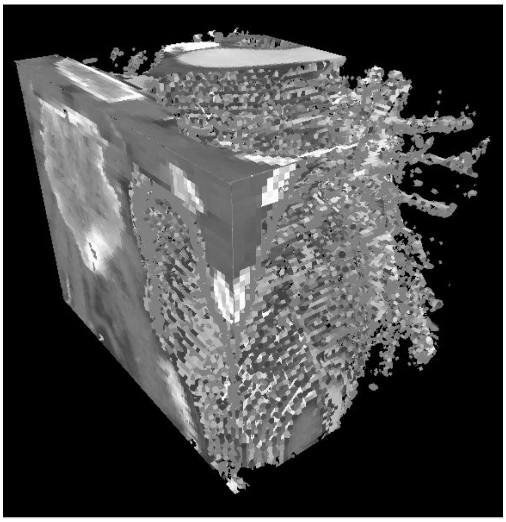


Fig. 12. The result of reconstruction from sharpened images

Fig. 13 shows the result of the second stage. The use of binary thresholding to extract the parts with specific grayscale color range resulted in a more visible heart model. Most of unneeded parts are removed, with the exception of several small parts. While this stage produces better result, it still need more improvement.

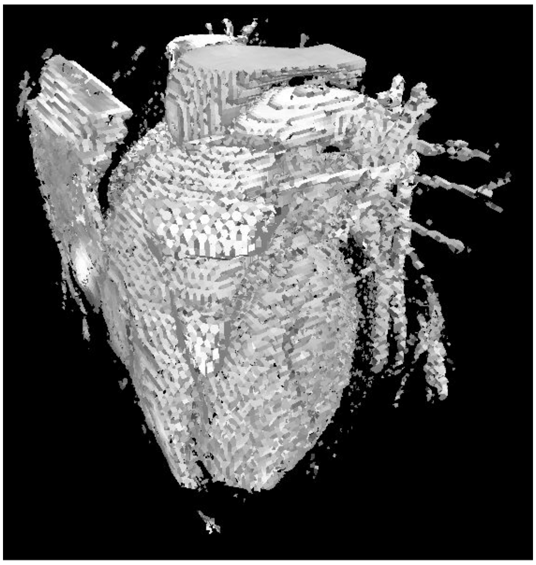


Fig. 13. The result of reconstruction after thresholding

The third stage, with the addition of Contour Area Filtering in preprocessing steps, resulted in a slightly improved 3D model as shown in Fig. 14. The extra step unable to fully remove noise from the previous stage, which are located on the edge of the images.

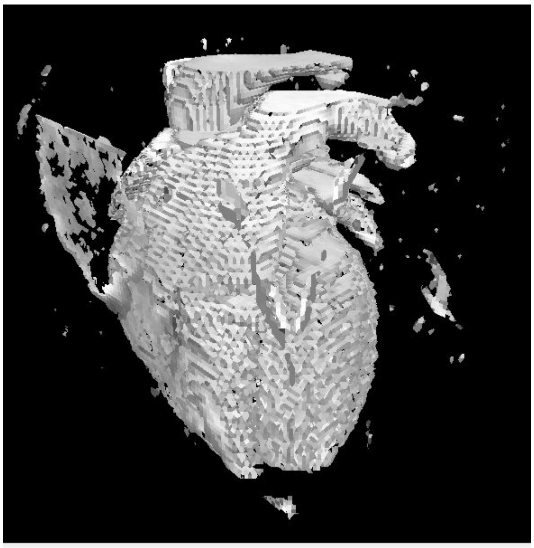


Fig. 14. The result of reconstruction after contour area filtering

The fourth stage includes erosion and dilation in preprocessing stage to remove the noise from previous stage. These two steps are specially used to remove small noise while keeping the original size of the heart from the images. The addition of these steps improves the result, as shown in Figure 15, and fully remove the unneeded parts.

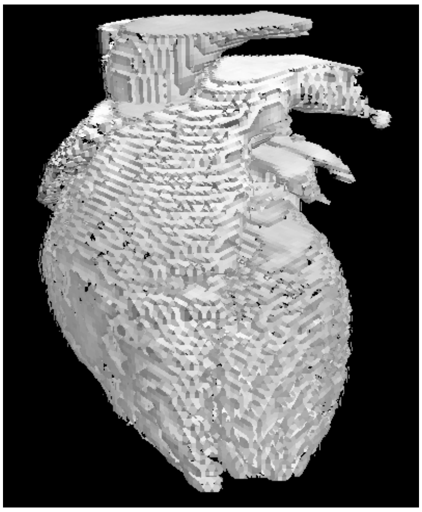
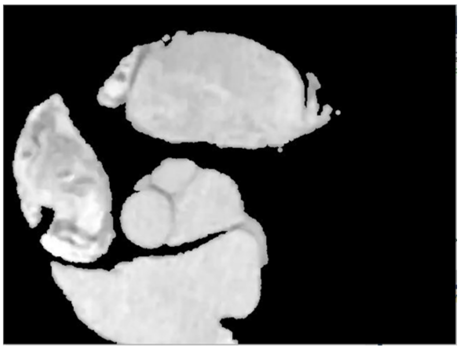
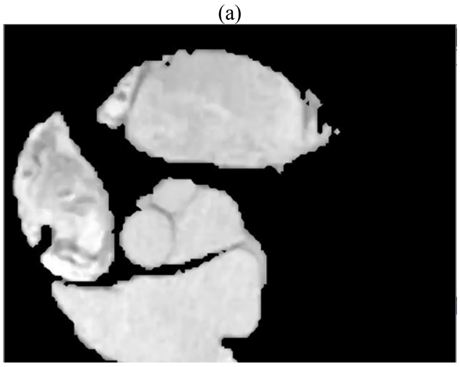


Fig. 15. The final result of reconstruction after erosion and dilation

The use of 64 images in 3D heart reconstruction is sufficient to produce decent result which is proven by the average error of pixel counts. The error is obtained by calculating the differences of grayscale pixel counts between input and output images. Noted that the input images used are the result of preprocessing steps and output images used are 2D images of Marching Squares Algorithm result, not the 3D images. These 2D images, as shown by an example in Fig. 16, are converted to grayscale histograms (Fig. 17).

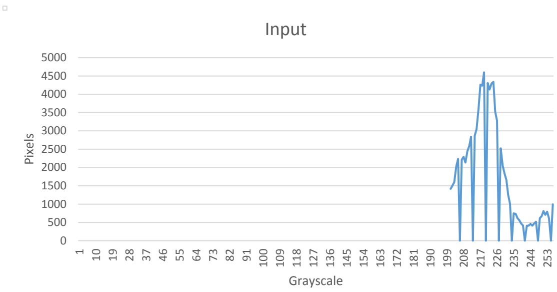


(a)

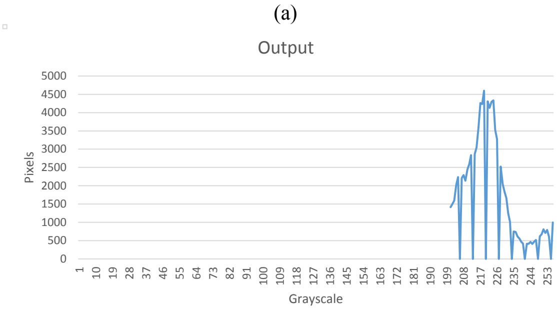


(b)

Fig. 16. Grayscale images of: (a) Input (b) Output



(a)



(b)

Fig. 17. Grayscale histograms of: (a) Input and (b) Output

The error histogram is obtained by calculating the difference between the two histograms as shown in Fig. 18. These steps are applied to each of the 64 images (input and output). The error of an image is then obtained by calculating the average error of each grayscale level. Average error of 64 images is 3220 pixels or 1% (from the total of 307200 pixels).

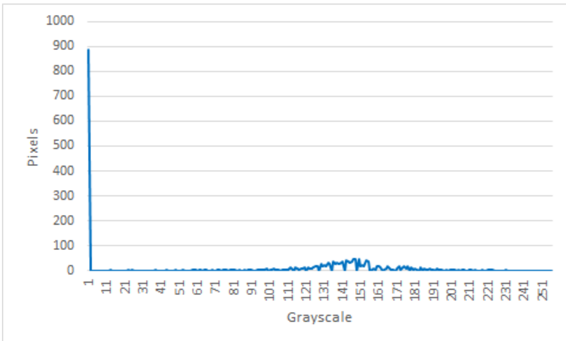


Fig. 18. The error value of each grayscale level in one image

V. CONCLUSION

From the experiment, it is concluded that the preprocessing stages are essential in the reconstruction. These steps are very useful to extract the unneeded parts from the whole images, even though the exact steps used are depending on the original CT-scan images. The steps used in this system are compatible with grayscale images, which divided the parts by color. Different type of images might need different kind of filtering processes. The use of 64 images in the 3D heart reconstruction is sufficient to produce a decent model, while it still need improvements, especially in smoothing surface. This problem needed to be resolved in future studies by combining other methods with Marching Cubes. The average error of the 64 images is 1% which is good enough to preserve the information. The system proposed is able to produce a decent 3D model of heart which can be rotated and sliced to display inner parts of heart. While the resolution and smoothness of the 3D model still need some improvements, it is already good enough to display the heart parts in different viewpoints.

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