

3D Segmentation and Visualization of Left Coronary Arteries of Heart Using CT Images

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ABSTRACT

Coronary heart diseases (CHD) are one of the most prevalent causes of death all over the world. Noninvasive imaging technique such as Computed Tomography (CT) has greatly assisted the diagnosis of coronary heart diseases. Coronary vessels are 3D structures in nature. From CT images we get 3D structures. For a treatment plan or physicians' surgical operations it is very important to segment out the coronary arteries of heart using CT images. After extraction of heart arteries it is also medically essential to visualize these arteries. In this paper novel image segmentation approach is proposed to segment the left coronary arteries of the heart and then a VTK pipeline is developed and implemented for 3D visualization of the segmented arteries. In this work after extraction of 3D heart shape the regional statistical information is incorporated in the structure through the Bayesian law. Finally the Marching Cube method is applied to extract the desired coronary arteries image. Then proposed VTK pipeline visualizes the segmented branches. The proposed segmentation framework segments out the main branches of the left coronary arteries, which is quite satisfactory.

Keywords

Segmentation, visualization, coronary arteries, CT, marching cube, VTK pipeline.

1. INTRODUCTION

Cardiovascular disease (CVD) is the most prevalent cause of death in the whole world. CVD includes high blood pressure, coronary heart disease (CHD), congestive heart failure, stroke, and congenital cardiovascular defects. Among these, CHD accounts maximum percent of deaths of CVD in the world [1]. The health and economic implications for early age CVD deaths in South Asian countries are profound and warrant prompt attention from governing bodies and policy makers of these countries [2]. Invasive coronary angiography is risky and it provides 2D anatomical structure which is not sufficient for the coronary arteries of heart as it is indeed 3D anatomical structure.

Invasive coronary angiography is more risky for observational patient where the physicians need to observe the improvement regularly. Threshold-based segmentation [3],[4] and region growing segmentation[5] are proposed for segmentation of CT and MRI images but they have several limitations and these methods can not be used individually. Several vessels extraction techniques are reviewed in different time [6]. In paper [7] they proposed an approach for 3D segmentation and reconstruction of human left coronary artery. Each voxel in the 3D dataset is assumed to belong to one of the three homogeneous regions: blood, myocardium, and lung. A priori knowledge of the regions is introduced via Bayes' rule. Posterior probabilities obtained using Bayes' rule are anisotropically smoothed, and 3D segmentation is obtained via MAP classifications of the smoothed posteriors. An active contour model is then applied to extract coronary arteries from the rest of the volumetric data with subvoxel accuracy. By applying their method they obtained 3 branches of the left coronary arteries (LM, LAD, LCX). Moreover the first bifurcation of the LAD is also captured. In paper [8] they proposed to apply a 3D multi-scale filter to the image of interest and isolate the coronary arteries from the filter response. The method in this work is based on Eigen values of the Hessian matrix of a 3D image. By applying their method they also obtained 3 branches of the left coronary arteries (LM, LAD, and LCX).

In this work we first extracted 3D shape of heart using a proposed algorithm then applying Bayes' rule we divide the volumetric heart data into three regions (blood, myocardium and background). We find out the blood filled region because this region includes coronary arteries. A Marching Cube model is then applied to extract the coronary arteries and obtain a 3D geometric model of coronary arteries. Finally a proposed VTK pipeline is applied to visualize the 3D model of extracted left coronary arteries of heart.

2. SEGMENTATION AND VISUALIZATION FRAMEWORK

Overall framework of the implemented work is shown in figure below-

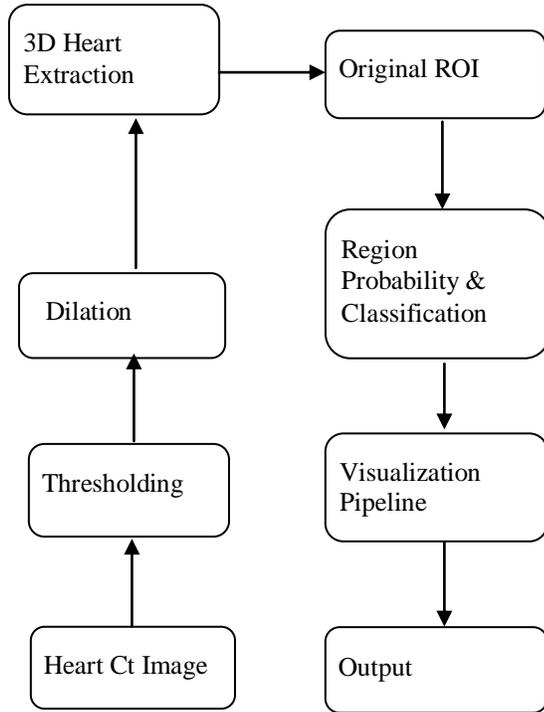


Fig1 segmentation and visualization framework

2.1 Thresholding

In thresholding process image is divided into two parts objects and background. Any point (x, y) for which $f(x, y) > T$ is called an object point otherwise the point is called a background point. It has many variations but in this work we apply simple thresholding operation.

2.2 Dilation

Dilation and erosion are the two primitive operations of morphological image processing. Dilation operation enlarges the object and shrinks the background [9]. In this work heart is the object. In the proposed work a 3X3 structuring element (whose all elements are 1) is multiplied with original image and the greatest value is set to the center of the mask.

2.3 3D heart Shape Extraction: Proposed

Algorithm

3D heart extraction is the important part for our work because without proper extraction of 3D heart shape we cannot extract the vessel exactly. Let R be a subset of pixels in an image. We call R

a region of the image if R is a connected set. In the proposed work region extraction is used to extract the heart and to omit the noise. A focus is fallen on ROI and then extraction of connected component algorithm is used to extract the desired region.

Proposed Algorithm: Let A is an array which contains the pixels of original image, X is an array with equal size A and contains Zero in each cell. B is structuring element, Buff is the buffer to contain index of cell if the image value is 1. After the execution of this algorithm X will contain the extracted heart. The algorithm is stated below—

Set a seed point in $X=1$ and enter the index of this point into Buff

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For each element in Buff
if( ( ( X ⊕ B ) && A ) && (!X) )
{
    X = 1;
    Buff = index of X;
}
    
```

2.4 Region Probability Estimation and Region

Classification

a. Cluster the voxels into three regions (blood-filled region, myocardium and background) using K-means clustering method and calculate the mean value (μ_c) and standard deviation for each class.

b. Calculate the probability density function using the following equation—

$$\Pr(V(x) = v | x \in c) = \frac{1}{\sqrt{2\pi\sigma_c}} \exp\left(-\frac{(v - \mu_c)^2}{2\sigma_c^2}\right)$$

Where $V(x)$ is the intensity value of the voxel at position $x = (x, y, z)$. We assume that the prior probability that a particular voxel will belong to a certain class (blood, myocardium or background) is equal and homogeneous, i.e., $\Pr(x \in c)$ is the same for each class and for all voxels.

c.. Apply the Bayes' rule to calculate the posterior probability [10] that a given voxel belongs to a particular class, given its intensity:

$$\Pr(x \in c | V(x) = v) = \frac{\Pr(v(x) = v | x \in c) \Pr(x \in c)}{\sum_{\gamma} \Pr(V(X) = v | x \in \gamma) \Pr(x \in \gamma)}$$

d.. The classification of the voxels is then obtained using the maximum a posteriori (MAP) probability estimation:

$$C(x) = \arg_{c \in \{bl, m, b\}} \max \Pr^*(x \in c | V(x) = v)$$

bl = blood, m = myocardium and b = background

3. EXTRACTION OF CORONARY ARTERIES: MARCHING CUBE

Marching cube method [11] extracts the various isosurface regions from the blood filled region of the heart. From the various iso-surface regions we have selected the arteries iso-surface

region. The different steps of Marching Cube algorithm is as follows:

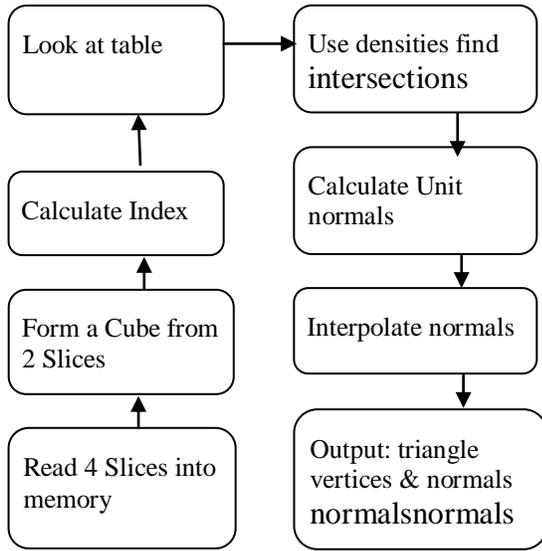


Fig 2: Marching Cube Algorithm steps

4. 3D VISUALIZATION OF THE EXTRACTED LEFT CORONARY ARTERIES OF HEART

Visualization toolkit (VTK) is one of the defacto standards for the visualization of the medical images [12], [13], [14]. For the accurate visualization VTK needs appropriate VTK pipeline. We have designed as well as implemented a VTK pipeline for visualization of the output. Fig3 shows the VTK pipeline.

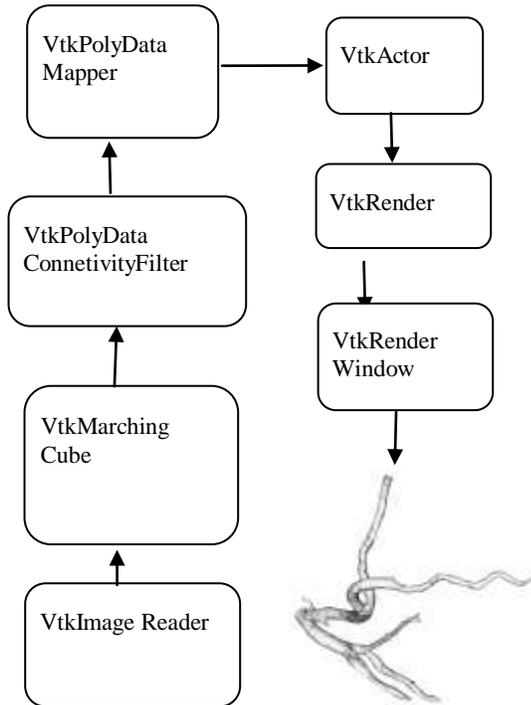


Fig 3: Applied VTK pipeline for artery visualization

vtkImageReader reads DICOM image. vtkMarchingCube generates iso-surfaces from volume. vtkPolyDataConnectivityFilter extracts connected cubes of voxels to form regions of isosurface. vtkPolyDataMapper maps the desired region of image in graphics primitives. In this work desired region is left coronary arteries of heart. vtkActor takes as input the output of a mapper and 'know' how to generate the visible representation of data. vtkRender generates a 2D image from a 3D scene. vtkRenderWindow is the piece of screen real estate in which the virtual camera image is displayed.

5. EXPERIMENTAL RESULT

Figure shows the different steps of the output

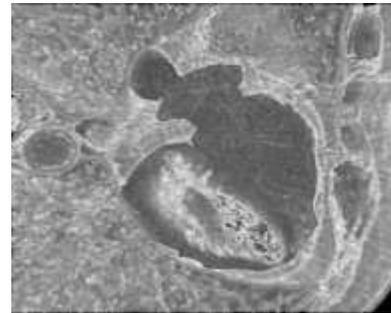


Fig 4a. Volume rendering of original image

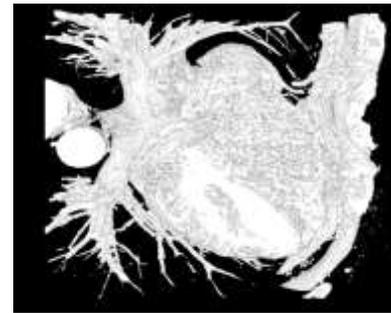


Fig 4b. Thresholding

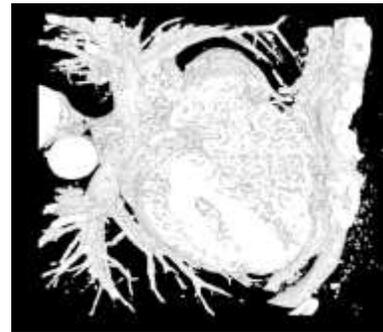


Fig. 4c dilation

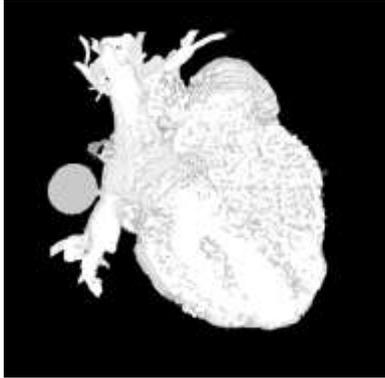


Fig. 4d 3D heart extraction

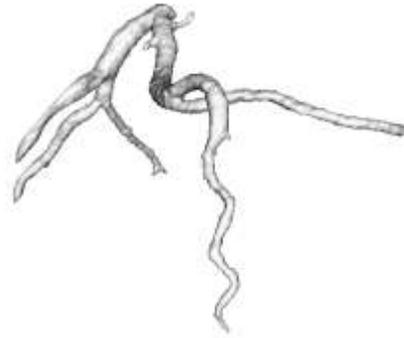


Fig. 4g 3D visualization of left coronary arteries

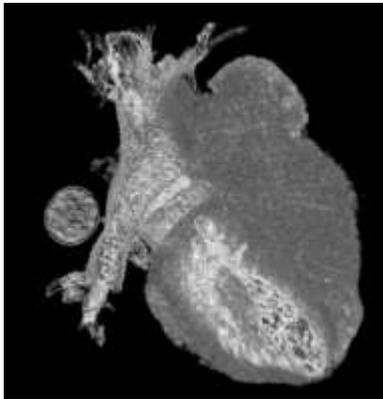


Fig. 4e original ROI image

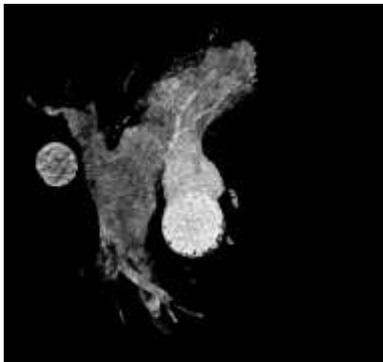


Fig. 4f Region probability and region classification

Fig 4: Steps of segmentation and visualization

Fig-4(a) shows 3D volume rendered input image. Fig-4(b) is the binary 3D output image after threshold operation is performed on Fig-4(a). Fig-4(c) shows the resultant 3D binary image after dilation is performed on Fig-4(b). After applying heart extraction algorithm proposed in section 2.3 on Fig-4(c) we get the 3D binary image shown in Fig-4(d). Fig-4(e) shows 3D gray image of Fig-4(d). Gray value of each pixel in Fig-4(e) is equal to gray value of Fig-4(a). Applying region probability estimation and region classification described in section 2.4 on Fig-4(e) we get the 3D image of Fig-4(f) as result. Region of interest (ROI) in this case is blood filled region of the heart Fig-4(f). Finally, we get the segmented left coronary arteries applying marching cube algorithm on Fig-4(f). Then the proposed VTK pipeline is applied to visualize the segmented arteries.

6. CONCLUSION

The original data had size of $512 \times 512 \times 225$ voxels. That is about 59 million voxels were computed for segmentation. The images were captured by Siemens 64 slice CT scanner. The proposed segmentation framework segmented five branches of the left coronary arteries of heart. The proposed VTK pipeline also visualized the extracted segmented branches exactly.

7. ACKNOWLEDGEMENT

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