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Segmentation of Coronary Artery Images and Detection of Atherosclerosis

Iman Abduljabbar Saad
Electronic Computer Center, Al-Mustansiriyah University, Baghdad, Iraq

Abstract: Millions of individuals are affected by the atherosclerosis which is consider a prevalent disease and leading cause of death in the world also it can cause the coronary artery disease. Since, most of the images which took from X-ray angiographies have different kinds of artifacts such as non-uniform illumination, low contrast, so, the aim of this study is to increase the efficiency of medical segmentation images to provide an integrated diagnostic system that works to distinguish the atherosclerosis. To ensure the performance of the segmentation algorithm with respect to the quality of the input image data, a set of enhancement tasks have been applied to improve the clarity of the artery structure and localize the coronary artery grid. The sub-stages of pre-processing includes: enhancement, segmentation, hole/gaps removal. Also, a method for detection the atherosclerosis is proposed. The successful ration of proposed system was (98%) from artery segmentation stage and 95% for detection atherosclerosis.

Key words: Atherosclerosis, enhancement, segmentation, detection, illumination, algorithm

INTRODUCTION

Coronary arteries are called coronary arteries because they surround the heart as a crown. Coronary heart disease occurs when the flexible muscle layer in the coronary arteries (i.e., arteries that feed the heart) becomes hard. With hardening of the arteries, the lining of the arteries hardens and swells with deposition of large amounts of cholesterol and calcium in the blood forming a plaque. These plates resemble a large pimple that protrudes into the artery canal, causing a partial obstruction that hampers blood flow. The number of these plates varies in people with coronary heart disease (Sigurdsson, 2016; Hagg, 2009). Coronary artery disease is associated with smoking, obesity, high blood pressure and chronic vitamin C deficiency. Having a family history of coronary artery disease is a strong indicator of the risk of developing the disease (Wilson *et al*., 1998). From the ways of arteries techniques to identify the atherosclerosis is X-rays (coronary angiography). It is used after injecting dye into the arteries (femoral or brachial) through using a tube in this artery. The process begins by catheter with local anesthesia in the areas listed above (the femoral artery and the brachial artery) and then twitching down to the aorta through the peripheral arteries. Upon arrival to the heart, dye is injected through the tube and then portrays those arteries (Pike, 2017). The subject of the medical image processing is one of the applications of this research.

Literature review: This study is reviews some of approaches that have been carried on this field and described as follow: Dehkordi *et al*. (2011) presented an study to investigate the coronary vessel extraction and enhancement techniques and presented capabilities of the most important algorithms concerning coronary vessel segmentation. Kumar and Amutha (2014) Suggested algorithm based on a combination of the watershed algorithm and "Discrete wavelet transform" along with "Morphological operations". The back propagation neural was used to classify coronary artery disease images into two types of stenosis type 1 or 2. The images that used to test the proposed algorithm were collected from 50 patients. This algorithm achieves 83.33% abnormal classification and 93.75% normal classification.

Zifan and Liatsis (2016) presented a novel scheme for extracting coronary arteries using 8 patient multivendor cardiac CTA images. A multi-atlas-based method is used to extract heart's region. Threshold preprocessing with subsequent morphological are used for detection a set of seed points which is used for applying statistics-based region growing. Each step of the algorithm is fully automated for an efficient and automated pipeline. This method is achieved (71 and 76%) segmented diseased and healthy vessels, respectively.

Nasr-Esfahani *et al*. (2016) proposed a method based on Convolutional Neural Networks (CNN) to detect vessel areas in angiography images. In the first step, the angiogram images are preprocessed to improve its contrast. And in the second step, the patches of pixels are used to evaluate the angiography images while the CNN is used to determine the vessel and background. The results showed that the proposed method achieved superior results in extracting the vessels.

Sanchez *et al*. a novel method for blood vessel enhancement based on Gabor filters tuned using the optimization strategy of Differential Evolution (DE) is proposed. Through the experimental results, this method achieved an accuracy of 0.9423 for the vessel segmentation, 0.9388 in training when using 40 images and for a test set of 40 images it obtains the highest performance with accuracy 0.9538.

Cruz-Aceves *et al*. (2017) proposed a method to automatically detect coronary artery stenosis in X-ray angiogram images. Firstly, for detection of coronary arteries the "Gaussian Matched Filters" (GMF) are applied. GMF method is tuned in a training step applying differential evolution for the optimization process. Secondly, a thresholding method is applied to extract vessel-like structures from the background of the Gaussian filter response. Thirdly, the Naive Bayes classifier is applied over a 3D feature vector to determine a vessel stenosis problem, accuracy of (0.941) was achieved in terms of vessel detection and segmentation accuracy was (0.962) using test set of 60 angiogram images and also in terms of coronary stenosis detection (0.90) with a test set of 20 patterns.

MATERIALS AND METHODS

This study gives an overview of the proposed algorithm for the segmentation of coronary artery and then detection atherosclerosis. The proposed structure of this method is described in Fig. 1.

Preprocessing: The first stage in the proposed method is the pre-processing. The goal of this stage is to prepare images and remove undesirable effects that have a negative impact on the next stages. In terms of visual appearance, all coronary artery images have different kinds of artifacts such as non-uniform illumination, low contrast between arteries and background. Thus, the artery structure in these poor-quality coronary angiography images is not always well clear and hence, cannot be correctly detected. This leads that artifacts will degrade the performance of the artery segmentation.

Gray image preparation: In this stage, the input RGB-colored image format is converted to gray scale. Each pixel in this image is represented by one byte instead of three bytes. The original image is transformed to the grayscale variant using the following Eq. 1:

$$I(x,y)=\frac{1}{3}\left(I_R(x,y)+I_G(x,y)+I_B(x,y)\right) \quad (1)$$

where, R, G, B alluded to the value of Red, Green and Blue, respectively.

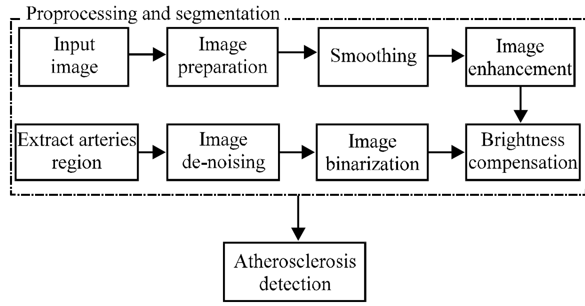

Fig. 1: Layout of proposed method

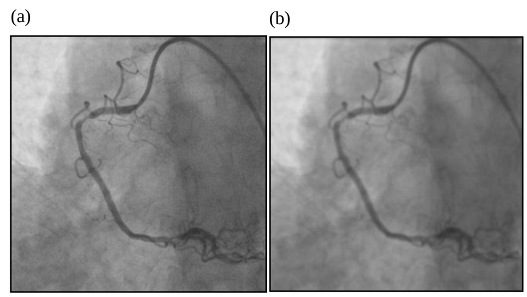

Fig. 2: Smoothed image: a) Gray image and b) Image after applying Gaussian filter

Smoothing: Since, the coronary artery image is noisy, this noise is handled by applying Gaussian filtering which used for smoothing the image as describe in the following Eq. 2 (Shih, 2010):

$$I_{Smooth}(x,y)=\frac{1}{\sqrt{2\pi\sigma^2}}e-\left(x^2+y^2\right)/2\sigma^2 \quad (2)$$

where, σ^2 is the variance and it controls the degree of smoothing in this research the adopted value of σ^2 is taken (0.5) and the kernel size is (5×5). Figure 2 shows the resulted image after smoothing.

Image enhancement: To achieve better image for suitable analysis, contrast enhancement should be done. So, the image brightness is adjusted to cover the whole dynamic range; This adjustment is accomplished by stretching the histogram of the image to cover the full intensity range (i.e., 0.255). The mapping function used for stretching task is a combination of gamma correction and linear contrast stretching functions. Linear contrast stretching is applied to stretch the image pixels values (I_{Enhc}) to be within a determined range (0.255). Gamma mapping is accomplished to enhance the degree of whiteness in bright areas or the blackness degree in dark areas. The combined gamma-linear mapping is accomplished using the following Eq. 3 (Al-Obiadie, 2016):

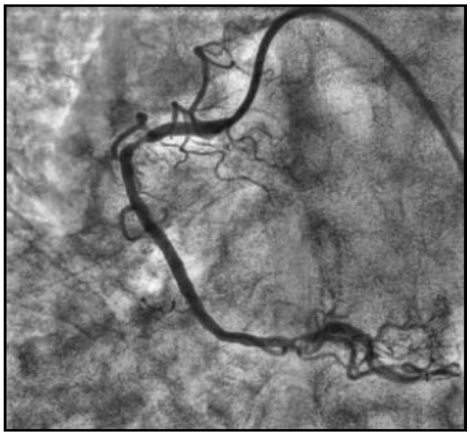

Fig. 3: Image after enhancement

$$I_{Enhc}(x, y) = 255\left(\frac{I_{smooth}(x, y) - G_{min}}{G_{max} - G_{min}}\right)^{\gamma} \quad (3)$$

Where:

I_{smooth} = The smoothed gray-image
γ = Parameter represents the strength of gamma correction
G_{min} and G_{max} = The range of stretching process

Their values are determined using the following Eq. 4 and 5:

$$G_{min} = \mu\text{-}\alpha * \sigma \quad (4)$$

$$G_{max} = \mu\text{+}\alpha * \sigma \quad (5)$$

Where:

μ, σ = The image's mean and standard deviation values, respectively
α = Parameter is used to control the strength of achieved linear extent Fig. 3 shows image enhancement

Image segmentation: Segmentation of coronary artery image means partitioning the image into artery part and a non-artery part. That means it separates pixels according to their values into dual collections, black as foreground and white as background. This stage consists of two steps as follow.

Brightness compensation: Coronary artery image may show different brightness/contrasts distribution for the regions of arteries and other image tissues and this causes degradation of segmentation accuracy because many of image pixels cannot categorized as foreground or background. In this study, the local variation of brightness is compensated using local contrast stretching. A simpler mechanism could be applied to accomplish local thresholding; It is based on making local mapping for the image to compensate the local brightness variations as described in the following mapping steps: the enhanced image $I_{Enhc}()$ is partitioned into non-overlapped blocks with size (n×n). For each block, a scanning window with size (p×p where p>n) is opened which cover block size and extends to the surrounding area. Mean μ and standard deviation σ of the pixels values located inside the window (p×p) are determined. For each pixel that belongs to the scanned block (n×n), the following mapping equation is applied:

$$I_{Str}(x, y) = \begin{cases} I_{Enhc}(x, y) \text{ if } I_{Enhc}(x, y) \geq \mu\text{-}\alpha\sigma \\ \mu - I_{Enhc}(x, y) \text{ otherwise} \end{cases} \quad (6)$$

where, α factor value is 0.5 and the size of block that was adopted in this stage is (4×4). Figure 4 shows image after mapping.

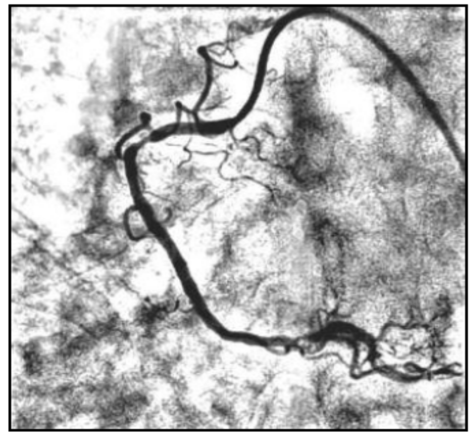

Fig. 4: Image after mapping

Image binarization: After local brightness mapping, thresholding become a good choice for binarization purpose to isolate arteries from the background by selecting an adequate threshold value T which is chosen automatically in the this research. The threshold assessment process is started with calculating the brightness mean value μ of the stretched image and the standard deviation value σ using the following Eq. 7-9 in a large block surrounding certain area of the image as shown in Fig. 5. This T is used as a local threshold value:

$$B_{min} = \mu\text{-}\alpha * \sigma \quad (7)$$

$$B_{max} = \mu\text{+}\alpha * \sigma \quad (8)$$

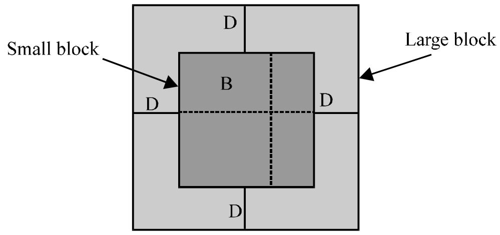

Fig. 5: Local thresholding

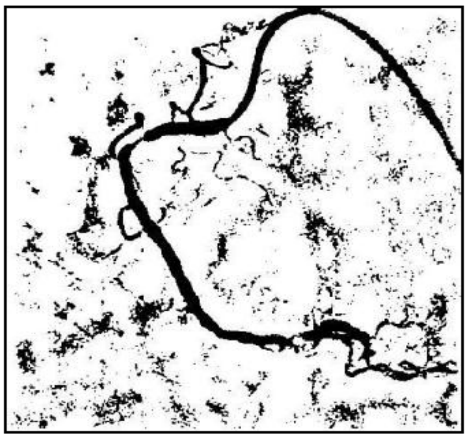

Fig. 6: Image after binarization

$$T = \frac{1}{2}\left(B_{min} + B_{max}\right) \tag{9}$$

where, α is a parameter that used to control the strength of achieved thresholding. The pixels of the small block B that lay within the central area of the large block (where large block width and height equal to B+2D) are binarized by comparing its value with the determined t-value to decide whether each pixel belong to artery or background as describe in the Eq. 10. The result of binary image is shown in Fig. 6:

$$I_{Bin}(x, y) = \begin{cases} 1 \text{ for } I_{Str}(x, y) \geq T \\ 0 \text{ for } I_{Str}(x, y) < T \end{cases} \tag{10}$$

For implementing the next steps, the complement process is applied on the binary image; Black and white are reversed as shown in Fig. 7.

Image de-noising: Median filter is mostly utilized as an efficient tool for noise removing while preserving the contour of the edges. The median filter organizes the pixels in a local window depending on the size of their intensity values and then put the middle value of this intensity order in the pixel value in the resulted image. In the proposed method, the adopted window size is (3×3) and the resulted image is shown in Fig. 8.

Fig. 7: Image after complement

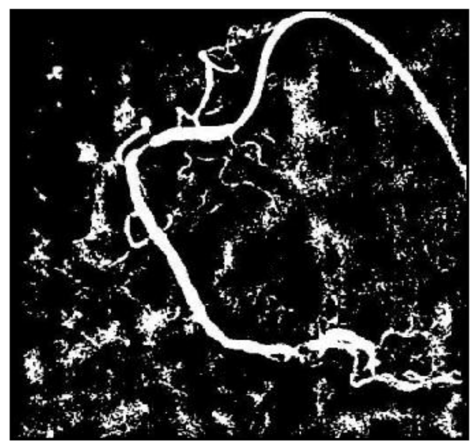

Fig. 8: Image after applying median filter

Extract arteries region: To allocate accurately the shape of arteries, the produced binary image should be enhanced by reducing the noise points (i.e., the holes/gaps) or small extra objects. All holes found in the coronary artery image will be filled in and all patches will be removed. In this study, morphological operators (i.e., seed filling, erosion and dilation) are used for this purpose.

Seed filling is used to enhance the produced binary image which starts with allocating a seed point and then collects all object points that are connected, directly or indirectly with that seed point. Seed filling operation is applied to pick up the unwanted small noise patches and to remove them. To eliminate the noise patches, the four connected neighbors of each artery pixel (e.g., pixel value is one) are checked to see if they are arteries pixels or not. The size of each collected set of pixels is checked and those show largest white size are registered as the arteries region.

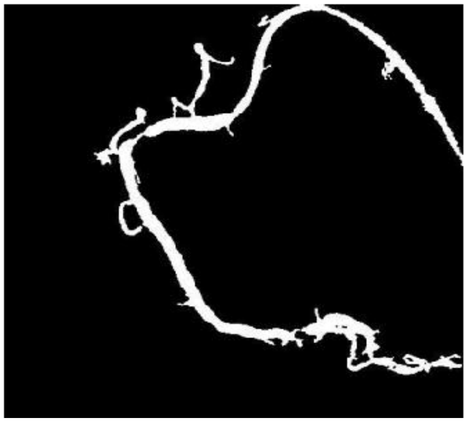

Fig. 9: Image after applying morphological operators

After using the seed filling, the erosion and dilation are used for gaps filling and noise removal. During the image dilation operation (i.e., the addition of pixels next to the border) on image background where its intensity value is black, its eight neighbors are scanned to decide whether it can be considered as a background (remain black) or as artery (converted into white). If the number of black neighbor points greater than threshold value then it is remained black otherwise it is converted into white. Then, for the erosion operation ((i.e., the suppression of the pixels next to the object's border)) each artery pixel its 8 neighbors are checked, if the number of white pixels greater than a predefined threshold value then it remains as it is otherwise it is converted to background pixel. The testing results show that the best value of threshold is set (6). Figure 9 shows the resulted image after applying morphological operators.

Detection of atherosclerosis: The purpose of this stage is detection of the atherosclerosis: stenosis (i.e., the abnormal narrowing of blood passage in the artery) and occlusion in the parts of the coronary artery due to presence fat deposition or calcifications. For detecting of calcification regions in the coronary arteries, artery diameter must be measured thoroughly. Since, thick arteries have a larger width as compared to small narrow ones, due to the presence of calcium or fat deposit in the artery, these differences in arteries sizes, requires use a measurement scale which varies within a certain range.

Centerlines algorithm which is based on skeleton method is used to perform the proposed algorithm for detecting artery atherosclerosis. The skeletonization's method via. morphological thinning (opening operation) which based on the resulted binary image from the previous stages, involves removing all pixels which do not affect the connectedness of a shape which can be determined locally. This thinning operation is applied repeatedly until there is no change yields a skeleton. The

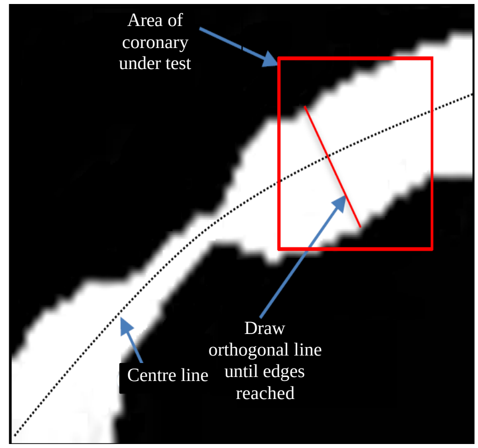

Fig. 10: Image after applying morphological operators

proposed method for detecting artery atherosclerosis is applied depending on the centerline method according to the following steps for each segment of the coronary artery and as shown in Fig. 10.

Step 1: Locate the first point and end point of centerline for the coronary artery segment.

Step 2: From the first point of the centerline drawing orthogonal line on it until reach the edges of the coronary artery.

Step 3: Measure the length of orthogonal line (represents first coronary artery diameter).

Step 4: Scan the coronary artery image by moving a (nxn) window across the centerline to calculate the diameters length.

Step 5: Check length of diameters that resulted from step 4:

- Step 5.1: if there is suddenly reducing of the diameters length to be equal about (50% from the previous diameters length), there is sub branch of the artery
- Step 5.2: if there is gradually reducing of the diameters length to be between (20-30% from the previous diameters length), there is mean a narrowing of the artery
- Step 5.3: if there is gradually increasing of the diameters length to be between (60-70% from the previous diameters length), there is an occlusion which causes expanding of the artery

Step 6: Repeat the step 4 until reach end point of the centerline.

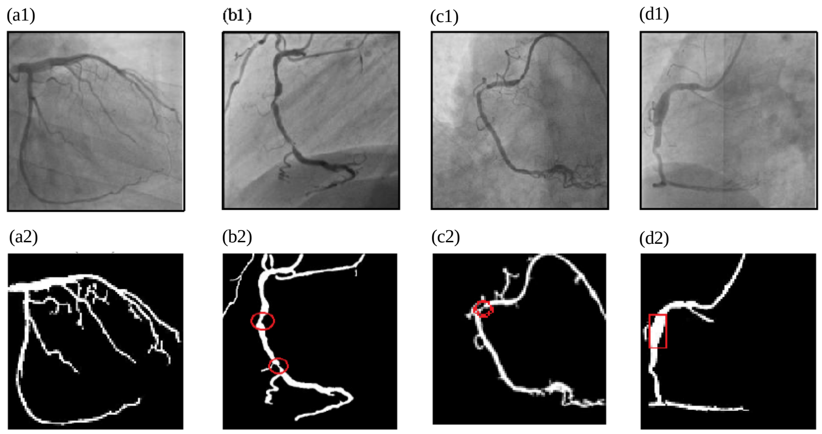

Fig. 11: a2) Results of segmentation artery and detection; b2) Normal artery; c2) Stenosis artery and d2) Occlusion artery

RESULTS AND DISCUSSION

The main focus of this study depends on coronary angiography images that were obtained from heart center in Iraq; The dataset contains 120 images of the heart arteries with resolution 512×512 pixels. Since, the heart feeds two coronary arteries, the right coronary arteries and the left coronary artery, so, there are 50 image for left and right normal arteries and 70 for left and right abnormal arteries (stenosis or occlusion). The proposed methods of the arteries segmentation and detection atherosclerosis are evaluated separately qualitatively and quantitatively.

The qualitative and quantitative evaluation results proved that proposed methods have high precision; It's gives good results reached to 98% in segmentation stage and 95% in detection atherosclerosis stage. The results in Fig. 11 show the effectiveness of the proposed method in the performance of artery segmentation and detection method.

CONCLUSION

In this study, an automatic methods for coronary artery segmentation and detection of the atherosclerosis were proposed. The aim of the proposed steps to eliminate noise and enhance the coronary artery image was to provide a high quality image for extracting the region of interest. So, this method was suitable for enhancement and segmentation the image despite of the large similarity to the pixels that represent the artery and pixels that represent the background in the original gray image. Also, using the morphological operators was good choice to eliminate irrelevant background region and focus only on the foreground where the artery can be found. The use of centerline algorithm with proposed algorithm for detection atherosclerosis led to a correct detection (stenosis or occlusion).

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