An Efficient Technique for Detection and Enhancement of Blood Vessels from Cardiac MRI

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Abstract— **Cardiovascular diseases, mainly caused by stenosis or aneurysms of arteries, are the leading reasons of death worldwide. Angiography, which is not only invasive but also risky, painful and costly, is the common method for the recognition of such diseases. However presently non-invasive and radiation free cardiac MRI is being used to evaluate the function and anatomy of the heart chambers, heart valves and blood flow through major vessels. The morphology, formation and plaque buildup conditions of blood vessels indicates diseases such as heart attack, stroke, angina, arrhythmias, heart failure etc. Thus, the vessels needs to be identified properly and clearly. In this paper, cardiac MRI is used for accurate extraction and enhancement of blood vessel, emphasizing upon the minor and somewhat discontinuous vessels. MRI technique in this field was less explored and is very challenging because of poor contrast difference between the vessels and organs and mentionable amount of noise. The detection process uses both morphological operators and image gradient characteristics. The result obtained by using morphological operators has better effectiveness in terms of noise reduction and accuracy.**

Keywords- Blood Vessels, MRI, Enhancement, Gradient, Morphological operation, Edge detection

I. Introduction

Nowadays, cardiovascular diseases are a major concern among all the human health problems as it is causing death at an increasing rate gradually [1]. Cardiovascular diseases indicate a class of diseases involving heart or blood vessels [2]. Among them inner/outer arterial wall thickness, aortic diseases like blockage, stenosis, plaque, aneurysm and dissection, proximal coronary artery lesions, congenital heart defects, pericardial disease etc. are worth mentionable [3]. According to the World Health Organisation (WHO), an expected 17.9 million people die every year from cardiac vascular diseases, which is of 31% of global deaths [4]. This statistics indicates the leading to many more deaths because of CVDs in the near future. It also emphasizes on the need of early diagnosis of CVD's and their effective treatment.

Heart diseases are mainly diagnosed using coronary angiogram, which makes use of X-ray imaging to observe blood vessels of the heart [5]. It is performed by inserting catheter in an artery in patient's groin or arm and threading through the blood vessels of his heart [6]. This process is risky and painful for the patient and also causes morbidity at 1.5% rate and mortality at 0.2% rate each year [7]. Although it is being commonly used to detect coronary diseases, it is an invasive process and takes a lot of preparations and post processing [6], [8]. Fig. 1 shows the angiography technique partly.

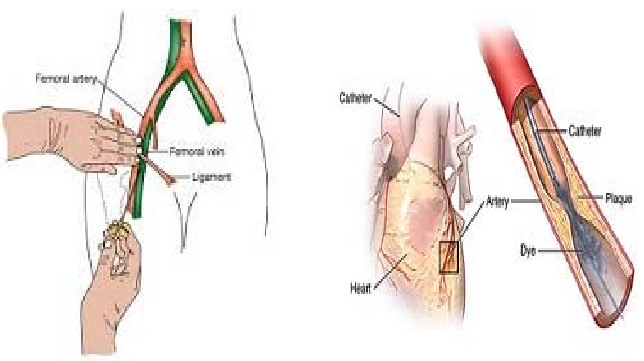

Fig. 1: Angiography technique [9], [10]

To overcome these difficulties, techniques like MRI, Nuclear Medicine, CT, Ultrasound are cardiac imaging techniques, which are most commonly used [11]. Among them, Cardiac magnetic resonance (CMR) imaging is a promptly evolving field due to its recent technical development providing high resolution and high contrast 3-dimensional images of the patients' heart, coronary vessels

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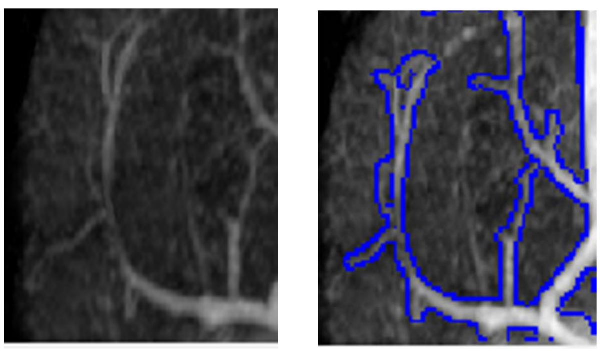
and the great vessels without causing pain and without subjecting him/her to ionizing radiation [12]. In the last few decades, revolutionary impacts have been made in healthcare from the provision of pathological and morphological information obtained from medical imaging. Cardiac MRI provides clear anatomical and functional information of the heart with the capacity of providing a wide field of view (FOV) and good contrast between the soft tissues [13], [14].Proper extraction and accurate interpretation of this information can ensure the development of new clinical applications contributing to the improvement in cardiology sector.

Various methods were employed before to perform segmentation of blood vessels in different body tissues such as the lungs, retina, liver and breasts [15]. A study by Shang et al. is prominent in this field [16]. They proposed to use a region growing technique inside a tube along with the direction of the detached vessel's end point. However, the algorithm might lead to false positives yielding areas greater than the tubular vessel structure. Another study is of Wink et al. [17]. It describes a different methodology of multiple vessel tracking at minimum cost path. The success of the method included coping with stenosis, noise and other difficult image conditions. This method had difficulty to cope with situations where blood vessels are curved. To perform blood vessel detection surrounding the areas of the heart and liver, the main challenge is to segment the vessels from the background due to very low contrast difference. Besides, the challenge is amplified in this case owing to the existence of fat and connective tissues and curved blood vessels at different points. Due to the previous studies, development of imaging the vessels is not difficult anymore, but the segmentation and enhancement of blood vessels especially those, which are unclear, detached or very small, is the challenge. The more promising issue is the detection from MRI owing to the anatomical formation and connectivity of blood vessels and other organs and same color contrast. In this paper, the detection of vessels that has been difficult due to their going through the organs' muscles and random curvature was the main challenge.



(a) Discontinuous vessel before processing

(b) Vessel detected after processing

Fig. 2: Hepatic artery

Since the use of MRI for such detection of vessels is relatively a new approach, the availability of dataset to be used for this purpose was not enough. The hospitals in Bangladesh could provide no cardiac MRI data as doctors are not familiar enough with the technique to detect the cardiac diseases from MRI. The purposes of this paper are to detect the blood vessels from cardiac MRI and enhancing them using necessary image processing techniques to identify the indication of diseases. Moreover, the unseen or visibly discontinuous vessels going through the muscles are also detected by using image gradient property. Another precise algorithm used for the detection purpose is done by means of morphological operators, which gives the clear and informative view of the vessels after processing the image. The aim is to compare the two different methods for apprehending the blood vessels clearly in a better and precise way.

II. ANALYTICAL TOOLS

A. Gradient

Gradient is a multi-variable generalization of the derivative. Every pixel of a gradient image processes the intensity change of the same point in the main image in a given direction [18]. The largest gradient values of the pixels in the gradient direction become edge pixels, and it can be traced in the direction perpendicular to the gradient direction. Mathematically, the image gradient intensity function at each image point is a two-dimensional vector whose components are given by the vertical and horizontal directional derivatives [19]. The components of the gradient in coordinates are the variables coefficients in the equation of the tangent space. In the 2-dimensional Cartesian coordinate system with a Euclidean metric, the gradient is given by

$$\nabla f = \frac{\partial f}{\partial x}\,\mathrm{i} + \frac{\partial f}{\partial y}\,j = \begin{bmatrix} g_y \\ g_x \end{bmatrix} \qquad (1)$$

Refer to "(1),"

$\frac{\partial f}{\partial x}$ is the derivative with respect to x (gradient in the x direction)

$\frac{\partial f}{\partial y}$ is the derivative with respect to y (gradient in the y direction)

The direction of the gradient can be determined by the formula:

$$\theta = \tan^{-1}\frac{g_y}{g_x} \qquad (2)$$

At every image point, the largest possible intensity increase is pointed by the gradient vector. The gradient vector length relates to the rate of change in the direction. Fig. 3 shows the gradient magnitude and direction for change of pixel intensity.

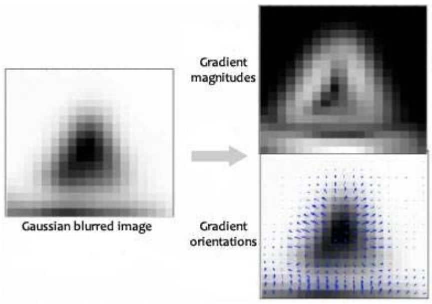


Fig. 3: Gradient magnitude and direction change from pixel to pixel [20]

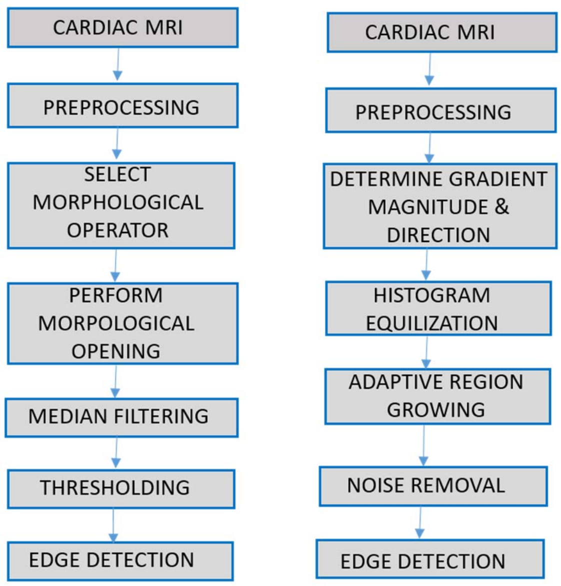
B. Morphological operators

A broad range of image processing operations that develops images based on shapes is called morphology [21]. In a morphological operation, each pixel is adjusted based on the value of other pixels in its neighborhood. By choosing the shape and size of the region, a morphological operation can be created that is sensitive to precise shapes in the input image. The morphological operator used for the purpose of enhancement and detection of vessel includes dilation, erosion and opening based on appropriate morphological structuring element.

In case of dilation, pixels are added to the object boundaries of an image. On the other hand, erosion removes pixels from object boundaries [22]. The structuring elements applied to process the image determine the pixel numbers to be added or removed from the object within the image. In this method, the structuring elements were chosen corresponding to the size and shape of the related organs connected to the vessels.

III. Methodology

Cardiac Magnetic Resonance Image has been chosen for blood vessel detection in the proposed method as MRI scans produce detailed images of internal body structures and soft tissues by using strong magnetic fields and RF pulses.



(a) Steps using morphological operator (b) Steps using gradient magnitude and direction

Fig. 4: Overview of proposed method

Dissimilarities between abnormal and normal tissue is often more vivid on an MRI and no radiation is involved here. Initially after adjusting the contrast of the image, other processing steps are performed to enhance the vessels and to extract the vessel edge. This necessitates following steps showed in Fig.4

A.Preprocessing

The preprocessing step is required to increase the image contrast as well as to prepare the image for the application of preceding steps. The input MRI is shown in Fig. 5. After resizing the input cardiac MR image, the image adjusting process is applied using MATLAB. The image intensity contrast is enhanced by using contrast stretching function to transform the values. The contrast of the output image is increased after converting the RGB image into gray scale image. The image is then complemented to calculate the light and dark areas of the image. In order to improve the gray scale image contrast, adaptive histogram equalization technique is used.

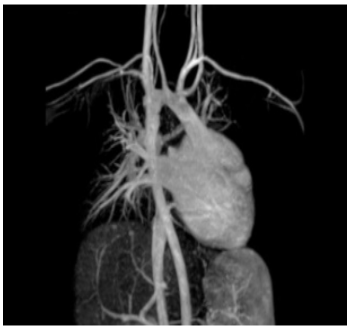
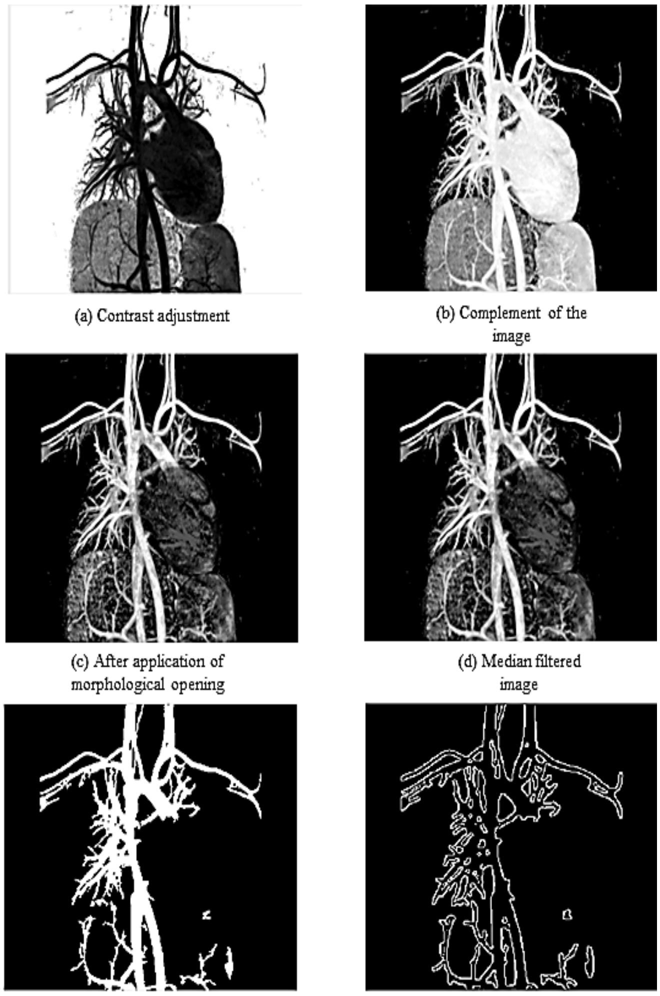


Fig. 5: Input cardiac MRI

B.Enhancement of vessels

Using Morphological Operators: Morphological operators are used to eliminate the imperfections in image structure. The used operations are a combination of two procedures, erosion and dilation. Structuring element which is a small matrix structure is used for the purpose of the operation. Morphological structuring elements declaring different shapes and radius are used to determine the shapes of different organs. The structuring elements used here are ball and disk. Morphological structuring element as well as morphological open operation are used to process the image to obtain the prominent view of the vessels from the background.

Using Gradient Magnitude: The gradient magnitude and direction can also be utilized for the enhancement of the required vessel structures. The contrast adjusted image is transformed into gradient image using first order partial differential operator [23] giving both the change in magnitude and direction of pixel contrast intensity for each pixel in the image. Each vessel indicated as parallel edges will be fragmented by applying Adaptive region growing system. The contrast of the vessels is not stable and so it is impracticable to segment the vessel edges applying threshold value. The gradient direction also changes as the vessels have a curvilinear structure. Thus, Adaptive value of gradient magnitude along with region growing is applied to segment the edges. Though this method can detect the minor and partly discontinuous vessels,the noise elements in the background also gets amplified .



(a) Contrast adjustment

(b) Complement of the image

(c) After application of morphological opening

(d) Median filtered image

Binary image from multiscale thresholding

(f) Edge detected by Canny edge detector

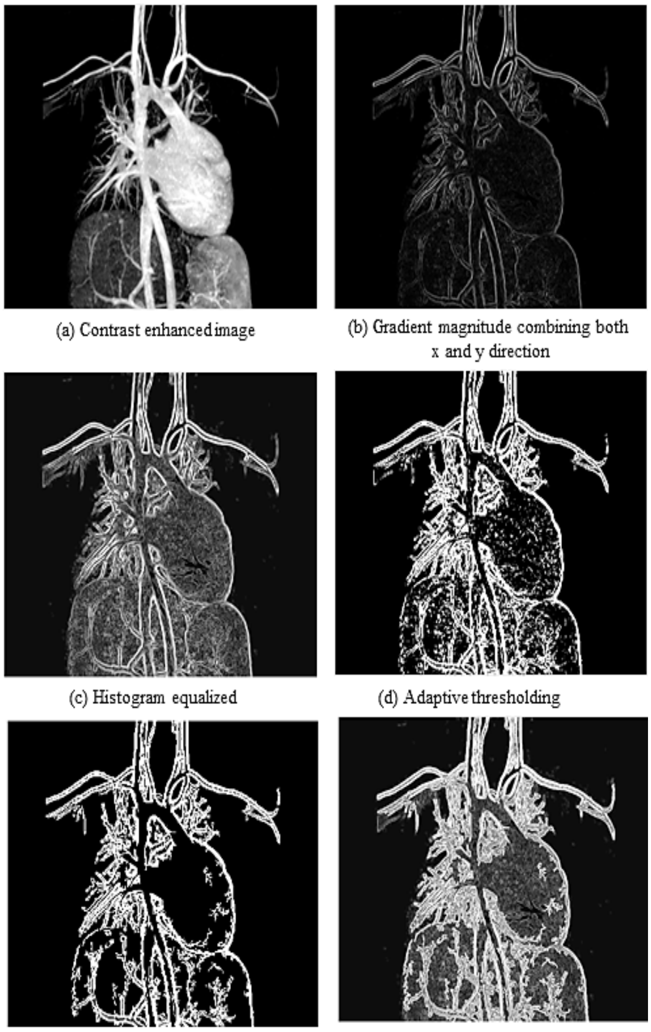
Fig. 6: Steps of enhancement using morphological operators

C.Median filtering

A nonlinear operation, Median filter is used to reduce noise from the background while preserving the edges. Since cardiac blood vessels have poor contrast difference, some noise is added to the image after performing morphological opening. A one-dimensional median filter of window size [3, 3] is used to reduce the noise and retain the edges necessary for detection.

D.Thresholding

The median filter image is processed by a proper multi scale thresholding technique in order to extract the vessel segments from the background. An efficient adaptive entropy based thresholding method is used which considers the spatial distribution of grey level since the image pixel intensities are dependent on each other. The grey levels detected from the multi scale technique gives the optimal threshold for the object of interest and background classification. The output of this step is a binarized image, which separates the vessels from the background very clearly.



(a) Contrast enhanced image

(b) Gradient magnitude combining both x and y direction

(c) Histogram equalized

(d) Adaptive thresholding

(e) Noise removal

(f) Vessel enhanced image

Fig. 7: Steps of Enhancement using gradient magnitude

E.Edge detection

To improve the detection of edges, it is necessary to find out the intensity changes in the surrounding area of a pixel [24]. This is achieved by finding the gradient magnitude of the image. However, gradient calculation based on intensity values are susceptible to noise and can often lead to the detection of some false edges. On the other hand, the edge points detected from the thresholded binary image present much stronger edge details. In our proposed method, we used the CANNY edge detector for proper detection of the edges to improve the presentation of edge detection with respect to noise. In the trade of between noise reduction and edge strength, the edge obtained from gradient gives more details at the cost of increased noise while the edge obtained from the threshold image after morphological operation compromises the detailing.

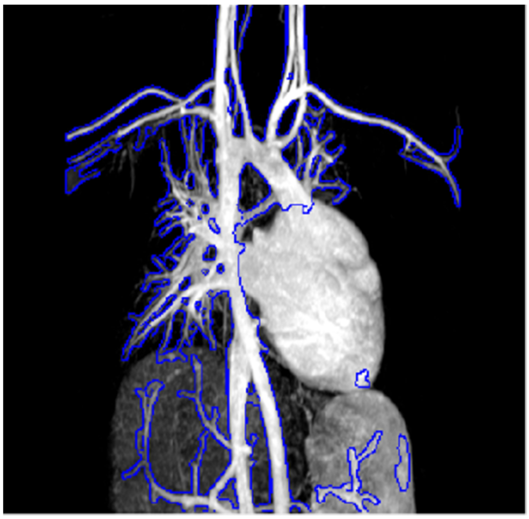


Fig. 8: Vessel enhanced Image after detection of vessel edges

IV. RESULT AND DISCUSSION

Fig. 8 shows the input cardiac MRI with the vessels enhanced after effective detection of the vessel edges and separating them from the background. The enhancement of the blood vessels was conducted by following two different algorithms, both of which had its own pros and cons. However, for the purpose of our paper, the edge detection following the algorithm involving morphological operators seemed to present a better overall performance. The outputs obtained after using different steps of our proposed method attached in Fig. 6 and Fig. 7 respectively give a clear indication that the first method reduces the noise level quite remarkably. The small vessels measuring 4.23 mm wide, as well as discontinuous vessel like the hepatic artery could be detected. The enhanced vessel segment was overlaid on the original MRI to highlight the vessels of interest from the background.

V. PERFORMANCE ANALYSIS

We used two different techniques for the enhancement of the blood vessels. “Fig. 6” shows the steps involved in enhancement by using morphological operator. From the figure, it is clear that this technique reduces the background noise surrounding the vessels and makes it easier to detect them. However, some minor vessels could not be traced precisely. Now, our second method using gradient magnitude to enhance vessels has been presented in “Fig. 7”. Though this method identifies some discontinuous vessels, it increases the noise level. This makes it difficult to detect the vessels properly. Therefore, after carrying out both the methods it is clear that the first method gives better output as our objective is to enhance the vessels properly so that more vessels can be detected with precision

VI. CONCLUSION

This paper presents efficient method for enhancement and detection of blood vessels surrounding the heart from cardiac MRI. The morphology, turbidity and orientation of these vessels give indication of diseases such as angina, heart attack, heart failure, carotid aneurysm etc. The foremost requirement for such analysis is the correct and robust detection of the vessels of interest. Both the major and minor vessels were detected almost precisely in this paper using morphological operations and gradient magnitudes. Due to lack of availability of cardiac MRI in the prospect of Bangladesh, our algorithm could not be applied on different sets of data. We would like to use our algorithm on a larger set of database for better validation of the methods used. The detected vessels can further be analyzed for determination of inner and outer width, orientation and formation to get prior knowledge about compromised heart conditions.

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