

Frangi's Vessel Detection Approach for Coronary Angiogram Segmentation

Geethu Sasidharan¹, Angitha George²

PG Scholar¹, Assistant Professor²

Computer Science and Engineering

St. Joseph's College of Engineering and Technology, Pala^{1,2}

Abstract— Now a day, cardiovascular disease is a serious problem to human health. For better clinical assessment of vascular diseases, the extraction and segmentation of coronary artery from X-ray angiographic images is very important. In this paper, a simple and powerful method for coronary artery segmentation from X-ray angiogram is proposed. This method combines Noise Adaptive Fuzzy Switching Median (NAFSM) filter, Frangi's vessel detection and Region Growing. This method uses Noise Adaptive Fuzzy Switching Median filter to enhance angiographic images. Frangi's vessel detection helps to detect vessels in coronary angiogram. The region-growing algorithm is used to segment detected coronary artery tree. The proposed method is robust to noise in angiograms. This method can successfully extract almost all distant, overlapped and smaller vessels of the coronary artery tree.

Keywords— Coronary angiograms, NAFSM filter, Frangi's vessel detection, Region growing.

I. INTRODUCTION

Now a day, cardiovascular disease is a serious problem to human health; it takes 13 million lives in each year. Block and stenosis are main problems with coronary artery. The coronary artery plays an important role in blood supply to heart. It carries oxygen rich blood to heart. So a problem in coronary vessel may cause angina, heart attack, Coronary Heart Disease (CHD) etc. Hence accurate assessment of coronary artery tree is important for diagnosis.

One of the gold standards of heart disease diagnosis is coronary angiography, in Fig. 1. Usually X-ray angiograms are most widely used. But the interpretation to the angiogram is very difficult because of noise, vessel overlap and foreshortening of vessel. For proper clinical assessment of cardiovascular diseases, coronary angiogram segmentation is important.

Coronary artery segmentation process is a challenging task because of its complex structure, numerous branches and low contrast of angiograms.

II. PROPOSED SYSTEM

Proposed system is Frangi's vessel detection approach for coronary angiogram segmentation. The system contains three modules- Noise Adaptive Fuzzy Switching Median Filter (NAFSM filter), Frangi's vessel detection and region growing. It uses Noise Adaptive Fuzzy Switching Median Filter for angiogram enhancement and Frangi's vessel detection to

detect coronary branches. For segmentation, it uses region growing. Flow chart of the proposed system is shown in Fig. 2.

Fig. 1: X-ray angiogram of coronary artery



Coronary Angiogram

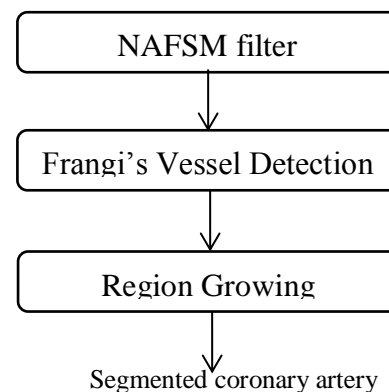


Fig 2: Proposed system

A. Noise Adaptive Fuzzy Switching Median Filter (NAFSM Filter)

Noise Adaptive Fuzzy Switching Median (NAFSM) filter [2][3] is used to remove salt and pepper noise from angiogram. All noise pixels are subjected to filtering

operation. If a noise free pixel is identified it is maintained in the output. The filter has two phases: - a detection phase and a filtering phase.

1) *Detection phase*: NAFSM filter uses histogram to estimate the two noise intensities, L_{salt} and L_{pepper} . This estimation is based on the assumption that an image containing salt-and-pepper noise will generate two peaks at the image histogram. So the detection stage starts by searching for two peak intensities.

These two intensities of salt-and-pepper noise are used to identify noise pixels in the image. A binary noise mask $N(i, j)$ is created to mark the noise pixel positions, as given below.

$$N(i, j) = \begin{cases} 0, & I(i, j) = L_{salt} \text{ OR } L_{pepper} \\ 1, & \text{otherwise} \end{cases} \quad (1)$$

where $I(i, j)$ is the pixel located at position (i, j) with intensity value I , $N(i, j) = 1$ represents noise-free pixels, it is maintained in the image. But $N(i, j) = 0$ represents noisy pixels, which is subjected to the filtering operation.

2) *Filtering Phase*: In this phase, all noise pixels that is pixels whose mask is set to 0 ($N(i, j) = 0$) are replaced by a correlation term. Here the filter uses a square filtering window of odd dimensions, given by

$$W_{2s+1}(i, j) = \{I(i+m, j+n)\} \text{ where } m, n \in (-s, s) \quad (2)$$

The filtering window size is initialized to $3 \times 3 (s=1)$. Then, number of noise free pixels in the window is calculated.

$$G_{2s+1}(i, j) = \sum_{m,n \in (-s, s)} N(i+m, j+n) \quad (3)$$

If the current filtering window does not have at least one noise free pixel, then the filtering window is expanded by one pixel at each of the four sides of the window. This procedure is repeated until the condition met. The noise free pixels are used to calculate the median pixel value.

$$M(i, j) = \text{Median}\{I(i+m, j+n)\} \text{ having } N(i+m, j+n) = 1 \quad (4)$$

Then local information in the filtering window is computed. This local information is known as local absolute luminance difference of pixel, given by

$$d(i+k, j+l) = \{I(i+k, j+l) - I(i, j)\} \quad (5)$$

Then maximum absolute luminance difference is calculated using this local information, this is given by

$$D(i, j) = \text{Max}\{d(i+k, j+l)\} \quad (6)$$

Then fuzzy reasoning is applied to the extracted maximum absolute luminance difference $D(i, j)$. This helps the filter to produce an accurate correction term.

$$F(i, j) = \begin{cases} 0, & D(i, j) < T_1 \\ 1 - e^{-aD(i,j)} \frac{D(i,j)-T_1}{T_2-T_1}, & T_1 \leq D(i, j) < T_2 \\ 1, & D(i, j) \geq T_2 \end{cases} \quad (7)$$

Where, T_1 and T_2 are thresholds. For optimal performance, the value of a , T_1 and T_2 are 0.5, 10 and 30 respectively.

The correlation term for restoring the noise pixels is given by

$$Y(i, j) = [I - F(i, j)] \cdot I(i, j) + F(i, j) \cdot M(i, j) \quad (8)$$

B. Frangi's Vessel Detection

In an angiogram image, blood vessels are less visible. So detection of blood vessels is important. Frangi's vessel detection is used for this purpose [5][7]. It uses eigenvalues of hessian matrix to find out tubular structures. Eigenvalues can indicate characteristics of 3D curved surfaces. In Frangi's method, 2D pixels are represented in 3D by adding intensity value as Z-coordinate, as shown below,

$$C = (x, y, I) \quad (9)$$

Where, I is the intensity of pixel (x, y) . Hessian matrix is the second order partial derivative of a function. It is given by

$$H = \begin{pmatrix} I_{xx}(x, y) & I_{xy}(x, y) \\ I_{yx}(x, y) & I_{yy}(x, y) \end{pmatrix} \quad (10)$$

From this hessian matrix, two eigenvalues can be calculated for each pixel. For tubular structures such as vessels, one of the eigenvalues will be a large negative value e_1 and the other will be a small positive or negative value e_2 . That is, $|e_2| \ll |e_1|$. The structure of vessel is extracted using the following equation,

$$V(x, y, e_1) = \begin{cases} \text{Log}(|e_1|+1), & e_1 < -1 \\ 0, & \text{otherwise} \end{cases} \quad (11)$$

To extract small and distant vessels, this operation is performed in different scales. Then maximum of V is calculated across multiple scales for getting final result. That is,

$$F(x, y) = \text{max}\{V(x, y, e_1(\sigma))\} \quad (12)$$

Where, σ is the scales. $\sigma = \sigma_1, \sigma_2, \dots, \sigma_n$.

C. Region Growing

Segmentation is the process of partitioning an image into its constituent regions. It is a very important step in visualization, image analysis, object representation, and many other image processing tasks. So the final result of medical image analysis depends on success or failure of segmentation. The vessel segmentation technique is a bottleneck of medical image processing. So fast, accurate and effective segmentation of vascular structures becomes an important issue.

One of the most efficient techniques for segmentation is region growing [4][6]. The region-growing algorithm consists of three stages: - seed selecting, growing rules and convergence principle. The algorithm starts with a single pixel, known as seed pixel and adds new pixels to the region of seed. The region growing algorithm is given below.

- i. Select a seed pixel.
- ii. Select each neighbouring pixels and add them to the region, if identical to the seed.
- iii. Repeat *step ii* for each of the new pixels. Terminate the process if no more pixels can be added.

The selection of seed point depends on nature of image. A seed should have following properties.

- It should be within the region area and close to the region's centre.
- The feature of the seed should be close to the region average.
- For an expected region, at least one seed must be generated to produce this region.

A histogram can be used to calculate seed point automatically. Choose the grey level value corresponding to the strongest peak in the histogram as seed.

Algorithm for calculating threshold value using histogram is given below.

1. Select an initial estimate for T .
2. Segment the image using T . Produce two groups of pixels.
 - a. Group₁ consisting of all pixels with grey level values $>T$.
 - b. Group₂ consisting of pixels with values $\leq T$.
3. Compute the average grey level values avg_1 and avg_2 for the pixels in regions Group₁ and Group₂.
4. Compute a new threshold value

$$T = (1/2)(avg_1 + avg_2)$$
5. Repeat steps 2 to 4 until $T < a$ predefined parameter T_0 .

The growing rule based on this threshold is established, it is given as

$$|I(x, y) - mean(x, y)| < T \quad (13)$$

If this condition is true, then pixel (x, y) is added to the region. Where $I(x, y)$ is the grey scale value of the pixel and $mean(x, y)$ is the mean intensity of pixels in the current window that is the mean intensity of seed pixel and its eight neighbours. The segmentation process terminate, if no pixels are found to match the above condition.

III. EXPERIMENTAL RESULTS

The proposed system was tested on 42 coronary angiographic images. The system was implemented in MATLAB 2011a on an Intel core i3 processor.

The proposed system has several characteristics i) It can successfully remove noise in angiogram ii) it can detect all vessel branches without human intervention iii) can accurately segment the complete vessel area.

The execution time T can be divided into, one minor component T_1 and two major components T_2 and T_3 . Where

T_1 is the time taken for vessel enhancement, and T_2 and T_3 are time taken for vessel detection and segmentation respectively.

A. Noise Adaptive Fuzzy Switching Median (NAFSM) filter

Noise Adaptive Fuzzy Switching Median filter is used to enhance angiogram by removing this noise. The filter consists of two phases: - detection phase and filtering phase.

In detection phase, all noisy pixels are detected. This is obtained by checking the intensity of each pixel. If the pixel intensity is either 0 or 255 (pixel intensity value 0 represents pepper noise and 1 represents salt noise), then the pixel is marked as noisy. For each pixel a noise mask is created. Mask of noisy pixel will be 0 and that of noise free pixels will be 1.

In Filtering phase, only noisy pixels (pixels whose noise mask is 0) are subjected to filtering operation. A filtering window of odd dimension (3x3, 5x5 etc.) is used in this phase. The median value and maximum absolute luminance difference are used to calculate the correction term. Also fuzzy reasoning is applied to maximum absolute luminance difference to calculate the probability of luminance difference. It uses three constants a , T_1 and T_2 , they are set to .5, 10 and 30 respectively.

Since it process only noisy pixels the output of the NAFSM filter is not blurred. Thus the filter can produce an accurate result. The output of the NAFSM filter is shown in fig 3.

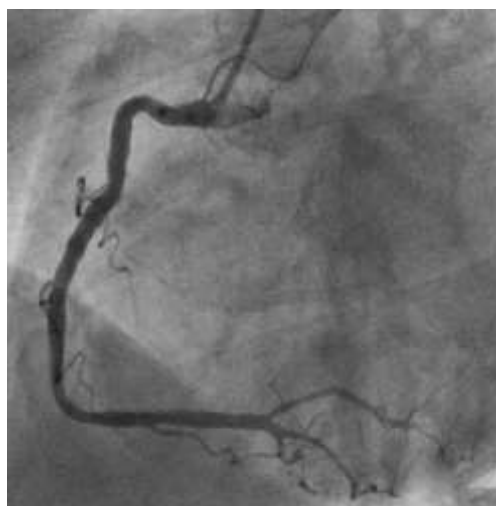


Fig 3: Enhanced angiogram using NAFSM filter

B. Frangi's Vessel Detection

Frangi's vessel detection is used to detect the vessel branches. It is based on eigenvalues of hessian matrix. Eigenvalues are important to find out tubular structures in images. In Frangi's method it gives each pixel a 3D representation. It is done by adding the intensity value of each pixel as the Z-coordinate.

Hessian matrix is a square matrix of partial derivative of a function. The detector finds out hessian matrix of each pixel and calculates the eigenvalues corresponding to each pixel. This helps it to determine, whether the pixel is a part of a

tubular structure or not. From hessian matrix two eigenvalues will get: $-e_1$ and e_2 . For tubular structures such as vessels, one of the eigenvalue will be a large negative value (e_1) and other will be a small positive or negative value (around zero) such that $|e_1| \gg |e_2|$.

Based on e_1 , the structure of the vessel is extracted. It is performed in different scales to extract smaller, distant and overlapped vessels in angiogram. In this project five different scales such as 1 to 10 in the interval of 2. The output of the vessel detection is shown in fig 4.

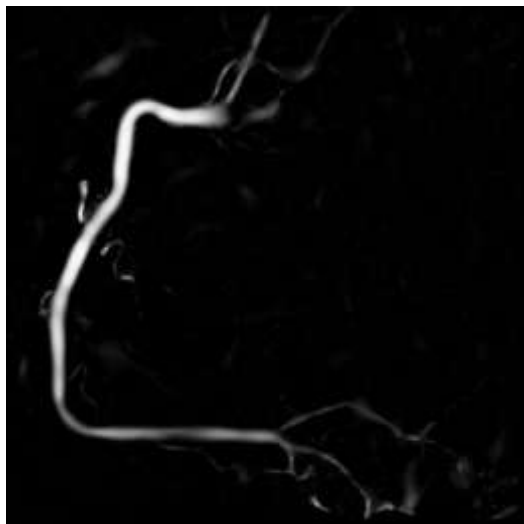


Fig 4: output of Frangi's vessel detection

C. Region Growing

In this project region growing is used to segment the coronary artery from angiogram. It is one of the most simplest and efficient segmentation methods. This module takes input from Frangi's vessel detection module.

The region growing algorithm starts by selecting a seed pixel. In this project the used manually select the seed pixel. This seed should be a pixel inside the desired region. Initially, the region contain only seed pixel, then it grows by adding new pixels to the region.

A new pixel is added to the region if it is similar to the region. The homogeneity can be checked based on any region characteristic such as average intensity, texture, colour, shape, size, variance etc. In this project average intensity is used.

$$|I(x, y) - \text{mean}(x, y)| < \delta \quad (13)$$

If this condition is true, then pixel (x, y) is added to the region. In this project, the threshold δ is set to 0.069. The segmentation process terminate, if no pixels are found to match the above condition. The output of region growing is shown in fig 5.



Fig 5: Result of region growing, the segmented coronary artery

The system is tested on about 40 angiograms. Some of the results are shown in fig. 6.

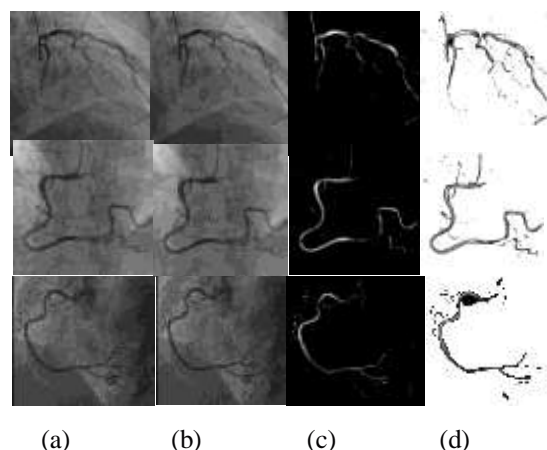


Fig 6: Sample outputs of proposed system. (a) Input image, (b) NAFSM filter, (c) Frangi's Vessel Detection (d) Region Growing.

IV. CONCLUSION

The proposed Frangi's vessel detection approach for coronary angiogram segmentation is able to provide an accurate segmentation of vascular tree. It effectively suppresses noise and can extract small and distant vessels. Noise Adaptive Fuzzy Switching Median filter avoids blurring of output by processing only noisy pixels. The adaptive behaviour of the filter enables to expand the filtering window size based on local noise density. Switching behaviour speeds up the filtering process and at the same time preserving image details by selecting only noise pixels. Fuzzy reasoning of the filter helps the system to produce an accurate correction term when restoring noise pixels.

The use of Frangi's vessel detection approach guarantees accurate output. Usually vessels in angiographic images are less visible. Frangi's method uses eigenvalues of hessian

matrix, which helps the system to detect all vessel tree branches. It is a multi-scale vessel detection approach. This feature helps to detect smaller vessels. Thus the proposed system can detect distant, overlapped and smaller vessels in the X-ray angiogram image. From the Franfi's output image, region growing module precisely segments the complete vascular tree. It is the simplest region based segmentation that groups pixels into large regions based on pre-defined criteria. In this project pixel intensity is used to check similarity. Region growing can correctly separate the regions. It can provide the original images which have clear edges with good segmentation results. The system is a simple and efficient approach for coronary angiogram segmentation, and requires a less computational effort.

REFERENCES

- [1] A Segmentation method of Coronary Angiograms based on Multi-scale Filtering and Region Growing , Shan Wang, Bonian Li, and Shoujun Zhou, 2012 International Conference on Biomedical Engineering and Biotechnology, 978-0-7695-4706-0/12 \$26.00 © 2012 IEEE DOI 10.1109/iCBEB.2012.39.
- [2] Noise-removing Algorithm for Fluorescein Angiogram of Diabetic Retinopathy, Zhang Jie and Li Shi-Yun, 2011 4th International Conference on Biomedical Engineering and Informatics (BMEI), 978-1-4244-9352-4/11/\$26.00 ©2011 IEEE.
- [3] Noise Adaptive Fuzzy Switching Median Filter for salt-and pepper noise reduction, Kenny Kal Vin Toh and Nor Ashidi Mat Isa, IEEE Signal Processing. Letters, vol. 17, pp. 281-284, March 2010.
- [4] Segmentation of Pulmonary Nodules in Thoracic CT Scans: A Region Growing Approach, Jamshid Dehmeshki, Hamdan Amin, Manlio Valdivieso, and Xujiang Ye, IEEE TRANSACTIONS ON MEDICAL IMAGING, VOL. 27, NO. 4, APRIL 2008.
- [5] Alejandro F. Frangi,Wiro J.Niessen, et al. "Multiscale vessel enhancement filtering." Medical Image Computing and computer-Assisted Intervention-MICCAI'98. 1998,1496:130:137.
- [6] Digital image processing, third edition, Rafael C Gonzales and Richard E Woods.
- [7] 3D frangi-based lung vessel enhancement filter penalizing airways, Daniel Jimenez-Carretero, Andres Santos, Sjoerd Kerkstra, Rina Dewi Rudyanto, Maria J. Ledesma-Carbayo, 978-1-4673-6455-3/13/\$31.00 ©2013 IEEE.
- [8] Koller T. M., Gerig G., Szekely G., et al. "Multiscale detection of curvilinear structures in 2-D and 3-D image", IEEE Trans. computer vision 1995, pp:864:869 .
- [9] Schrijver M. , Slump CH. "Automatic segmentation of the coronary artery tree in angiographic rejections",Proceedings of Pro-RISC,2002,28-29.
- [10] Shoujun Z, Jun Y, WuFan C et al. "New approach to the automatic segmentation of coronary artery in X-ray angiograms". Science in China Series :Information Sciences.2008,51(1):28-39.
- [11] S.M.Pizer, E.O.P.Amburn and J.D.Austin, "Adaptive histogram equalization and its variation," Comput Vision Graphics Image Process,vol.39 ,pp.355-368,1997
- [12] Blondel C, Malandain G, Vaillant R, et al. "Reconstruction of coronary arteries from one rotational X-ray projection sequence.Institut National De recherche En Informatique Et En Automatique. 2004
- [13] Yan X, Guangshu H, Lihua S, "Adaptive tracking extraction of vessel centerlines in coronary arteriograms using Hessian matrix",J Tsinghua Univ, vol.47, No.6, 2007, pp:889-992 .