Automated Segmentation of Angio Vessels

S.Sathish Kumar,
Research Scholar, Sri Chandrasekharendra
Saraswathi Viswa Mahavidyalaya, Kanchipuram.

Senior Lecturer, Asia Pacific University College of
Technology & Innovation, Kuala Lumpur, Malaysia.

R.Amutha
Professor,
SSN College of Engineering,
Chennai, India.

ABSTRACT

Segmentation is one of the major steps in the analysis of medical images, as it outputs the attributes extracted from the input images. The need for automated width detection lies in analyzing the presence or absence of specific anomalies.

The paper presents the segmentation of the Coronary artery tree from the angiographic images. This is done by extracting or segmenting the vessels and thereby detecting its width. The proposed algorithm consists of two main steps, namely the pre-processing and the segmentation. In the pre-processing step, the Hessian matrix analysis is done to track the coronary vessel structures from the original image and the Frangi 2D filter is used to enhance the angiogram image. In the second step, the segmentation is done by morphing the filtered image and finally the width of the segmented blood vessel in the coronary angiogram image is determined. Also various parameters such as the Total Vessel Length (TVL), Total Input Image Area (TIIA), Segmented Image Area (SIA) and Vessel Image Percent (VIP), Sensitivity, Specificity, and the computational time are calculated for the performance evaluation and are compared with the existing methods. The results prove that the proposed method is very efficient than the existing methods.

General Terms

Computing-Algorithms

Keywords

Angiographic image, Gabor filter, Hessian Matrix Image enhancement, Frangi 2D filter, Morphology, Segmentation, width detection.

1. INTRODUCTION

Segmentation plays an important role in the field of image processing. It is defined to be a process of partitioning a given image into several non-overlapping regions. This feature of segmentation is used to detect tumours, regions of interest, edges of blood vessels, and a lot more from the given image. Angiogram is performed to detect, if there is any block in the flow of blood within the blood vessels. Hence the detection or extraction of the blood vessels is very important and must be very accurate. When it comes to the Coronary angio, the Coronary blood vessels need to be extracted accurately for the diagnoses, treatment and clinical study of the various vascular diseases. This is because it is difficult to detect the edges and the noise as they belong to the scope of high frequency [3,4].

In a real world practical environment, the scanned medical images contain object boundaries and shadows and noise. Hence, it may be difficult to distinguish the exact edge from the noise.

Edge detection is usually done to segment the blood vessels from the angiogram images. Edge detection algorithms are followed by linking and boundary detection procedures. Edge detection is used for detecting discontinuities in gray level. The first and second order digital derivatives are implemented to detect the edges in an image. Edge is defined as the boundary between two regions with relatively distinct gray-level properties. An edge is a set of connected pixels that lie on the boundary between two regions [3, 4].

Morphology is an image processing tool used to extract features based on shape. It is a powerful set of binary image processing operations developed from a set-theoretical approach. Erosion and dilation are the two basic morphological operations [2, 6, 7].

In this paper, first the given image is edge segmented, and then the widths are detected automatically and displayed. The existing method is finally discussed with the proposed method.

The rest of this paper is organized as follows. After the introduction in section 1, an overview of the existing method is given in section 2. The implementation detail of the proposed algorithm is given in section 3. The results are discussed in section 4. The conclusion and future work are given in section 5.

2. EXISTING METHOD

The existing method uses the multiscale Gabor filtering and the Hessian matrix analysis to enhance the given image and to extract the angio vessels from the original angiographic image. The Hessian matrix is used to obtain the vessel feature map and the vessel direction map from the original angiogram image. The Gabor filter is a linear filter which is used to detect the edges of the vessel and the median filter is used to remove the noise. Thus they are used to obtain an enhanced image [1]. Fig 1 shows the flow diagram of the existing method.

Before segmenting the blood vessels from the angiographic image, it has to be enhanced. Hence as a measure of multiscale detection, the Hessian matrix is used. This is done by convolving the angiographic image with the normalized second order Gaussian derivatives at different scales. Then the filter response is normalized for each scale by selecting the maximum response.The different type of input parameters such as vessel feature and direction to segment the vessel elements along the same angio vessel were used by the existing method, but is limited in extracting the accurate segmented angio vessel due to noise and the width of the extracted angio vessel is not detected at random points.

```
┌─────────────────────┐
│    INPUT IMAGE      │
└─────────────────────┘
           │
           ▼
┌─────────────────────┐
│   PRE-PROCESSING    │
│  (Median and Gabor  │
│     Filtering)      │
└─────────────────────┘
           │
           ▼
┌─────────────────────┐
│   SEGMENTED IMAGE   │
└─────────────────────┘
```
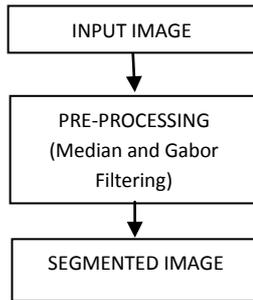
Fig 1: Flow diagram of the existing method

3. PROPOSED METHOD

The proposed algorithm consists of three main steps, namely:

Step 1: Pre-processing

Step 2: Morphological operations

Step 3: Width detection

In Fig 2, first the input image is preprocessed using the Hessian matrix analysis and the Frangi 2D filter is used to get the enhanced image. Then the morphological operations are done to segment the detected angio vessels from the background image. Finally the width of the segmented angio vessel is detected at random points along the segmented vessel automatically.

```
┌──────────┐      ┌─────────────────────┐
│  INPUT   │─────▶│   PRE-PROCESSING    │
│  IMAGE   │      └─────────────────────┘
└──────────┘                 │
                             ▼
              ┌─────────────────────┐
              │   MORPHOLOGICAL     │
              │    OPERATIONS       │
              └─────────────────────┘
                             │
                             ▼
              ┌─────────────────────┐
              │   SEGMENTED IMAGE   │
              └─────────────────────┘
                             │
                             ▼
              ┌─────────────────────┐
              │   WIDTH DETECTION   │
              └─────────────────────┘
```
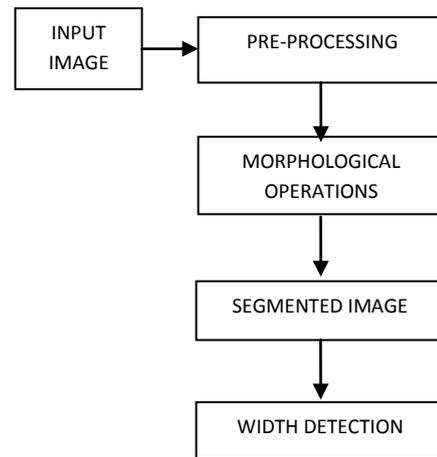
Fig 2: Flow Diagram of the proposed method

Thus, the above mentioned algorithm is used to detect the width of the angiogram vessel from the given angiographic image automatically.

3.1 Pre-processing

This step is done to remove the noise using the Frangi 2D filter and the Hessian matrix is used to provide the enhancement of the input angiogram image. Image enhancement process consists of a collection of techniques that seek to improve the visual appearance of an image. Thus the basic aim of this step is to make the image look better. The objective of the enhancement technique is to process an image so that the result is more suitable than the original image for a particular application.

The Hessian matrix analysis is done to track the Coronary vessel structures from the original image. The Eigen values of the Hessian are the principal curvatures and their product is the Gaussian curvature, which is the determinant of the Hessian.

Thus, for the Hessian matrix, the Eigen vectors form an orthogonal basis showing the direction of curve, which is the gradient of the image.

- If both the Eigen values are positive, then it is a local minima,
- If both the Eigen values are negative, then it is a local maxima,
- If the Eigen values have mixed sign, then it is a saddle point.

So, if the product of the Eigen values are positive, then they are either both positive or both negative, which means that they are at the local extremes.

Further the major features are detected by applying a threshold to the obtained determinant values. The tree or results of the Hessian analysis is stored for future reference. This is finally applied to obtain the vessel feature map and the

vessel direction map. The Hessian matrix used is a simple second order Gaussian derivative function.

First the Eigen values and the Eigen vectors are calculated and are sorted by their absolute values. The Frangi 2D filter uses the Eigen vectors of the Hessian to compute the likeness of an image region to vessels. The input parameters such as the Frangi scale range, the Frangi scale ratio and the correction factors are defined.

HESSIAN MATRIX

FRANGI 2D FILTER

MORPHOLOGICAL OPERATIONS
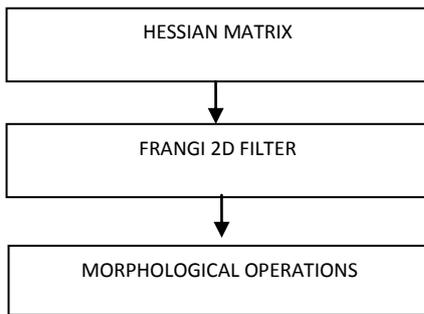
Fig 3: Pre-processing steps

Secondly, the matrix with the scales on which the maximum intensity of every pixel is found and the matrix with the directions of the pixels is also found. Then the direction of the minor Eigen vector and the similarity measures are calculated. Finally the output image is computed.

Thus the image obtained at the output of the Frangi 2D filter is an enhanced image, which means that the pixel is the maximum found in all scales. Fig 3 shows the steps involved in the pre-processing.

3.2 Morphological operations

Morphology is a part of biology that deals with the shape and structure of the objects. This is done to process and analyze the images. There are two basic operations involved in this process namely, erosion and dilation. A boundary point is defined as a pixel that is located inside an object, but has a neighbor outside the object. A simple erosion process eliminates all the boundary points from an object, leaving the object smaller in area by one pixel all around its perimeter. This is useful for removing a segmented image object. A simple dilation process adds all the background points into the object that touches it, leaving it larger in area by that amount. This is useful in filling holes in the segmented objects. The process of erosion followed by dilation is called as opening and the process of dilation followed by erosion is called closing. When erosion is done in such a way that the single – pixel objects are left intact, then the process is said to be shrinking. This is useful when the total object count must be preserved.

The morphology transformations are done to extract the features in images, which are derived using the Minkowski

addition and subtraction. This includes the various steps shown in Fig 4.

GRAY 2 BINARY IMAGES

FILLING THE HOLES

COMPLEMENTING THE IMAGE

ERODING THE IMAGE

CLEARING THE BORDER
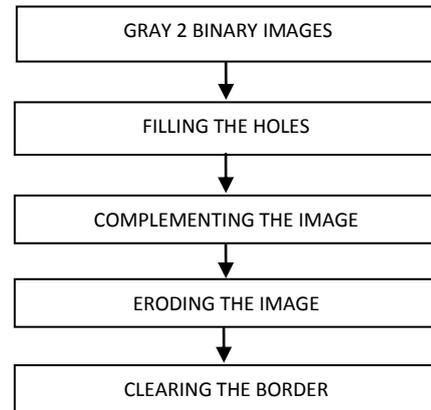
Fig 4: Morphological operations

As a first step the grayscale image is converted to a binary image. Then the holes in the binary image are filled, complemented and eroded. The gray scale value of an image is decreased by erosion, which is a transformation of shrinking. Thus, the contour of an image is smoothed.

Finally the structures that are lighter than the surroundings and that are connected to the image border are suppressed. Also, the overall intensity level is reduced in addition to the suppression of the border structures.

Thus, the morphological operations are done to detect the edges of the angiogram images and at the same time to denoise the image.

3.3 Width detection

All the connected components or an object that have fewer than P pixels forming another binary image is removed. As the image is in the form of a matrix, the entire image rows and columns are divided into equal parts to determine the width. Then a loop is assigned so that the parts are processed one after the other, such that the number of objects present in that row is used to determine the width of the angio vessel. In a similar way, the loop is repeated for all the segments and finally the width is detected. Hence, the user can select a particular point to detect the width of the vessel at that point of the angiogram image.

4. EXPERIMENTAL RESULTS

The proposed algorithm was tested on the real images acquired from 22 patients. Each image had a size of 256x256 pixels. All the algorithms were implemented in MATLAB 7.0 on a Pentium IV Personal Computer (with Central Processing Unit 2.8G and 512M memory). A Graphical User Interface is created with three push buttons, one to select the input image, next to segment the image and the last to detect the width of the angio vessel at random points.

The performance of the proposed algorithm was evaluated in two stages.

The first stage evaluation is done by comparing the proposed algorithm which involves the Frangi 2D filter with that of the Gabor filter for segmentation. The second stage evaluation is done by deriving the various performance measures in order to improve the efficiency of the proposed algorithm.

For simplicity only four input angiogram images are shown and their various stages of segmentation is shown in this paper.

4.1 Performance Measures

The performance of the proposed algorithm is evaluated by calculating the following parameters:

4.1.1 Total Vessel Length [TVL]

From the algorithm the vessel length in all the segments is calculated and then the length from all algorithms is added to derive the entire length of the vessel running in the angiogram. This is done using the matrix concept. The number of columns having the objects of that particular value is calculated to know the length of the vessel in that particular segment. This is repeated for all the segments for the calculation of the total vessel length.

4.1.2 Segmented Image Area [SIA]

From the segmented image, the area of the vessel from the original image is calculated and its percentage of occupancy from the image is obtained. The concept used here is the total number of objects present in the segment of a particular value is calculated, and the total area from all the segments is calculated. This process is for the segmented image.

4.1.3 Total Input Image Area [TIIA]

For the original image the same process is used to calculate the entire area of the input image.

4.1.4 Vessel Image Percent [VIP]

In this parameter, the percentage of the vessel present in the angiogram is calculated. Thus, the ratio of the area of the vessel after segmentation to the total area gives the percentage of the vessel in the angiogram.

Fig 5- 8 shows the plot of TVL, SIA, TIIA and VIP for each image using Gabor filter and Frangi 2D filter. It could be observed from the first plot, that the total vessel length extracted from the input angiogram images using the Frangi 2D filter is very high has compared to the Gabor filter. Also, from the remaining plots it is observed that the segmented image area, total input image area and the percentage of the vessel extracted from the input angiogram images using the Frangi 2D filter is very high has compared to the Gabor filter.
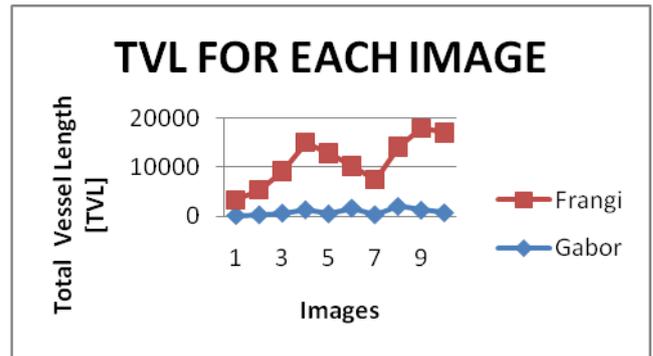
Fig 5 : Plot of TVL for each image
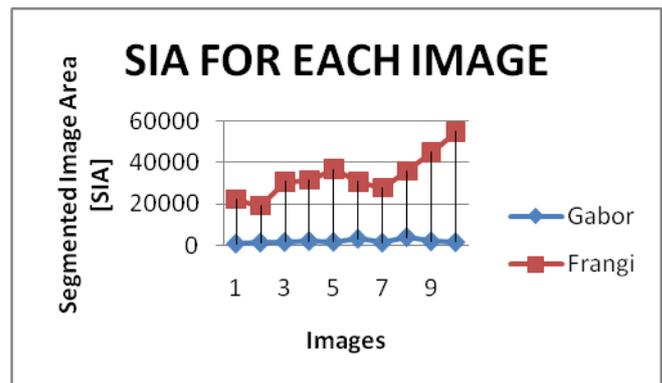
Fig 6: Plot of SIA for each image
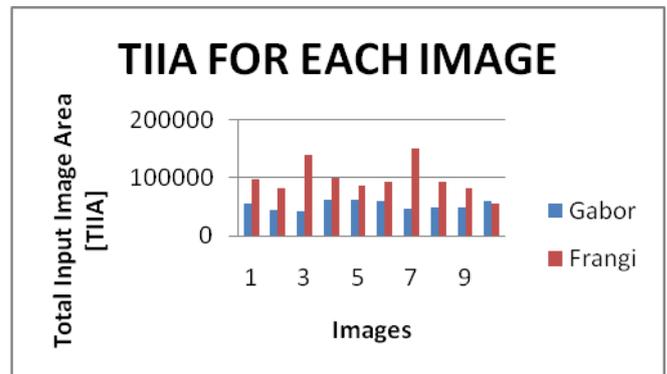
Fig 7: Plot of TIIA for each image
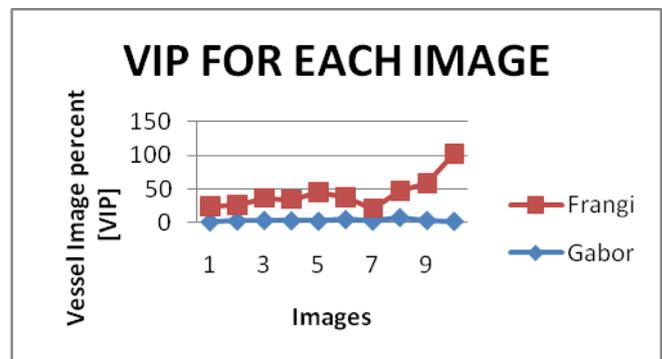
Fig 8: Plot of VIP for each image

4.1.5 Sensitivity and Specificity

Two metrics are used to evaluate the performance of the proposed method. They are the True positive Rate (TPR) and the False Positive Rate (FPR). TPR is defined to be the number of correct positive results obtained during the test from all the positive samples used. FPR is defined to be the number of incorrect positive results obtained during the test from all the negative samples. Sensitivity is equivalent to TPR while Specificity is (1- FPR).

Thus, the Sensitivity is defined to be the closest to one while the Specificity is defined to be the closest one to zero. So according to this, the proposed algorithm is said to be the best.

It can be seen from Fig 9 that the sensitivity of 5 out of the 10 angiogram images are very close to one while 2 are above one and 3 are less than 0.5 using the proposed algorithm. But as far as the existing algorithm is concerned only 2 angiogram images are very close to one while the remaining images are not so.

Also, it can be seen from Fig 10 that the specificity for all the 10 angiogram images are very close to zero using the proposed algorithm while that of for the existing algorithm only 5 angiogram images are close to zero while the remaining images are not so.

Fig 9: Sensitivity

Fig 10: Specificity

Table 1. Sensitivity and Specificity means calculated for the proposed and the existing algorithm for 10 simulated angiogram images

Simulated Data	Frangi 2D Filter	Gabor Filter
Mean Sensitivity	0.700354	0.405556
Mean Specificity	0.011077	0.157325

Table 1 shows the specificity and sensitivity mean values calculated for the set of simulated images for both the algorithms.

Thus from the simulated data it could be seen that the proposed algorithm using the Frangi 2D filter has the best specificity and sensitivity, which are 0.011077 and 0.700354 respectively. While the existing algorithm involving the Gabor filter has a specificity of 0.157325 and sensitivity of 0.405556, which are less as compared.

4.2 Timing parameters

The preprocessing time is defined to be the time taken by each angiogram image to undergo the various preprocessing stages involved in the algorithm. The preprocessing time for 22 angiogram images using Frangi 2D filter and Gabor filter is shown in Fig 11.
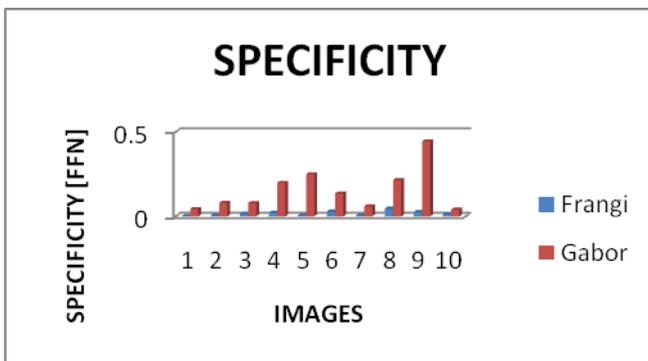
Fig 11: Preprocessing Time

Table 2 shows the various timing parameters involved in the entire process. Here, the total execution time is defined as the time involved in the preproceesing stage plus the time involved in the segmentation and detection stage. It could be seen that the preprocessing time involved is just 2.27 seconds for the proposed algorithm which involves the Frangi 2D filter, while the existing algorithm using the Gabor filter takes 3.6 seconds. Also, from the literature, the Multi scale Gabor and Probalilistic tracking operator method takes 36.7 seconds for preprocessing.

Also, it could be seen that the segmenetation and detection time for both the proposed and the existing methods are same , just 1.11 seconds, while the method from the literature takes 17.1 seconds.

Also, the total execution time for the entire process is 53.8 seconds for the method specified in the literature and the existing algorithm takes 4.71 seconds while the proposed

algorithm takes only 3.38 seconds which is very less comparatively.

Finally, it could be concluded that the proposed method takes a very less computational time for executing the entire process as compared to the existing methods.

Table 2. Comparison of the total execution time for the various methods

Filter	Preprocessing Time (seconds)	Segmentation and Detection Time (seconds)	Total Execution Time (seconds)
Frangi 2D	2.27	1.11	3.38
Gabor	3.6	1.11	4.71
Multiscale Gabor and Probabilistic tracking operator (from [1])	36.7	17.1	53.8

4.3 Simulated outputs

Fig 12 shows the input images for the automatic width detection. Fig 13 shows the Gabor filtered image for the various input images. Fig 14 shows the Frangi 2D filtered image, while Fig 15 – 18 shows the various outputs of the morphological operations. Fig 19 shows the segmented image, Fig 20 shows the selection of random points for the width detection and finally Fig 21 shows the width detected angiogram image.
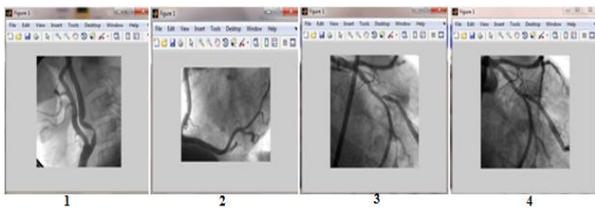
Fig 12: Input Angiogram Images
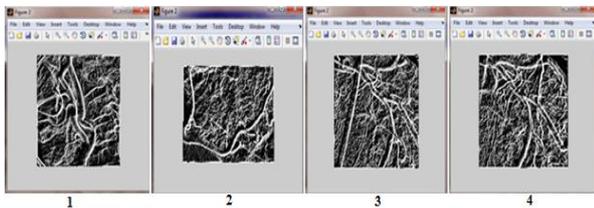
Fig 13: Gabor filtered images
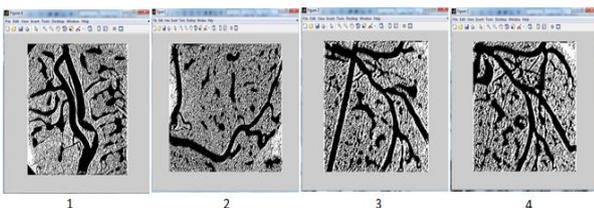
Fig 14: Frangi 2D filtered images
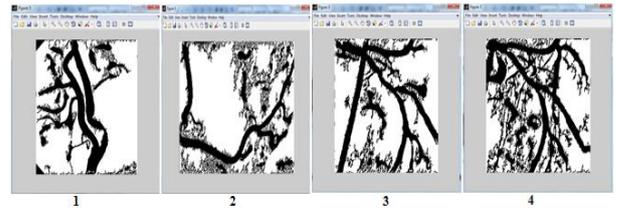
Fig 15: Filling of the Holes
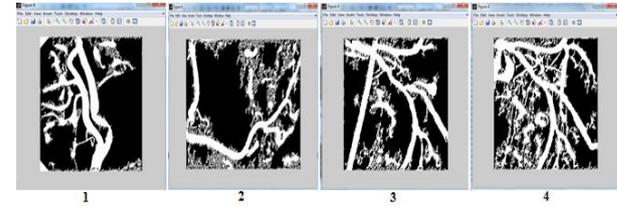
Fig 16: Complemented images
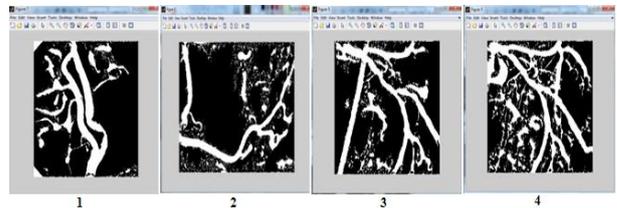
Fig 17: Eroded images
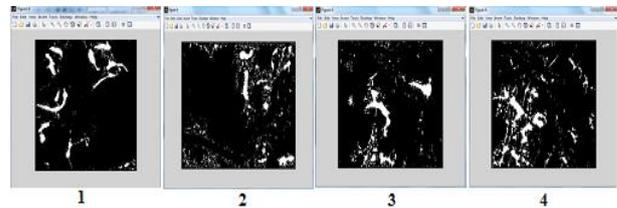
Fig 18: Border Cleared images
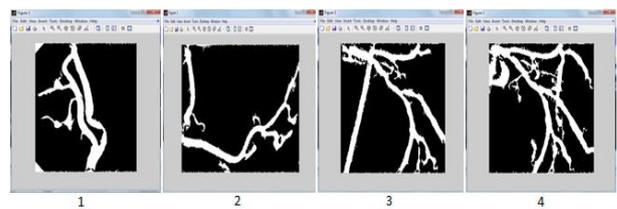
Fig 19: Segmented images
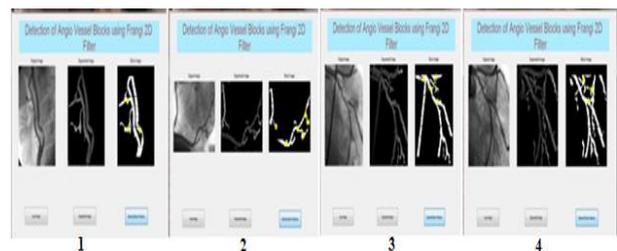
Fig 20: Selection of random points for the width detection
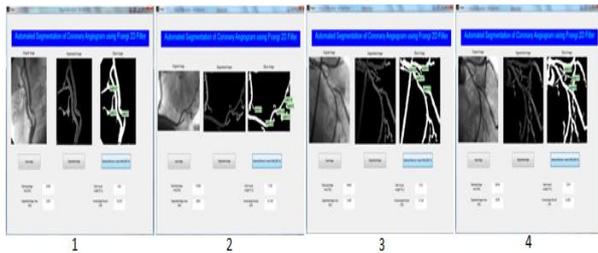
Fig 21: Width detected Angiogram image along with the various parameters

5. CONCLUSION

In this paper, the proposed algorithm segments the blood vessels automatically from the given Coronary angiogram image and detects the blocks and the width of the segmented angiogram image.

The performance results show that the proposed algorithm is unique in nature and gives better results in terms of accurate segmentation with increased TVL, SIA, TIIA and VIP, and a highly reduced computational time.

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