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Retinal Blood Vessel Segmentation for Diabetic Retinopathy Using Multilayered Thresholding

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Abstract: ***The most important disease that cause vessels structure to change is diabetic retinopathy. When the pancreas does not secrete enough amount of insulin diabetic retinopathy occurs. The symptoms of diabetic retinopathy include cotton wool spots, hemorrhages, hard exudates and dilated retinal veins. There are advance care of diabetic is present but still vision loss is also present. The risk of vision loss can be reduced significantly by timely diagnosis of diabetic retinopathy. For segmentation vessels play as one of the important landmark feature. Vessel segmentation algorithm can save time, patients' vision and medical cost. The present study is focused to develop method for enhancement and segmentation of vessel. We present a method that uses Curvelet transform for vessels enhancement and multilayered thresholding technique for vessel segmentation. Curvelets are a non-adaptive technique for multi-scale object representation. Being an extension of the traditional wavelet concepts, they are becoming popular in same fields, namely in scientific computing and image processing. Curvelet transform having two main features directionality and anisotropy scaling law. These features represent the edges along curves more efficiently than the traditional wavelet. For accurate vessel segmentation morphological operation and multilayered thresholding is used. In multilayered thresholding technique, we apply different thresholds values iteratively and keep track of retinal blood vessels in successive layers. In medical imaging system, the accuracy of result is very critical; that is way we used publicly available DRIVE and STARE database.***

Keywords: Retinal Blood Vessel, Curvelet Transform, Morphological Operation, Multilayered Thresholding.

1. Introduction

One of the most important diseases that cause retinal blood vessels structure to change is diabetic retinopathy that leads to blindness. Diabetic affects almost 31.7 million Indian populations, and has associated complications such as stroke, vision loss and heart failure. Diabetic disease is occurs when the pancreas does not secrete enough amount of insulin. This disease affects slowly the circulatory system including that of the eye. Diabetic retinopathy is a common cause of vision loss among the diabetic population. Despite various advances in diabetes care over the years, vision loss is still a potentially devastating complication in diabetic population. The risk of severe vision loss can be reduced significantly by timely diagnosis and treatment of diabetic retinopathy.

Retinal blood vessel structure in retinal images has an important role in detection of diabetic retinopathy. There are several methods present for automatic retinal blood vessel segmentation. Retinal blood vessel segmentation is the basic foundation for developing retinal screening systems since blood vessels serve as one of the main retinal landmark properties. The most common symptoms of diabetic retinopathy include cotton wool spots, hemorrhages, hard exudates and dilated retinal veins. A patient with diabetic retinopathy disease has to undergo periodic screening of retina.

We present a method that uses Curvelet Transform and multilayered thresholding technique for retinal blood vessel segmentation. Curvelet transform having two important properties anisotropy scaling law and directionality. These properties represent the edges along curves much more efficiently than the traditional wavelet. Multilayered thresholding technique is used for accurate retinal blood vessel segmentation; we apply different thresholds values iteratively and keep track of retinal blood vessels in successive layers.

This section provides a detailed introduction of retinal blood vessels, diabetic, diabetic retinopathy and techniques which are used in the segmentation process.

A. Diabetic

Diabetes mellitus commonly referred to as diabetes in which there are high blood sugar levels. Symptoms of high blood sugar include increased hunger, frequent urination and increased thirst. Acute complications include nonketotic hyperosmolar coma and diabetic ketoacidosis. Long-term complications include damage to the eyes, foot ulcers, chronic kidney failure, and cardiovascular disease. Diabetes is due to either the cells of the body not responding properly to the insulin produced or the pancreas not producing enough amount of insulin.

B. Diabetic Retinopathy

Diabetic retinopathy is a complication of diabetes mellitus. This high sugar content damages blood vessels in the body and can affect body organs such as the heart, eyes, and kidneys. Diabetes affects the retina by causing deterioration of blood vessels in the retina. Breakdown of vessels may result in abnormal blood vessels that grow on the surface of the retina or fluid leaking into the center of the retina which can bleed and scar. This can lead to loss of central and peripheral vision.

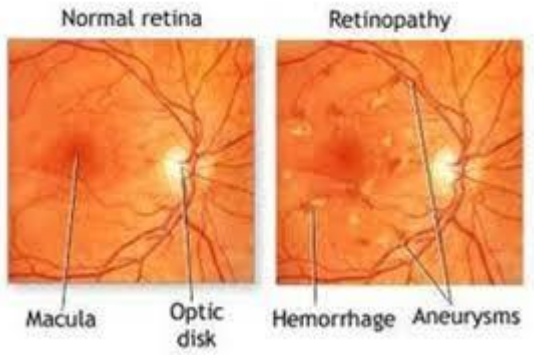

Figure 1: Difference between normal and diabetic retina

C. Curvelet Transform

Curvelets are an appropriate basis for denoting images which are smooth apart from singularities along smooth curves. This property holds for text, geometrical diagrams, and cartoons. The edges are increasingly straight as one zooms in on such images. Curvelet transform take advantages of this property, by defining the higher resolution do not have this property; they have detail at every scale.

D. Thinning Operation

Thinning is a morphological method that is used to remove selected foreground pixels from binary images, somewhat like opening or erosion. Thinning operation is used for numerous applications, but is especially helpful for skeletonization. In skeletonization, thinning is generally used to tidy up the output of edge detectors by reducing all lines to single pixel thickness. Thinning operation is often applied to binary images and produces another binary image as output.

E. Multilayered Thresholding

It is difficult to find one threshold value for accurate vessel segmentation without any supervised algorithm. In multilayered thresholding technique, we apply different thresholds values iteratively and keep track of blood vessels in successive layers.

2. Methodology

Automatically locating the accurate vessel pattern is very important in implementation of vessel screening system. A blood vessel screening system to facilitate the specialists is an application of medical systems.

A. Input Image

The photographs for the DRIVE database were obtained from a diabetic retinopathy screening program in the Netherlands. The screening population consisted of 400 patients of diabetic. The input images are read from the DRIVE database which has 40 fundus color images taken with a Canon CR5 non-mydriatic 3CCD camera with a 45 degree field-of-viewThe Structured analysis of the retina (STARE) data was conceived and initiated in 1975 by Michael Goldbaum. STARE database was funded by the U.S. National Institutes of Health. During its history, over thirty people contributed to the project, with backgrounds ranging from medicine to science to engineering. Clinical knowledge and pictures were provided by the Shiley Eye Center at the University of California, San Diego, and by the Veterans Administration medical center in San Diego.

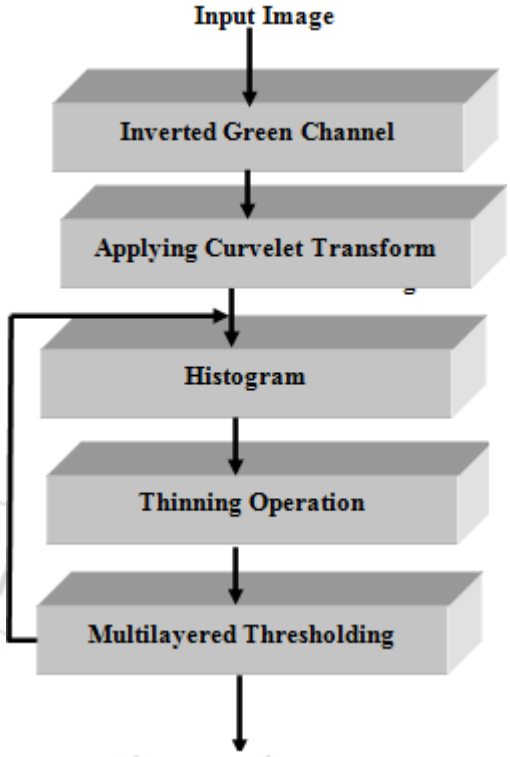

Figure 2: Flow diagram of retinal blood vessel enhancement and segmentation

B. Inverted Green channel

Input image is in RGB color model having an almost empty blue band and red band is normally saturated but green channel gives good representation of retinal image features. Furthermore, blood vessels appear lighter than background that is why we have used inverted green channel for vessel enhancement and segmentation.

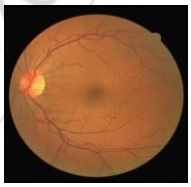

Figure 3: Input Image

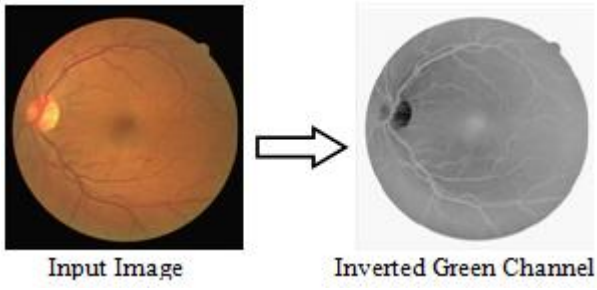

Figure3: Input image to inverted green channel conversion

C. Vessel Enhancement

The problem with vessel segmentation is that the visibility of vascular pattern is usually not good especially for thin and invisible vessels. So, it is necessary to enhance the vessels. Normally matched filters, Gabor filters and Curvelet Transform are used for this purpose but here we have used Curvelet Transform to enhance the thin vessels.

Curvelet transform having two main features directionality and anisotropy scaling law. These features represent the edges along curves much more efficient. Since blood vessels have directional pattern, so Curvelet Transform is best option due to its directional selectiveness capability.

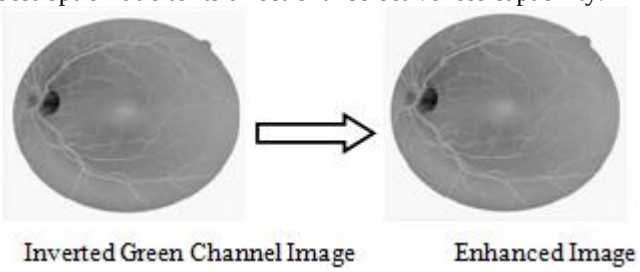

Figure 4: vessel Enhancement

D. Image Histogram

An image histogram is a type of histogram that acts as a graphical representation of the tonal distribution in a digital image. It plots the number of pixels for every tonal value. By viewing the histogram for a specific image a viewer will be able to decide the whole tonal distribution at a glance. In this work at the start of segmentation, initial threshold value T_{max} is selected using histogram of enhanced image.

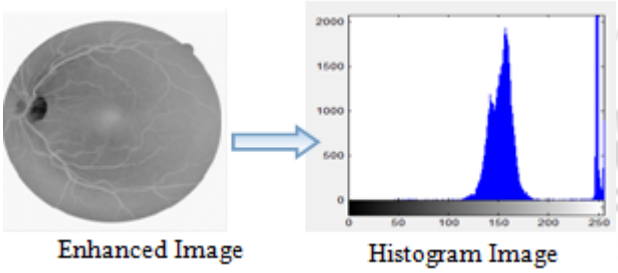

Figure 5: Histogram Image

E. Thinning Operation

Thinning is a morphological operation that is used to remove selected foreground pixels from binary images, somewhat like erosion or opening. It can be used for several applications, but is particularly useful for skeletonization and Medial Axis Transform. In this mode it is commonly used to tidy up the output of edge detectors by reducing all lines to single pixel thickness. Like other morphological operators, thinning operators take two pieces of data as input. One is the input image, which maybe either binary or gray scale. The other is the structuring element, which determines the precise details of the effect of the operator on the image. Thinning is applied to binary images, and produces another binary image as output. In this work the segmented image $I_{segmented}$ is then skeletonized I_{thin} using thinning morphological operator given in as a result of which all vessels are now only one pixel wide. Figure 6 shows the image after thinning process.

Figure 6: Thinned Image

Segmentation

In order to track the segmented vessels, I_{edge} edge image highlighting edge pixels of all vessels is computed using equation for each pixel p in thin image I_{thin}.

$$edge(p) = \frac{1}{2}\sum_{i=1}^{8} \left| I_{thin}(P_i \bmod 8) - I_{thin}(P_i - 1) \right|$$

Where p0 to p7 are the pixels belonging to an clockwise ordered sequence of pixels defining the 8-neighborhood of p and $I_{thin}(p)$ is the pixel value. $I_{thin}(p) = 1$ for vessel pixels and zero elsewhere. Edge(p) = 1 and Edge(p) = 2 correspond to vessel edge point and intermediate vessel point, respectively. The vessel edges obtained from this algorithm must be filtered to preserve only the true edges. In order to eliminate false edges due to break in vessel and small segments from I_{edge} apply multilayered thresholding. Initialize difference image I_{diff} and segmented vessel image I_{vessel} with I_{edge}. Reduce the threshold value by one and calculate $I_{segmented}$ for next iteration. Final segmented image $I_{segmented}$ is used to form a gray level segmented image which contains selected blood vessels only with their original intensity values. Initialize difference image I_{diff} and segmented vessel image I^{i}_{vesse} with I_{edge}. Reduce the threshold value by one and calculate $I_{segmented}$ for next iteration. Following steps are then performed iteratively:

1) Compute I^{j}_{thin} using segmented image $I^{i}_{segmented}$ for jth iteration where i<j.
2) Find out edge image I^{j}_{edge} by removing false edges, small segments and validating the edges.
3) Calculate $I^{j}_{diff}(x, y)=I^{j}_{edge} - I^{i}_{edge}$ where i<j. only keep those pixels in I_{diff} which are connected to vessel edge pixels in I_{edge}. If new added vessel segments are more than 10 pixels add them in I_{vessel}.
4) If $I^{j}_{vessel} - I^{i}_{vessel} = 0$, stop iteration otherwise set $T_{max} = T_{max} - 1$ and calculate $I^{j}_{segmented}$. Final segmented image $I_{segmented}$ is used to form a gray level segmented image which contains selected blood vessels only with their original intensity values. Figure 7 shows the segmented output image.

Figure 7: Segmented Output Image

In our project classification is based on the pixels. Each pixel is categorized as vessel or non-vessel. Two widely known measurements are used for evaluation of his method sensitivity and selectivity. Sensitivity and specificity are terms used to evaluate a clinical test. They are independent of the population of interest subjected to the test. Positive and negative predictive values are useful when considering the value of a test to a clinician.

The true positive fraction (TPF), also called sensitivity, is determined by dividing the number of pixels correctly classified as vessel pixels (TP) by the total number of vessel

pixels in the ground truth.

$$Sensitivity = \frac{TP}{TP + FN}$$

Specificity is determined by dividing the number of pixels correctly classified as background pixels (TN) by the total number of background pixels in ground truth.

$$Specificity = \frac{TN}{TN + FP}$$

Where false negative (FN) appears when a pixel in a vessel is segmented in the non-vessel area, and a false positive (FP) when a non vessel pixe4l is segmented as a vessel pixel. True positive (TP) and true negative (TN) when a pixel is correctly segmented as a vessel or non vessel. The accuracy of the binary classification is defined by

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN}$$

The accuracy shows the degree of conformity between the output and the manual of original image. Thus, the accuracy is strongly related to the segmentation property and shows how proper are the segmentation method. For this reason it is used to evaluate and compare different methods.

3. Result

This chapter provides a detailed description of the segmentation stage of the proposed system presented in this thesis. The chapter starts with a brief description of the input database and then moves on to discuss the experimental result. Lastly, a performance evaluation has also been done which includes accuracy, sensitivity and specificity for all images of DRIVE and STARE database discussed above. Through computer simulation, using MATLAB Version 8.1.0.604 (R2013a), we analyzed the performance of the algorithms in DRIVE and STARE database.

A. Input Image

The input images are read from the DRIVE database. Each image was captured using 8 bits per color plane at 768 by 584 pixels

B. Experimental result after inverting the green Channel

When the RGB components of the fundus colored images are evaluated separately, the green channel shows the good blood vessel contrast, whereas the red and blue channels show low contrast. Hence, the green channel was selected. The green channel is inverted as shown in figure 9, so that the retinal blood vessels appear brighter than the background.

C. Experimental result of curvelet transform

The Curvelet transform is adapted to show the images containing edges and so it is a good technique for edge enhancement. The enhanced image using FDCT is shown in figure 10.

D. experimental result of Histogram

At the start of segmentation, initial threshold value is selected using histogram. Histogram Image is shown in figure 11.

E. Experimental result of thinning operation

The segmented image is then skeletonized using thinning
In morphological operator given in as a result of which all blood vessels are now only one pixel wide. The thinned image using morphological operation is shown in figure 12.

F. experimental result of multilayered thresholding

It is difficult to find best threshold value for retinal blood vessel segmentation without any supervised rule. Multilayered thresholding, we apply different thresholds values iteratively and keep track of retinal blood vessels in successive layers. The segmented output image using multilayered thresholding is shown in figure 13.

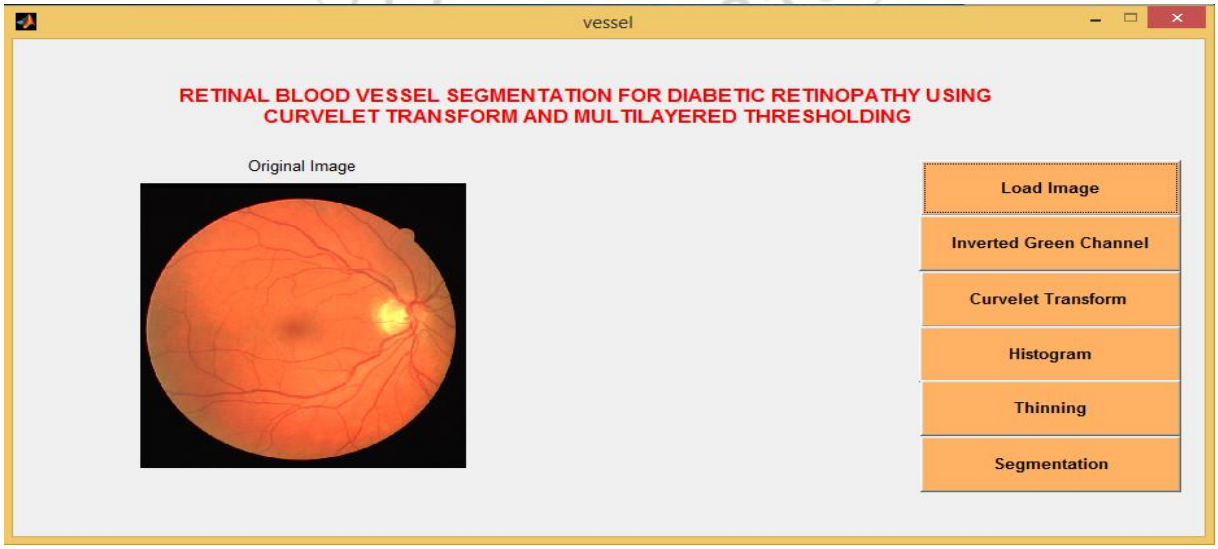

Figure 8: Load retinal image (DRIVE database)

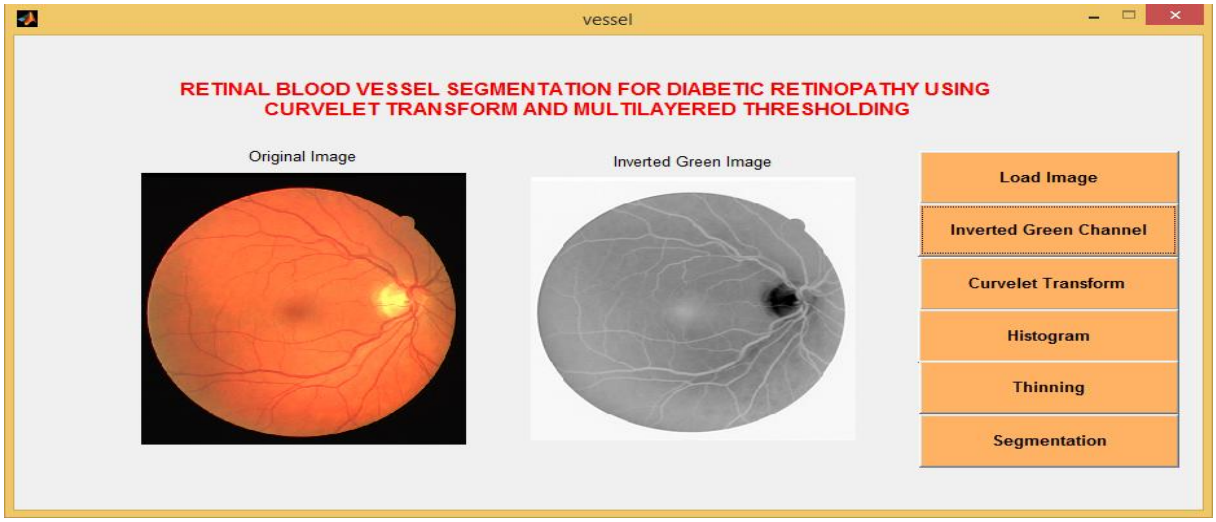

Figure 9: Output after inverting the green channel

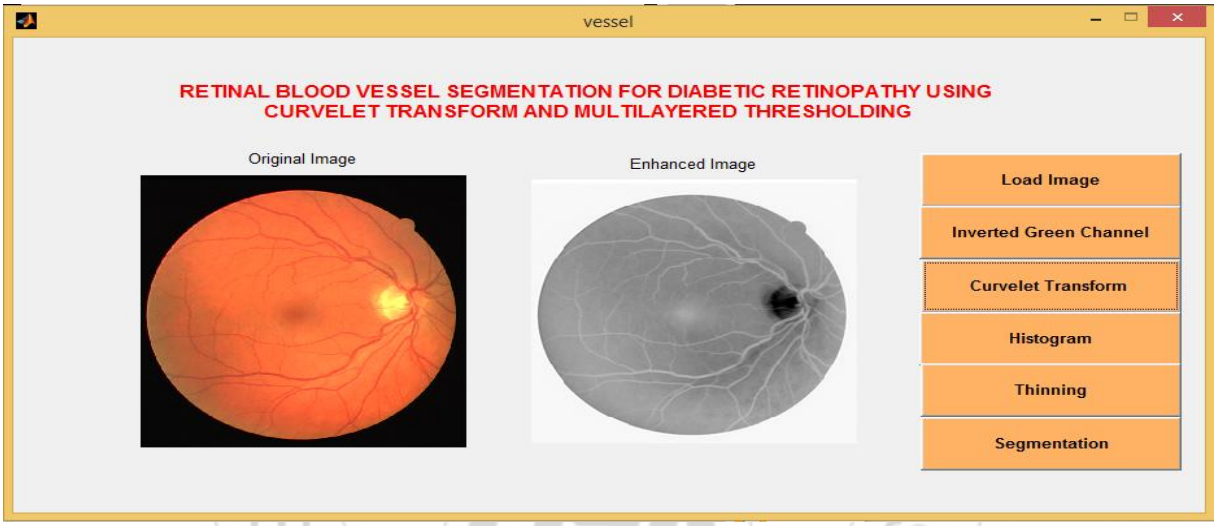

Figure 10: Output of Curvelet transform for vessel enhancement

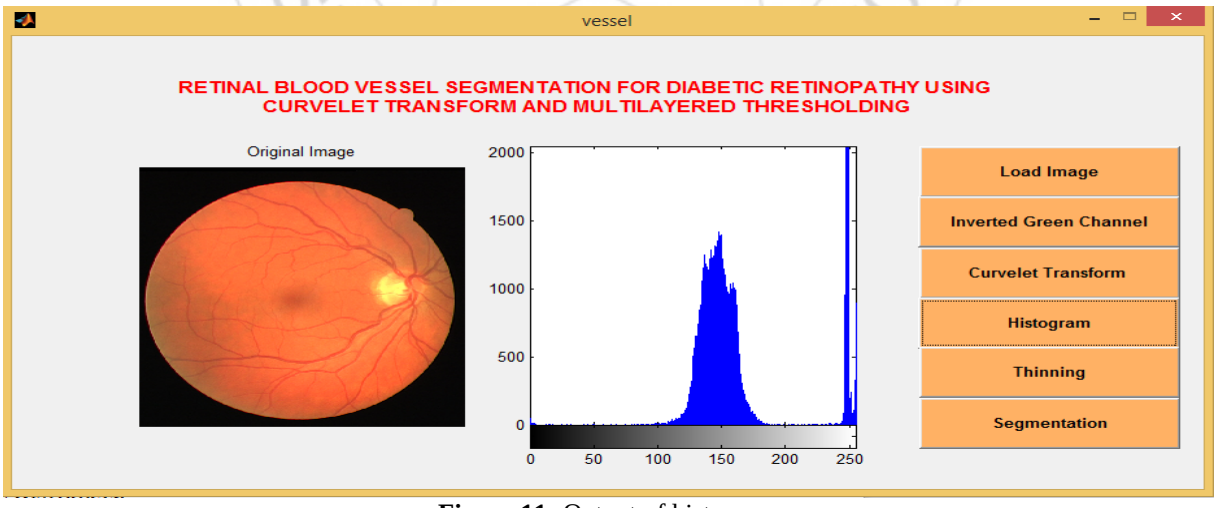

Figure 11: Output of histogram

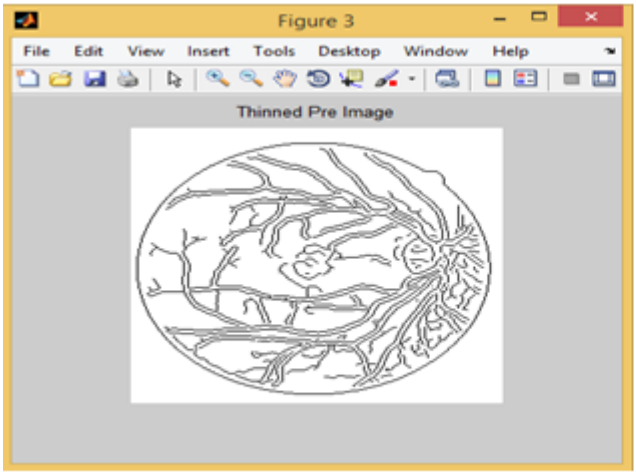

Figure 12: Thinned image

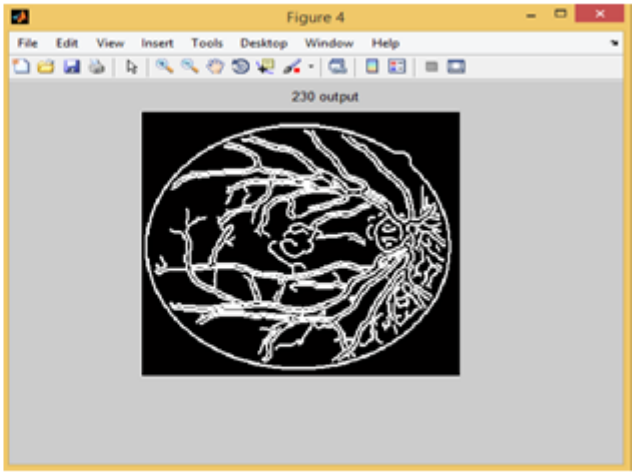

Figure 13: Segmented output image

Table 1 shows the values of TP, TN, FP, and FN for 02_test image (DRIVE database)

Table 1: Table showing TP, TN, FP, FN for test image (DRIVE database)

Image	Tp	Tn	Fp	Fn
02_test (DRIVE)	315088	5805	315088	9067

Various terms used to describe the clinical efficiency of a classification based on the terms are tabulated in table 5.1. With the help of these terms various performance measures has been computed that are used to evaluate the performance of the proposed technique. The performance measures are as follows:-

$$Sensitivity = \frac{TP}{TP + FN}$$

$$Sensitivity = \frac{315554}{315554 + 7854} = 0.9720$$

$$Specificity = \frac{TN}{TN + FP}$$

$$Specificit\,y \frac{5805}{5805 + 315088} = 0.9819$$

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN}$$

$$Accuracy = \frac{315088 + 5805}{315088 + 5805 + 315088 + 9067} = 0.9725$$

Table 2 shows the average accuracy, average sensitivity and average specificity for both DRIVE and STARE database. While figure 14 and 15 depicts the Graph showing the average parameter (accuracy, sensitivity and specificity) of DRIVE and STARE database respectively.

Table 2: Table showing average accuracy, sensitivity and specificity Parameter for DRIVE and STARE database

Database	*Average Accuracy*	*Average Sensitivity*	*Average Specificity*
DRIVE	0.9724	0.9720	0.9856
STARE	0.9883	0.9880	0.9766

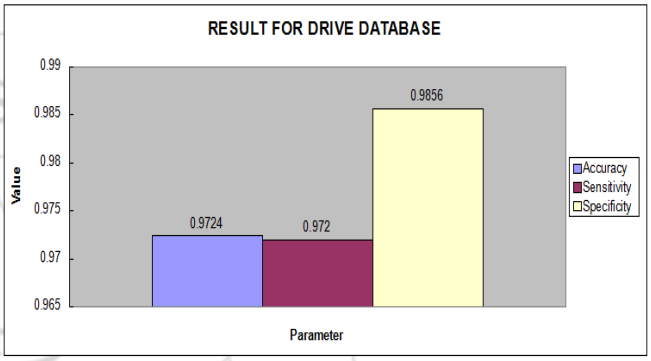

Figure 14: Graph showing the average parameter for DRIVE database

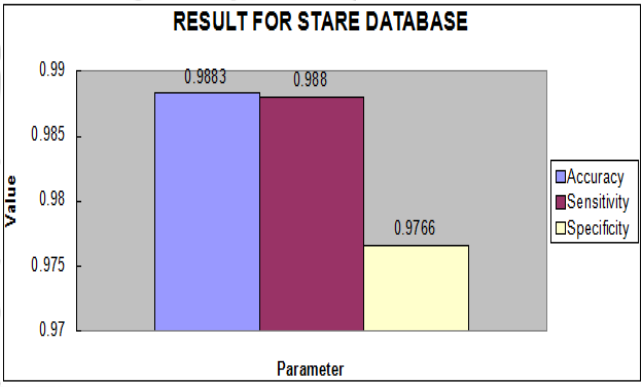

Figure 15: Graph showing the average parameter for STARE database

The accuracy of proposed technique is tested using two publicly available databases, i.e., DRIVE and STARE. We compare our results with Jiang et al. [1] , Staal et al.[2], Soares et al. [3] and Fraz et al.[6] Table 3 and 4 shows the comparison between proposed technique and other existing techniques with respect to accuracy.

Table 3: Segmentation result 1 (DRIVE database)

Method	Accuracy
Jiang et al.	0.8911
Staal et al.	0.9441
Soares et al.	0.9466
Akram M. U. et al.	0.9469
Proposed Method	0.9724

Table 4: Segmentation result 2 (STARE database)

Method	*Accuracy*
Jiang et al.	0.9009
Staal et al.	0.9516
Soares et al.	0.9480
Akram M. U. et al.	0.9502
Proposed Method	0.9883

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