DETECTION OF BLOOD VESSELS AND MEASUREMENT OF VESSEL WIDTH FOR DIABETIC RETINOPATHY

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ABSTRACT

The proposed method measures the retinal blood vessel diameter to identify arteriolar narrowing, arteriovenous (AV) nicking, branching coefficients to detect early diabetic retinopathy. It utilizes the vessel centerline and edge information to measure the width for a vessel segment. From the input retinal image, the vascular network is extracted using the local entropy thresholding method. The vessel boundaries are extracted using sobel edge detection method. The skeletonization operation is applied to the vascular network and mapping the vessel boundaries and the skeleton image. The branching point detection method is then performed to localize all crossing locations. A rotational invariant mask to search the pixel pairs from the edge image, and calculate the shortest distance pair which provides the vessel width (or diameter) for that cross-section. Variation in the width measurement identifies the diabetic retinopathy.

INDEX TERMS

Computer Vision, Image Processing, Edge Detection, Mapping, Diabetic Retinopathy.

1. INTRODUCTION

Computer vision is the branch of Artificial Intelligence that focuses on, well, Image Processing. In 1966-1980s Computer Vision Engineers explicitly works for the shift towards geometry and increased mathematical rigor. In 1990- 2000s face and broader recognition, statistical analysis in vogue and video processing starts [1]. Diabetic Retinopathy is an ocular manifestation of diabetes, a systemic disease, which affects up to 50% of all patients who have diabetes for 10 years or more [6]. Diabetic macular changes in the form of yellowish spots and extravasations that permeated part or the whole thickness of the retina were observed for the first time by Eduard Jaeger in 1856. It was only in 1872 that Edward Nettleship published his seminal paper "On edema or cystic disease of the retina" providing the first histo-pathologic al proof of "cystoid degeneration of the macula" in patients with diabetes. In 1876, Wilhelm Manz described the proliferative changes occurring in diabetic retinopathy and the importance of fractional retinal detachments and vitreous hemorrhages [3]. In 1950s, a number of clinical trials have characterized the natural history of DR and the efficacy and safety of DR treatment strategies [2]. DR is an apparent breakdown of the blood-retinal barrier (Cunha Vaz 1976, Krupinet al. 1978,

Klemen et al. 1980) [4]. Normally the circulating blood is separated from the extravascular compartment of the retina by tight encircling functional complexes between contiguous endothelial cells in the case of the intra retinal vessels (inner blood-retinal barrier) and between cells of the retinal pigment epithelium (outer blood-retinal barrier) [5]. A number of multi-centered clinical trials during the last ten years have contributed substantially to the understanding of the natural history of diabetic retinopathy and have established the value of intensive glycemic control in reducing both the risk of onset and the progression of diabetic retinopathy [5].Despite this intimidating statistics, research indicates that at least 90% of these new cases could be reduced if there was proper and vigilant treatment and monitoring of the eyes[7]. Diabetic Retinopathy often has no early warning signs, which may cause vision loss more rapidly. Diabetic Retinopathy tends to appear and progress in stages beginning with Mild Non-Proliferative Diabetic Retinopathy, progressing to Moderate Non Proliferative Diabetic Retinopathy, further advancing to Severe Non-Proliferative Diabetic Retinopathy and without proper attention developing in to the most severe stage, Proliferative Diabetic Retinopathy . Mild Non-Proliferative Diabetic Retinopathy is characterized by the presence of dot and blot hemorrhages [11] and micro aneurysms[10] in the Retina during your eye examination[8][9]. In Moderate Non-Proliferative Diabetic Retinopathy some of the small blood vessels in the Retina may actually become blocked. The blockage of these tiny blood vessels causes a decrease in the supply of nutrients and oxygen to certain areas of the Retina[8]. Severe Non-Proliferative Diabetic Retinopathy is characterized by a significant number of small blood vessels in the Retina actually becoming blocked, which results in areas of the Retina being deprived of nourishment and oxygen. A lack of sufficient oxygen supply to the Retina results in a condition called Retinal Ischemia[12][8]. Proliferative Retinopathy is the most severe stage of Diabetic Retinopathy and carries a significant risk of vision loss. The Retina responds to a lack of oxygen, by attempting to compensate for the reduced circulation by growing new, but abnormal blood vessels-a process called neovascularization [13][8].

2. SYMPTOMS OF DIABETIC RETINOPATHY

A symptom is something the patient senses and describes, while a sign is something other people, such as the doctor notice. For example, rowsiness may be a symptom while dilated pupils may be a sign. Diabetic retinopathy typically has no symptoms during the early stages. Unfortunately, when symptoms become noticeable the condition is often at an advanced stage. Sometimes the only detectable symptom is a sudden and complete loss of vision. The only way patients with diabetes can protect themselves is attend every eye examination their doctor tells them to go to. Based on the research done by the Professors Tapp RJ, Shaw JE, Harper CA et al it is identified that patient can be prevented from the loss of vision if Diabetic Retinopathy is detected earlier. The blood vessel in the retina bulges called microneurysms causes the vessel width to vary (when the vessel bulges) compare to the other vessels or the other eye of the human. This symptom will be taken as earlier sign for the Diabetic Retinopathy and sometimes burst in the blood vessels causes tiny blood spots (hemorrhages) in the retina. Therefore the methods are proposed below to measure the blood vessel width more accurately to identify diabetic Retinopathy earlier.

3. PROPOSED ALGORITHM

The proposed blood vessels width measurement algorithm based on the vessel edge and centerline. The major advantage of our technique is that it is less sensitive to noise and works equally for the low contrast vessels (particularly for minor vessels). Another advantage of our technique is that it can calculate the vessel width even when it is one pixel wide. The proposed

algorithm is composed of four steps. Since blood vessels usually have lower reflectance compared with the background, we apply the matched filter to enhance blood vessels with the generation of a MFR image. Secondly, an entropy-based thresholding scheme can be used to distinguish between vessel segments and the background in the MFR image. A length filtering technique is used to remove mis-classified pixels. Vascular intersection detection is performed by a branch point detection method. Then the vessel width is measured by proposed width measurement technique.

A. Preprocessing

The color components are considered separately because green channel exhibits the best vessel/background contrast while the red and blue ones tend to be very noisy in case of RGB. The proposed method work on the inverted green channel images, where vessels appear brighter than the back-ground. The two dimensional matched filter kernel is designe d to convolve with the original image in order to enhance the blood vessels.

B. Matched Filter

In [15], This concept is used to detect piecewise linear segments of blood vessels in retinal images. Blood vessels usually have poor local contrast. The two dimensional matched filter kernel is designed to convolve with the original image in order to enhance the blood vessels. A prototype matched filter kernel is expressed as

$$f(x, y) = -\exp(-x^2), \text{ for } |y| \leq L/2 \qquad (1)$$

where L is the length of the segment for which the vessel is assumed to have a fixed orientation. Here the direction of the vessel is assumed to be aligned along the y-axis. Because a vessel may be oriented at any angles, the kernel needs to be rotated for all possible angles. A set of twelve 16x15 pixel kernels is applied by convolving to a fund us image and at each pixel only the maximum of their responses is retained. The operator generates a template of values that are then applied to groups of pixels in the image.

C. Local Entrophy Thresholding

MFR (Matched Filtering Retinal) image is processed by a proper thresholding scheme in order to extract the vessel segments from the background. An efficient entropy-based thresholding algorithm, which takes into account the spatial distribution of gray levels, is used because an image pixel intensities are not independent of each other. specifically , we implement a local entropy thresholding technique ,described in [16] which can well preserve the spatial structures in the binarized /thresholded image. A local entropy thresholding technique, described in which can well preserve the spatial structures in the binarized/thresholded image. Two images with identical histograms but different spatial distribution will result in different entropy(also different threshold values).The co-occurrence matrix of the image F is an $P \times Q$ dimensional matrix ,that gives an idea about the transition of intensities between adjacent pixels, indicating spatial structural information of an image. Depending upon the ways in which the gray level i follows gray level j, different definitions of co occurrence matrix are possible. The co-occurrence matrix asymmetric by considering the horizontally right and vertically lower transitions.

$$t_{ij} = \sum_{t=1}^{P} \sum_{tk=1}^{Q} \delta \; where \; \delta = 0 \; otherwise \qquad (2)$$

the probability of co-occurrence of gray levels i and j can therefore be written as

$$P_{ij} = \frac{t_{ij}}{\sum_i \sum_j t_{ij}} \qquad (3)$$

if s, $0 \leq s \leq L-1$, is a threshold. Then s can partition the co-occurrence matrix into 4 quadrants, namely A, B, C, and D
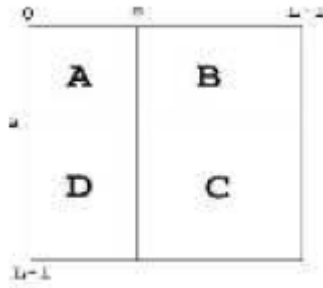

Fig.1.Quadrants of co-occurrence matrix [16].

Let us define the following quantities

$$P_A = \sum_{i=0}^{S} \sum_{j=0}^{S} P_{ij} \qquad (4)$$

$$P_C = \sum_{i=s+1}^{L-1} \sum_{j=s+1}^{L-1} P_{ij} \qquad (5)$$

Normalizing the probabilities within each individual quadrant, such that the sum of the probabilities of each quadrant equals one. The second-order entropy of the object can be defined as.

$$H_a^2(s) = -\frac{1}{2} \sum_{i=0}^{S} \sum_{j=0}^{S} P_{ij} \log_2 P_{ij} \qquad (6)$$

Similarly, the second-order entropy of the background can be written as

$$H_c^2(s) = -\frac{1}{2} \sum_{i=s+1}^{L-1} \sum_{j=s+1}^{L-1} p_{ij} \log_2 P_{ij} \qquad (7)$$

Hence, the total second-order local entropy of the object and the background can be written as

$$H_t^2(s) = H_a^2(s) + H_c^2(s) \qquad (8)$$

The gray level gives the optimal threshold for object back ground classification.

D. Vessel Edge Detection

The Sobel operator is used for edge detection algorithms. Technically, it is a discrete differentiation operator computing an approximation of the gradient of the image intensity function. At each point in the image, the result of the Sobel operator is either the corresponding gradient vector or the norm of this vector. The operator uses two 33 kernels which are convolved with the original image to calculate approximations of the derivatives - one for horizontal changes, and one for vertical.

E. Vessel Centerline Detection

Vessel skeleton is obtained by applying mathematical morphology reducing the vessel to a centerline of single pixel width. The perifoveolar capillaries were detected by the authors to locate candidate pixels(central part of vessel).Selection of vessel centerline candidates are done by using directional information provided from a set of four directional difference of Offset Gaussians filters. Connection of the candidate points are obtained in the previous step, by a region growing process guided by some image statistics. Validation of centerline segment candidates is based on the characteristics of the line segments; this operation is applied in each one of the four directions and finally combined, resulting in the map of the detected vessel centerlines.

F. Vessel Branch Point Detection

The vessel skeletons have to be converted into vessel segments separated by interruptions at the branching points. Segment start and end positions are determined as follows.Each of the centerline pixels on the vessel skeleton is analyzed within its 33 neighborhood, and branching points are detected as centerline pixels with more than 2 neighbors. The detection of vessel end points is required for the graph search and they are determined as the centerline pixels with only one neighbor.

G. Vessel Width Measurement

In [17][18],The vessel edge detected image and centerline detected image will be mapped to find the vessel width for a particular vessel centerline pixel position. For this purpose a pixel is selected from the vessel centerline image, considering the mask at its center. The mask is to find the potential edge pixels in any side of that centerline pixel position. Therefore, the mask is applied to the edge images only. Instead of searching for all the pixel positions inside the mask, width measurement method calculate the pixel position by shifting by one up to the size of the

mask and at the same time it rotate the position from 0 to 180 degrees. For increasing the rotation

angle we use the step size (depending on the size of the mask) less than $\dfrac{180^{\circ}}{masklength}$. Hence, the method access every cell inthe mask using this angle.
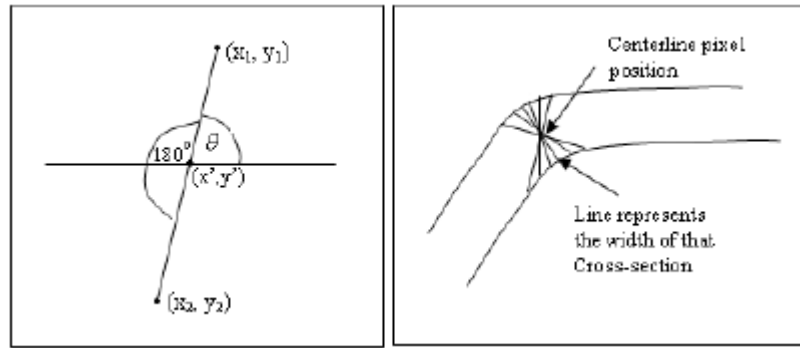

Fig. 2. Finding the mirror of an edge pixel(left) and width or minimum distance from potential pairs of pixels (right).

For each obtained position gray scale value is searched to check whether it is an edge pixel or not. Once we find an edge pixel then find its mirror by shifting the angle to 180 degree and increasing the distance from one to the maximum size of the mask (fig. 2) In this way the method produce a rotational invariant mask and pick all the potential pixel pairs to find the width or diameter of that cross sectional area.

$$x = x' + r * \cos\theta \quad and \quad y = y' + r * \sin\theta \qquad (9)$$

where (x′, y′) is the vessel centerline pixel position, r =1, 2, ..$\dfrac{marksize}{2}$ and θ = 0, .., 180. For any pixel position, if the gray scale value in the edge image is 255 (white or edge pixel) then we find the pixel (x2, y2) in the opposite edge(mirror of this pixel) considering θ = 0 + 180 and varying r this can be described in [17],[18]. After applying this operation we obtain the pairs of pixels which are on the opposite edges (at line end points) giving imaginary lines passing through the centerline pixels. From these pixels pairs, find the minimum Euclidian distance

$$\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \qquad (10)$$

the width of that cross-section. This enables us to measure the width for all vessels including the vessels one pixel wide (for which we have the edge and the centerline itself).
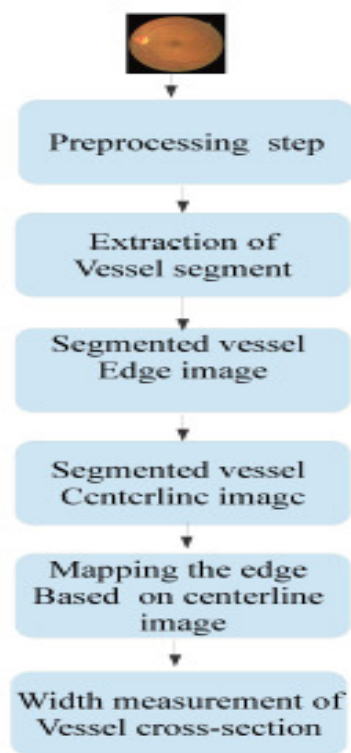
Fig. 3. The overall system for proposed vessel width measurement method

4. EXPERIMENTAL RESULTS

Fig.4. Original Fundus Image

Fig.3. represents the Fund us image is the inner lining of the eye made up of the Sensory Retina.

Fig.4. shows the Green Channel Conversion. The green channel conversion is helps to reduce the contrast of the image and used to separate the background and vessel segment.

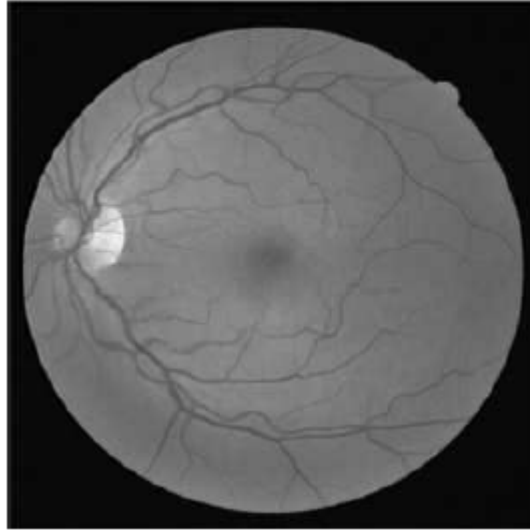Fig 5 shows the Gaussian filtering, to remove Gaussian noise and is a realistic model of defocused lens. Large values
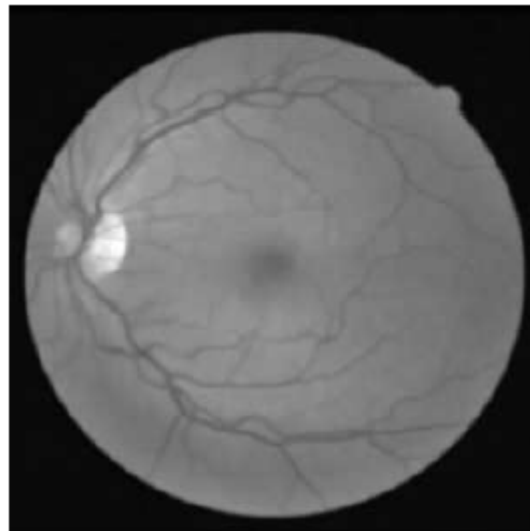

Fig. 5. Green Channel conversion

Fig. 6. Gaussian Filtering Image

for sigma will only give large blurring for larger template sizes. Noise can be added using the sliders. The radius slider is used to control how template size.
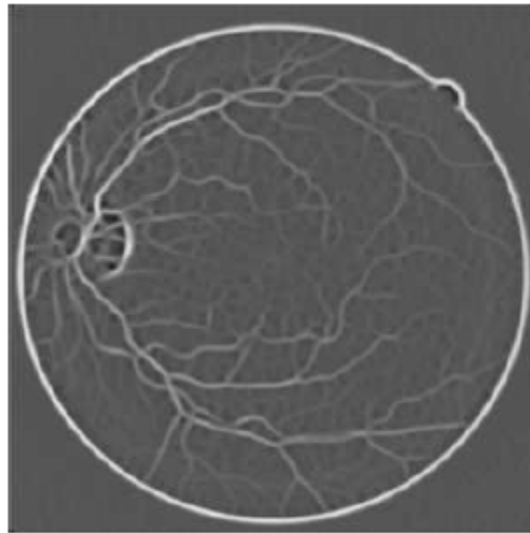

Fig. 7. Matched Filtering Image

The concept of matched filter detection is used to detect piecewise linear segments of blood vessels in retinal images. Blood vessels usually have poor local contrast as shown in Fig. 6. The two-dimensional matched filter kernel is designed to convolve with the original image in order to enhance the blood vessels.
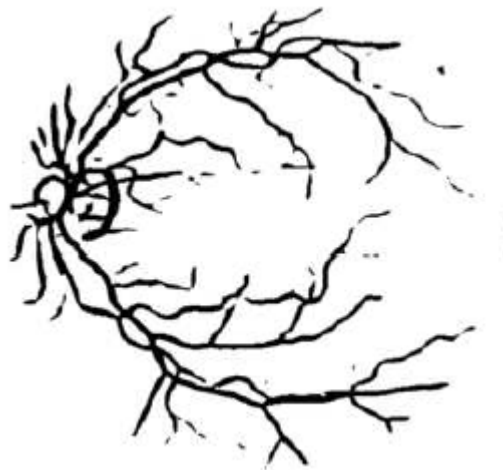

Fig. 8. Local Entropy Thresholding Image

Local entropy is a proper thresholding scheme in order to extract the vessel segments from the background as shown in Fig.7. It takes the spatial distribution of gray levels which is used to identify the pixel intensities. The pixel intensities are not independent of each other.

Fig.8. shows the length filtering which is used to produce a clean and complete vascular tree structure by removing misclassified pixels. It isolates the individual objects by using the eight-connected neighborhood and label propagation.

Fig. 9. Vascular Tree Structure

Fig.9. shows the edges of the detected vasculature tree structure (vessel boundaries).The edges of vessels are detectedusing the sobel edge detection method.
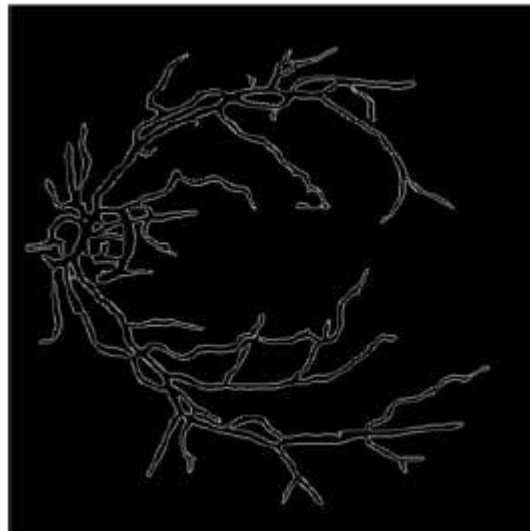

Fig. 10. Boundary of the vessel segment

The skeletonization of each vessel segment has shown in the Fig.10. It detects by using the morphological operators. This is also known as centerline detection of each vessel segment.
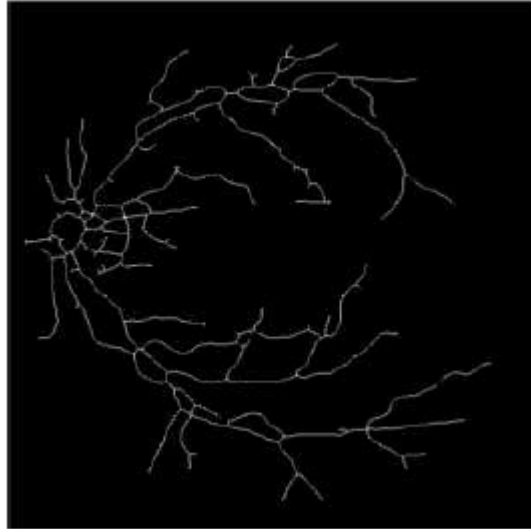
Fig. 11. Skeletonization of vessel segment (Centerline)

Fig.11. shows the mapping of vessel boundaries and centerline of retinal vessel. This is used to find the vessel width for a particular vessel centerline pixel position. The branching point of each vessel segements are detected and displayed in the Fig.12.The branching point are plotted in green color circle point. This points helps to determine the cross-section point of each vessel segment.
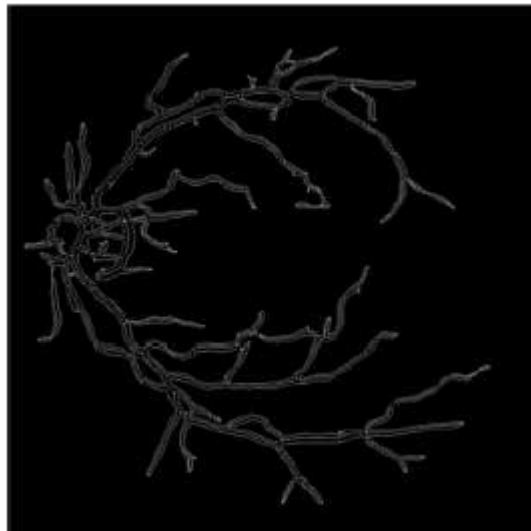

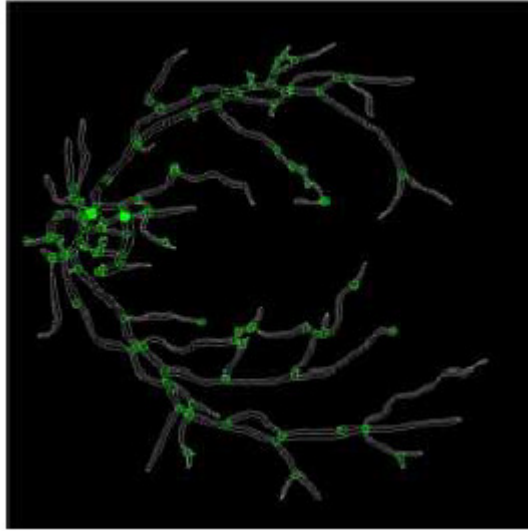Fig. 12. Mapping of Boundary and skeletonization Image

Fig. 13. Branching Point of each vessel segment

Fig.13. shows the branching points and ending points of each vessel segment. The branch points are plotted in blue color point and ending point of each vessel are plotted in red color point. And then the green color line segment shows the width or diameter of the particular vessel.
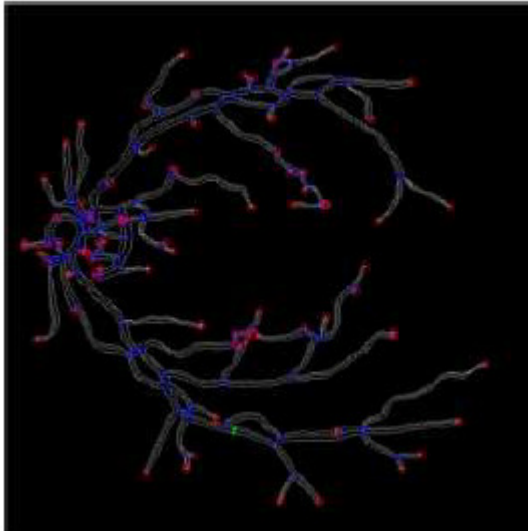

Fig. 14. Branch point, End point of vessel and Vessel width

Fig.14. shows the number of ending points and branching points which is plotted in the previous step. It also display the vessel width of particular vessel position.

```
No of ending points:82.
No of branches :104.
The point of vessel edge
   258.0000   260.0000
   480.0000   473.0000

The vessel width:
   7.2801

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Fig. 15. Vessel width

With the width calculated above, comparison based on vessel width calculation will takes place between manual width calculation and proposed method and the error(%) is displayed. The result is analyzed below based on the output obtained.

5. CONCLUSION AND FUTURE WORK

The proposed method assists for early detection and extraction of blood vessels and vessel width measurement in diabetic affected retinal image using the local entropy thresholding scheme and branch point detection. It reduces the computational simplicity compared to neural networks. It also identifies segmentation results for normal retinal images and images with obscure blood vessel appearance. In future classifying the artery and vein vessel segment and calculate the Arteriolar to Venular diameter Ratio (AVR) using this proposed vessel width estimation. A decreased ratio of the width of retinal arteries to veins [arteriolar-to-venular diameter ratio (AVR)], is well established as predictive of cerebral atrophy, stroke and other cardiovascular events in adults. Tortuous and dilated arteries and veins, as well as decreased AVR are also markers for plus disease in retinopathy of prematurity.

TABLE I
RESULT ANALYSIS

Cross-Section	manual width	proposed method	Error(%)
1	5.5369	5.3728	0.1641
2	5.5512	5.4721	0.0791
3	5.4381	5.3852	0.0529
4	5.219	5.1990	0.0200
5	5.1988	5.0990	0.0998
6	5.2733	5.1846	0.0887
7	5.3769	5.2980	0.0789
8	5.4316	5.3852	0.0464
9	5.45	5.3967	0.0533
10	5.4457	5.3798	0.0659

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