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BLOOD VESSEL EXTRACTION AND BIFURCATIONS DETECTION USING HESSIAN MATRIX OF GAUSSIAN AND EUCLIDIAN DISTANCE

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ABSTRACT

One of the sign for diagnosing diabetic retinopathy is Intraretinal Microvascular Abnormalities (IRMA). IRMA is located in the superficial retina area that adjacent to the non-perfusion area resulting venous beading at least two quadrant in the fundus image. The difficulties in venous beading detection are the characteristics of the objects in retinal blood vessel images were varied. There are arteries and veins inside the fundus image. Two of these vessels also contain bifurcation. Bifurcation detection is a very crucial step to obtain the optimum result and proper classification between normal veins with the veins that have the beading. This study, the blood vessel and Eigen value of hessian matrix will be extracted from the fundus image. The extraction result then processed using morphological and Euclidian distance to detect the bifurcation point of the retinal fundus image. This step is the early stage of venous beading detection. Bifurcation detection was performed by combining morphological operation to eliminate the noises of fundus image as well as to compute Euclidian distance of the vessel. The result of this study is expected to detect bifurcation point accurately. The outcome of bifurcation features extraction will be used to classified normal veins from venous beading.

Keywords: *Bifurcation, Eigen Value, Euclidian Distance, Hessian Matrix, Venous Beading*

1. INTRODUCTION

Non-Proliferative Diabetic retinopathy classification based on The Early Treatment of Diabetic Retinopathy Study (ETDRS) [1] was performed by observing the symptoms in the quadrant of retinal image [2]. One of the indicators that related to Diabetic Retinopathy is the emerging of venous beading as one of the clinical symptoms where the vascular of fundus image become swollen [3]. Venous beading detection is the early stage in classifying retinal blood vessel image [4]. There are some visual differences between artery and vein (*e.g.*, the position of artery is deeper whereas the vein rather outside, the color of artery is bright red while the color of the veins is darker red, the diameter of the vein is thicker compare to artery with the ratio 2:1[5]. In retinal blood vessel contain bifurcation point. Bifurcation on retinal blood vessel is two lines that meet at one end, described by coordinates x, y and angle θ from the line of the blood vessel that formed a branch [6].

Several studies related to blood vessel extraction and bifurcation detection have been performed by many researchers. The research in [7] automatically detect venous beading and compute the tortuosity for the thickened and depletion area of the vein. The researchers used the green channel image is processing step, histogram equalization for image improvement and median filter for noise reduction (the objects beside the vein).

The study in blood vessel segmentation using filter Gabor was performed in [8]. This filter allows noise reduction and separate the blood vessel with retinal background image. The researchers used canny morphology operation to detect the edge of the vein. The resulted blood vessel has origin feature obtained by computing the ratio of average diameter of arteries to veins (AVR). AVR is an artery average diameter to veins on candidate of segmented blood vessel greyscale image.

Artery and veins classification can be carried out without training data. The researchers took centerline vessel pixels that was labeled manually at the starting and end point of the blood vessel and then classified them into the artery and the veins. The classification was performed separately on two quadrant in clockwise. The classification are vessel classification from combination quadrant from quadrant 1 to 4. The classification result highly depend on segmentation result (for centerline pixels extraction). The performance of classification process also depend on the blood vessel area in retinal fundus image [9].

The studies in bifurcation detection on retinal fundus image have been done using several stages in its process [10]. The researchers in [10] used 2D median filter, morphology operation and threshold in their preprocessing stage. Bifurcation detection was performed as a first stage on cardiovascular detection. The initial process was carried out by converting green channel and image's contrast improvement to extract the blood vessel. The enhancement of the image was done using complementary function of blood vessel image. The following step was performing cross number to detect the centerline of the pixels. If the value of center pixel equal to 1 then this pixel has at least 3 more neighboring pixel. Accordingly, this point was expressed as a point of bifurcation.

The bifurcation detection carried on by previous researchers do not include the algorithm to reduce some noises perfectly (*e.g.*, exudates, microaneursym, dot and blot hemorrhages) on fundus image. The experiments performed only for the images without noise (healthy image) that bifurcation detection could not yet give the optimum result. In this study, bifurcation detection on retinal fundus images will be detected as the first stage of venous beading detection process. This detection was perform by computing the Euclidian distance and inserting the morphology steps to eliminating the noises. The result of this study is expected to be able to detect bifurcation point correctly where the result from bifurcation feature extraction will be used for classifying the veins between normal veins and distention veins (venous beading).

2. METHODS

2.1. Retinal Blood Vessel Characteristic

This study used 100 images with health characteristic and images that suspected to have diabetic retinopathy from Stare dataset with .ppm format and variety field of view (fov) [11]. The blood vessel inside the retina are divided into two categories: artery and vein. Artery and veins inside retina have visual differences in color and thickness in pixel vessels as can be seen in Figure 1.

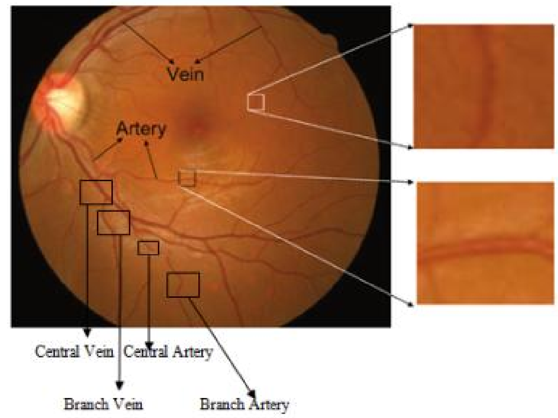

Figure 1: Artery and vein in fundus image

2.2. Preprocessing

This study used 100 images with health characteristic and images that Diabetic Retinopathy [11][12] to The preprocessing process was carried out before bifurcation point detection. The following is the algorithms of the preprocessing steps:

1. Read the fundus image
2. Performing green channel extraction.
3. Performing histogram equalization in order for the image having an equitable greyscale image distribution. For greyscale image distribution to earlier histogram, the distribution was applied by mapping each value of the pixel in early histogram into a new pixel value [13]. Redistribution can be written using equation 1 and 2:

$$P_r(r_k) = \frac{n_k}{n} \tag{1}$$

$$r_k = \frac{k}{L-1}, 0 \le k \le L-1 \tag{2}$$

Where :
nk is the pixel value on greyscale *k*,
n is the amount of all image pixels

4. After performing histogram the following step is to conduct filtering process. The filtering process was carried out by extend the length of multidimensional of an image. In general, the convolutional process to obtain the retinal image mask can be seen in Figure 4.
5. The convolution process was carried out between $f(x, y)$ images with matrix hessian of Gaussian. Matrix hessian of Gaussian was obtained by the second derivative from Gaussian function at each of fundus image that

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illustrated the intensity variety of the blood vessel. Matrix hessian can be computed using the formula below :

$$H(x,y)=\begin{bmatrix} D_{Gauss_{xx}} & D_{Gauss_{xy}} \\ D_{Gauss_{xy}} & D_{Gauss_{yy}} \end{bmatrix} \quad (3)$$

Where:

$H(x,y)$ = Hessian matrix of an image

$D_{Gauss_{xx}}$ = Blood vessel extraction in x axis

$D_{Gauss_{yy}}$ = Blood vessel extraction in

$D_{Gauss_{xy}}$ = Blood vessel extraction in diagonal

To obtain the element of Hessian matrix, the images were convoluted with the second derivative [14] of Gaussian function with the following formula:

$$D_{Gauss_{xx}} = f(x,y) * G_{xx} \quad (4)$$

$$D_{Gauss_{yy}} = f(x,y) * G_{yy} \quad (5)$$

$$D_{Gauss_{xy}} = f(x,y) * G_{xy} \quad (6)$$

Where G_{xx}, G_{yy} and G_{xy} are scale space which are computed using:

$$G''_{xx} = \frac{1}{2\pi\sigma^4}\left(\frac{x^2}{\sigma^2}-1\right)e^{\frac{-(x^2+y^2)}{2\sigma^2}} \quad (7)$$

$$G''_{xy} = G''_{yx} = \frac{1}{2\pi\sigma^6}(xy)e^{\frac{-(x^2+y^2)}{2\sigma^2}} \quad (8)$$

$$G''_{yy} = \frac{1}{2\pi\sigma^4}\left(\frac{y^2}{\sigma^2}-1\right)e^{\frac{-(x^2+y^2)}{2\sigma^2}} \quad (9)$$

Where :

Scale space = standard deviation of Gaussian function

$*$ = Convolution operation

s = The amount of Kernel Gaussian used

Example for $\sigma = 0.6$:

$$G''_{xx} = \begin{bmatrix} 0.1357 & -0.3062 & 0.1357 \\ 0.5444 & -1.2280 & 0.5444 \\ 0.1357 & -0.3062 & 0.1357 \end{bmatrix},$$

$$G''_{yy} = \begin{bmatrix} 0.1357 & 0.5444 & 0.1357 \\ -0.3062 & -1.2280 & -0.3062 \\ 0.1357 & 0.5444 & 0.1357 \end{bmatrix},$$

$$G''_{xy} = \begin{bmatrix} 0.2121 & 0 & -0.2121 \\ 0 & 0 & 0 \\ -0.2121 & 0 & 0.2121 \end{bmatrix}$$

$$G''_{yx} = \begin{bmatrix} 0.2121 & 0 & -0.2121 \\ 0 & 0 & 0 \\ -0.2121 & 0 & 0.2121 \end{bmatrix}$$

Kernel is a small matrix used in convolution process. This study applied 3x3 convolution window. Figure 2 shows a schema to obtain image mask with convolution.

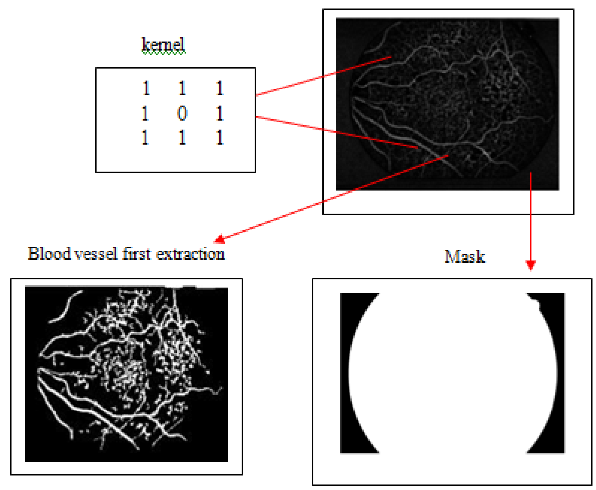

Figure 2 : Convolution Process to Obtain Retinal Image Mask

Assumed that all pixels which are outside the matrix $f(x,y)$ yield zero value, below are the algorithms to determine the convolution value between 3×3 kernel size with the retinal image :

1. Placed the kernel in the location of the first pixel. The next step is to compute the value of the convolution pixel at this position.
2. Performed kernel shifting with the size of one pixel to the right side then re-compute pixel convolution process. Performed step 2 repeatedly until all the pixels in this line are computed (No more pixel in this line)
3. Performed kernel shifting with the size of one pixel down (The pixel in the next line) then return to step 1 and 2 until all the pixels in this line are computed

Figure 3 shows the convolution process to obtain mask retinal image

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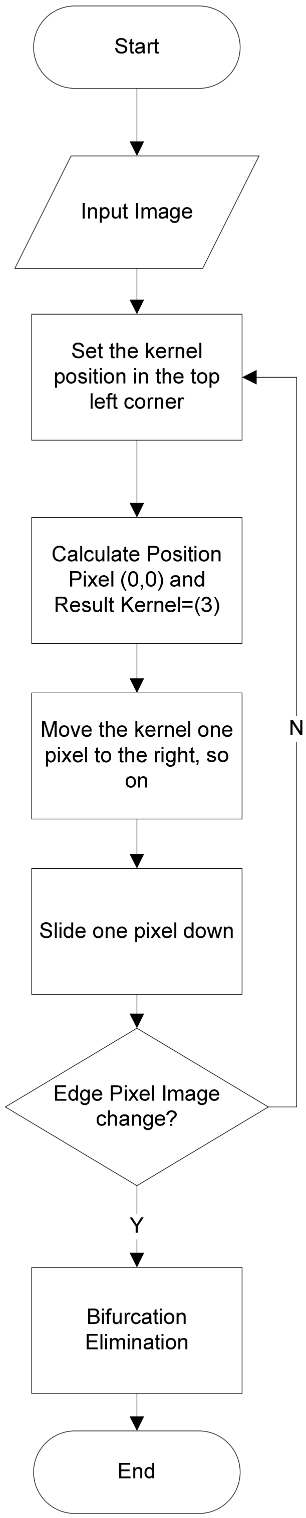

Figure 3 : Retinal Image Mask Convolution Flowchart

6. Performing top-hat filtering to strengthen all the part of the blood vessel that located in darker area as can be seen in Figure 4. This study will extract each of the veins that will be extracted into smaller element and more details.

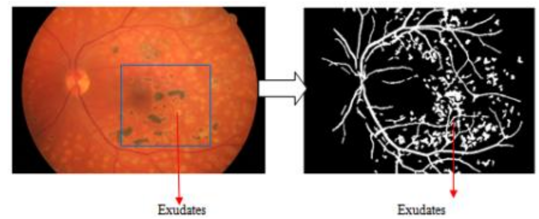

Figure 4 : The Extracted Blood Vessel Image With Exudates

7. Performing bottom-hat filtering to strengthen the vein and artery images in the bright area. Bottom-Hat is a filtering process to differentiate image resulted from closing operation with the original image using the following formula :

$$Bhat(f) = (f \bullet b) - f \quad (10)$$

This study used top and bottom-hat filtering with the purpose to eliminate the objects of an image using structuring element in opening and closing operation that do not fit. This procedure was performed to extract only the blood vessel (*e.g.*, the vein and artery) and to eliminate the other objects that were considered as the noise (for example exudates) as can be seen in Figure 5 below :

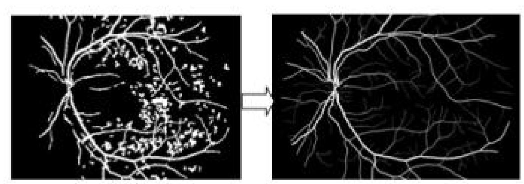

Figure 5: The Result From Blood Vessel Extraction

2.2 Bifurcation Point Detection Algorithm

Retinal blood vessel bifurcation are two lines that meet at one of its end, which are x, y coordinate and the angle of θ from the blood vessel in furcation form as can be seen in Figure 6.

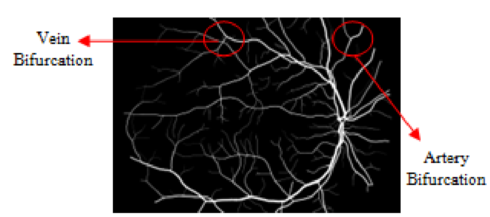

Figure 6 : Artery and Vein Bifurcation

The searching process of furcation above started from the (3, 3) pixel. This starting point was

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selected due to impossibility of the branch retinal artery and vein fall below (3, 3) pixel, given the previous bifurcation contain central retinal artery skeleton and vein. The steps taken in this research to determine blood vessel using bifurcation and crossover are:

1. Read the extracted blood vessel image $I(\mathrm{x}, y)$
2. Identified the bifurcation point and the crossover. For 3x3 window, if the value of central pixel is equal to 1 and has 3 neighboring pixels then the central pixel is the bifurcation point. If the value of central pixel is equal to 1 and only has 1 neighboring pixel then the central pixel is the crossover point. Example for bifurcation pixel representation can be seen in Figure 7.

0	1	0
0	1	0
1	0	1

Figure 7 : Bifurcation Pixel Representation

3. Determine the average distance between the neighboring lines. The average distance can be computed using the formula of Euclidian distance:

$$D = \frac{\sum_{i=1}^{x} \frac{a_i}{b_i} + \sum_{j=1}^{y} \frac{a_j}{b_j}}{x + y} \tag{11}$$

Where :

x and y = The amount of image skeleton I line and

a_i and b_i = The length of i[th] line and the amount of Pixels with the value 1 on i[th] line

a_j and b_j = The length of j[th] column and the amount of pixels with the value 1 on j[th] column

4. Assuming each of bifurcation point and crossover on blood vessel skeleton image I with 2 coordinate parameters x and y and θ orientation. In bifurcation, the value of θ will be determinate differently with crossover value, with the following characteristics:
   a) The 3 lines connected to the furcation points of retinal blood vessel extracted images contain varied direction.
   b) The furcation will be divided into 3 new final point where its 3 neighboring pixels from furcation point and each part of the flow line connected to the earlier furcation will be divided.
   c) The outline of this plot will explore the starting point which is the end point and the length equal to D.
   d) All the x coordinate in the indentation line will be added.
   e) The result of the summation will be dived by D to obtain P_x. The next step is to determine P_y using the same ways. The direction of each final end point can be obtain using the following formula :

$$\theta = \tan^{-1} \frac{(p_y - q_y)}{(P_x - q_x)} \tag{12}$$

In bifurcation, there were 3 black pixels region that determine the furcation point of the blood vessel. The black pixel region can be seen in Figure 8.

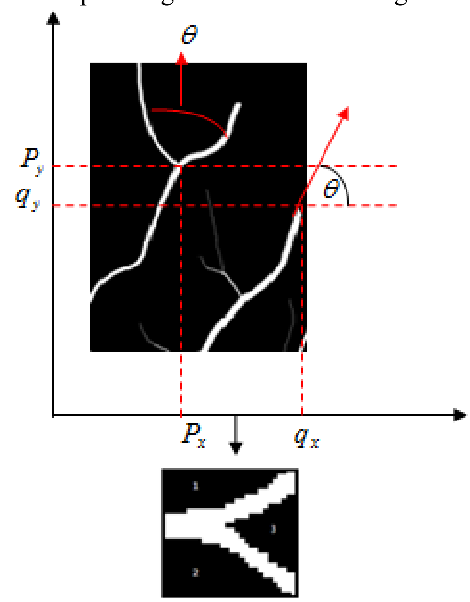

Figure 8 : Bifurcation Of Blood Vessel Pixel

In this study, the bifurcation point detection on the extracted retinal vein image will be used as a centerline in computing the thickness of the blood vessel. The result of bifurcation will be used as elimination process. The bifurcation elimination phase was performed to eliminate the branched blood vein. The blood that arrived inside the vein of retinal fundus image will enter inside the central of the fundus. Therefore to simplify the venous beading detection the elimination of arteries and veins branches were performed. The elimination phase will be start at a certain point, then the shortest distance between points will be compute with the following algorithms:

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1. Determine two variables B (*branch*) as a branching point and E (*endpoint*) as the end of the branch.
2. Compute the distance of skeleton image with row column vector B coordinate and vector E from location point by computing the shortest distance between two.
3. Determine the location of the shortest pixel that near the bifurcation pixel.
4. Eliminate those pixels.

Blood vessel segmentation process can be seen in Figure 9.

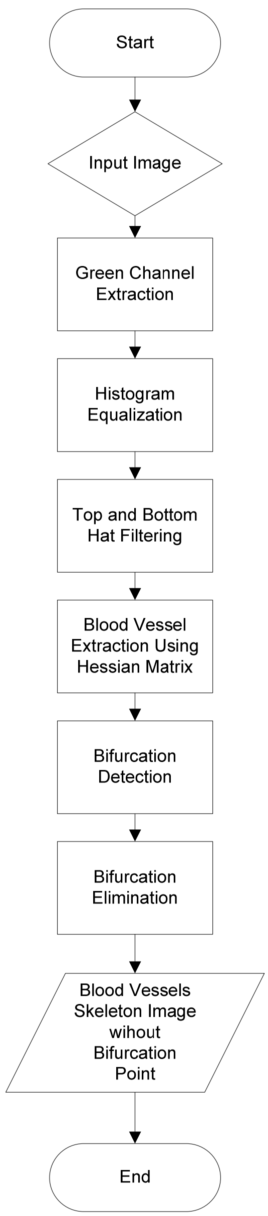

Figure 9 : Blood Vessel Segmentation Flowchart

The process of bifurcation elimination can be seen in Figure 10

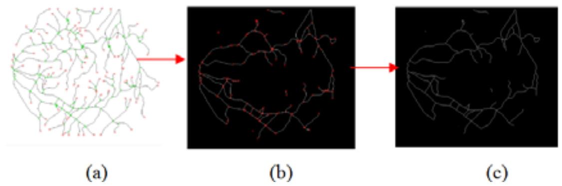

Figure 10.(a) Blood Vessel with Bifurcation Point, (b) Elimination Result without Bifurcation Point, (c). Blood Vessel Image Skeleton without Bifurcation.

After the branches of the skeleton were removed, the image skeleton with the eliminated bifurcation were obtained. The result of this skeleton will be used as a seed point as pixel centerline from binary image candidacy of the main vessel (veins and central arteries) as can be seen in Figure 11.

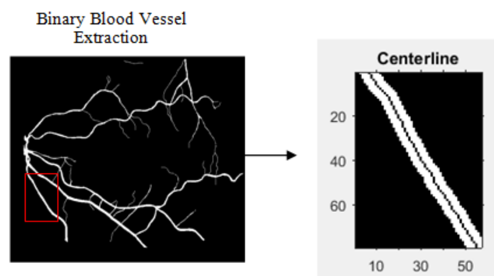

Figure 11: Retinal Blood Vessel Centerline

3. RESULT AND DISCUSSION

The purpose of bottom-hat filtering transformation in this study is to eliminate the object from an image using structuring element in opening and closing operation that incompatible. The bottom-hat filtering transformation process was carried on to extract only the blood vessel (the veins and arteries) and to eliminate other objects that were considered as noises (*e.g.*, exudates).

Skeleton morphology method consist two pixel arrays in its process. They are image and structuring element. Structuring element in skeleton contain a pattern that specialized in coordinating some points that have the same relativity to a center point (origin). This pattern was represented with cartesian coordinates for each element as small boxes. This study adapts skeleton morphology in binary structure that was performed in an image. If the pixel in blood vessel image has at least one of its four neighbors (p_0, p_2, p_4, p_6) with the value less than the grey value of each or all the eight neighbors is less than the value of their grey value, then their binary value turned to one (1) or zero (0).

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The result how to obtain the skeleton blood vessel image can be seen in Figure 12.

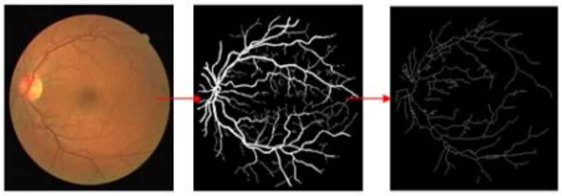


Figure 12 : The Result of Noise Removal and Skeleton Process

The shape of blood vessel that has a branching point creates an open curve. It will be assumed as a closed curve to be able to describe the distance of the blood vessel center point. These techniques in centroid method defined as a distance from the edge of the curve to the curve center point. The result of bifurcation point can be seen in Figure 8. The process of bifurcation detection and image crossover can be seen in Figure 13.

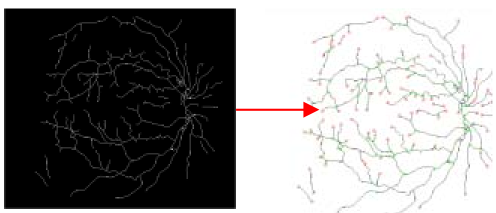


Figure 13 : (a). Skeleton Image, (b). Bifurcation Point

The result of bifurcation will depend on the outcome of noise elimination at the second stage of extraction on both vascular image. In some noise elimination, there were some blood vessel that covered with noise in the form of exudate. These covered blood vessel were also eliminated as can be seen in Figure 14. In the boxed section colored with red, the missing arteries can be seen due to the noise elimination of the first step of extraction.

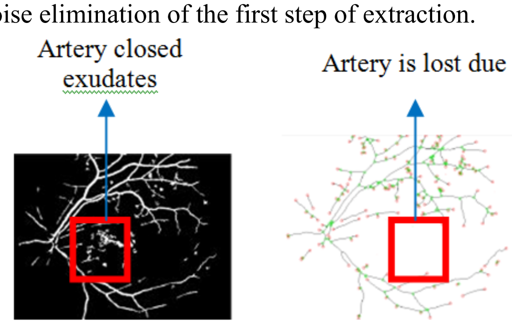
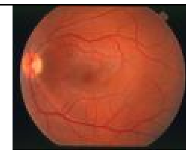
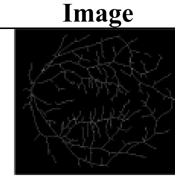
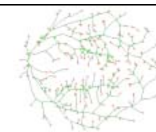
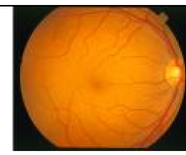
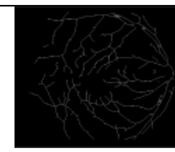
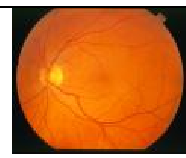
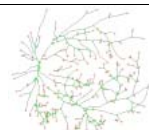
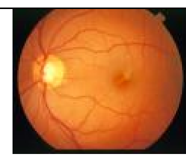
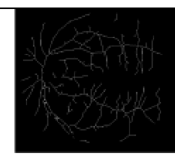


Figure 14 : (a). Blood Vessel Extraction with Noise, (b). Bifurcation Detection Result

Table 1 shows the images resulted from vascular bifurcation extraction.

Table 1: The Result Of Retinal Blood Vessels Extraction And Bifurcation Point

Blood Vessel Extraction	Skeleton Image	Bifurcation Point
		
		
		
		
		

4. CONCLUSION

Based on the experiments, overall vein images were successfully extracted. The Hessian matrix of Gaussian employed in this research can describe the intensity of blood vessel variation around each point of fundus image correctly. The sizes of the vessel were obtained from all the eigenvalue of Hessian Matrix in order to extract the blood vessel properly. Determining the point of bifurcation of the extracted blood vessel can be performed correctly and successfully. The smaller the Euclidian distance $d(x, y)$ are the more similar two compared pixels so that these two pixels were considered as bifurcation point. On the other hand, the greater the distance value of $d(x, y)$, the pixels that going to compared are more dissimilar.

The result of bifurcation elimination will be used to obtain the centerline image. For advance research, the centerline image will be used to compute the vessel thickness as seed point. The blood vessel that have venous beading can be determined by measuring the venous thickness with the size that above normal size.

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