Detection of Blood Vessels in Retinal Images Based on Top-Hat Transform

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Abstract—**This paper is proposed to detect a blood vessel in retinal images by improving the previous method called a local entropy thresholding. The system is test by using the sample from DRIVE and STARE database and is run by using MATLAB R2011b. The first step is done by extracting the green channel of RBG image since it gives better contras for the retinal images. Next, the retinal image is enhanced by morphological transformation called opening by reconstruction. This basically remove small object thus, clearing the image. Next, Top-Hat transform is applied to the retinal image. This transform is useful for uncovering detail which is rendered invisible shading or illumination over the image. After that, the step is furthered by a mask generation and match filter. The process is then followed by applying a local entropy thresholding and length filtering for blood vessel extraction. The performance of the result is determined by calculating a sensitivity and accuracy which is compared with existing hand-labelled results from DRIVE and STARE database. The average accuracy and sensitivity for proposed method is 0.89 and 0.71.**

***Keywords*— retinal images, local entropy thresholding, opening by reconstruction, Top-Hat transform, length filtering**

I. Introduction

Eye is very important in our daily life that they gives which allows us to see dimensions of objects, shapes and colors by processing the light they reflect or emit. Retina is a part of eye. [1].Since most of the problems leading to vision loss occur are sources from retina, it is important for an ophthalmologist to be able to do an accurate analysis in so that any abnormality in retina can be detected earlier.

The retina is the only location where blood vessel can be directly captured [1] Eye disease such as glaucoma [2]and diabetic retinopathy[3] are one of disease related to retina that serves as the main leading of blindness. Even though there are many different techniques have been proposed in order to detect the blood vessel in retinal image, there is still some issue on how accurate and fast the method works. Blurred retinal image may be mistakenly as lesions graded as normal. Therefore a sufficient clarity of blood vessel extraction is needed for the retinal image. Furthermore, studies have shown that people who suffer from diabetes benefit from regularly attending a screening session[4]. Therefore a better method for detecting a blood vessel must be search since early detection of disease may prevent further damage to patient's eye thus reducing the probability of blindness. This paper is proposed to be able to identify the blood vessel in retinal image so that any abnormality behavior can be detected earlier for further treatment. The method is done by improving the existing method of local entropy thresholding by applying Top-Hat transform. The system is basically tested with the sample obtained from STARE [4] and DRIVE [5] database by using MATLAB R2011b software.

In this paper, section II will discuss about some methods used by the previous researcher. Section III is basically a methodology which discuss about the propose method for improvement. The technique on how the blood vessel is extracted is discussed in section IV. This follows by the result and discussion in section V and conclusion in section VI.

II. Blood Vessel Detections

Basically many methods have been proposed previously in order to detect and extract the blood vessel in retinal images. Some of those previous method are a novel method to extract blood vessel, segmentation based method, and feature point detection. Most of the method is basically follow the flow as shown in Fig. 1.

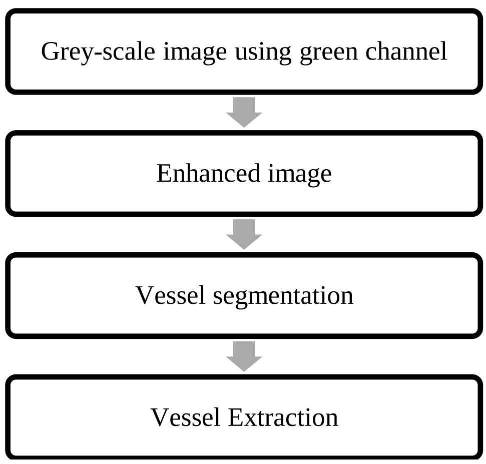

Fig. 1 Basic flow of blood vessel extraction

A. A Novel Method for Blood Vessel Detection From Retinal Images

In this proposed method[6], they present a novel method to segment retinal blood vessels to overcome the variation contrast of large and thin vessel. The method includes pre-processing which involves background normalization, image binarization and large vessel extraction. Next is feature extraction follows by classification of fragment and finally thin vessel growth which is based on tracking method. The limitation of this method is low accuracy due to the inflated width of large vessel in image processing.

B. Segmentation Based on Fractal Dimension in Spatial-Frequency Domain

In this proposed method[7], the fractal dimension value of each pixel is computed in order to extract the vessel from their retinal background. In this method, a wavelet packet transformation is used to reduce the non illumination effect while reserving thin vessel and low contrast vessel information. . The limitation of this method is that is it is not suitable for different size of retinal images since the fractal dimension value depends on the window size selection.

C. Blood Vessels and Feature Point Detection on Retinal Images

In this proposed method[8] the matched filter is used to enhanced vessel with respect to background. By using threshold operator based on Gaussian probability density function, the separation between vessels and background is accomplished. After all the steps, the endpoint, intersections and overlapping vessels are extracted. The limitation of this method is there is a generation of false vessels especially in the area of optical disk and also the reconstruction of small capillaries starting from the detection of the endpoint.

III. METHODOLOGY

In this paper, some improvement was attempted to the previous method which called as a local entropy thresholding. [9],[10] Basically the local entropy thresholding aims to maximize the local entropy foreground and background without considering the unbalanced proportion between them. For the proposed method, a morphological process and Top-Hat transform is applied to enhanced image. For morphological process, an opening by reconstruction was used.

This step is basically a morphological transformation which enables the objects which survive an initial erosion to be exactly restored to the original shape. This element can remove any objects within which the structural element and object cannot contain. [9]. Before performing the local entropy thresholding method, the greyscale retinal image is enhanced by using morphological process and a Top-Hat Transformation. The very first step is actually by converting the RGB image to a greyscale image. This is basically done by extracting the green channel of RGB image. The next step is to produce clear image by applying an opening by reconstruction. This followed by mask generation, match filter, local entropy thresholding and length filtering. The flow of the steps is summarized in the Fig.2.

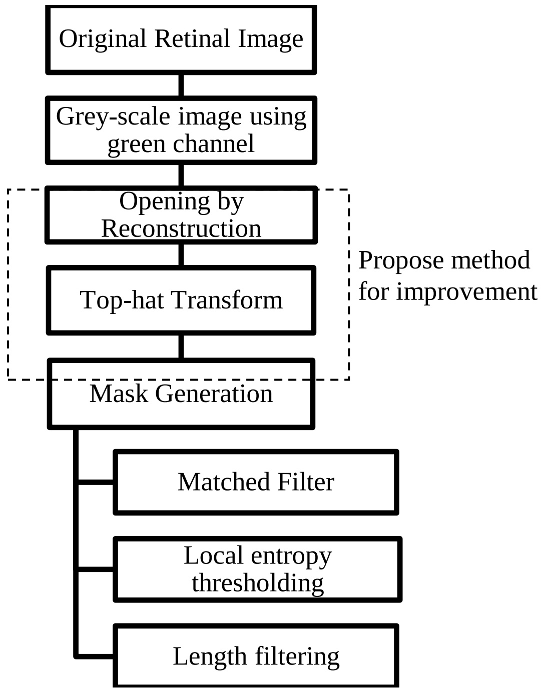

Fig. 2 Flow of the proposed step

IV. BLOOD VESSEL EXTRACTION TECHNIQUE

A. Converting RBG Image to Greyscale Image

The most basic process is started with colour fundus image (RGB) converted to gray level contrast. Since green channel (second channel) exhibits the best contrast between the background and vessel[8], the greyscale retinal images from the green channel is employed for further development.

B. Opening by Reconstruction

To enhance the image, a morphological process is applied to enhanced image. In morphological process, an opening by reconstruction was used. This step is basically a morphological transformation which enables the objects which survive an initial erosion to be exactly restored to the original shape. This element can remove any objects within which the structural element and object cannot contain [17] In a simplest definition, this step is basically to remove small object and produce clear image

C. Top-hat Transform

The next step for image enhancement is by applying a top-hat transform to the image. Basically there are two types of top-hat transform. In this case, a white top-hat transform is used to contrast the vessels and the background. This step is important since the blood vessels always appeared darker than the background. Top-hat transformation is defined as the difference between the image and the image after opening with structuring element, b(I-Θb)[17]. This operation is actually to extracts small elements and details from given. Opening has the general effect of removing small light details in the image whilst leaving darker regions undisturbed. Moreover this transformation is useful for uncovering detail which is rendered invisible shading or illumination over the image. The Matlab function of *imtophat* is used for this transformation. The definition image A structuring element B is define as follow:

$$A\ (A\ominus B)\oplus B. \qquad (1)$$

D. Mask Generation

Mask generation aims at labeling pixels belonging to the fundus Region of Interest (ROI) in the entire image. In fundus images, those dark surrounding region in the image is a pixel outside ROI. [9],[10].The mask generation is shown in Fig. 3(e).

E. Matched Filter

By using Gaussian shaped curve, the cross sectional of blood vessel can be approximated. Match filter detection is basically used to detect piecewise linear of blood vessel in retinal images. In order to enhance the blood vessels, the two-dimensional matched filter kernel is used. This step is basically applied to enhanced blood vessel. A prototype matched filter kernel is expressed as equation 2. L is the length of the segment for which the vessel is assumed to have fixed orientation. A set of twelve 16x15 pixel kernels is applied by convolving to a fundas image ant at each pixel only the maximum of their response is retained.[9], [10].

$$f(x.y) = -\exp\left(\frac{-x^2}{2\sigma^2}\right),\ for|y|\ \leq L/2 \qquad (2)$$

F. Local Entropy Thresholding

In this algorithm, the gray level corresponding to the maximum of total second-order local entropy of the object and the background gives optimal threshold for object-background classification. Basically this method is used to exploit the entropy of the gray levels in the image [9],[10]. The equation of total second order entropy is shown in equation 5. Equation 3 shows the second order entropy of the object while equation 4 shows the second-order entropy of the background. The result is shown in Fig. 3(h).

$$\mathrm{HA}^{(2)}(\mathrm{s}) = \frac{1}{2}\sum_{i=0}^{s} \quad \sum_{j=0}^{s} Pij^A log_2\, Pij^A \qquad (3)$$

$$\mathrm{HA}^{(2)}(\mathrm{s}) = \frac{1}{2}\sum_{i=s+1}^{L-1} \quad \sum_{j=s+1}^{L-1} Pij^C log_2\, Pij^C \qquad (4)$$

$$\mathrm{HT}^{(2)}(\mathrm{s}) = \mathrm{HA}^{(2)}(\mathrm{s}) + \mathrm{HC}^{(2)}(\mathrm{s}) \qquad (5)$$

G. Length Filtering

This step is actually done remove isolated pixels by using the concept of connected pixel labeling. This step is needed since there are some misclassifies pixels in the image. Therefore this step helps to produced clean image. The length filtering will isolate the individual objects by using the eight-connected neighborhood and label propagation [10]. After this algorithm is performed, only resulting classes will exceed a certain number of pixels. The results is shown in Fig. 3(g)

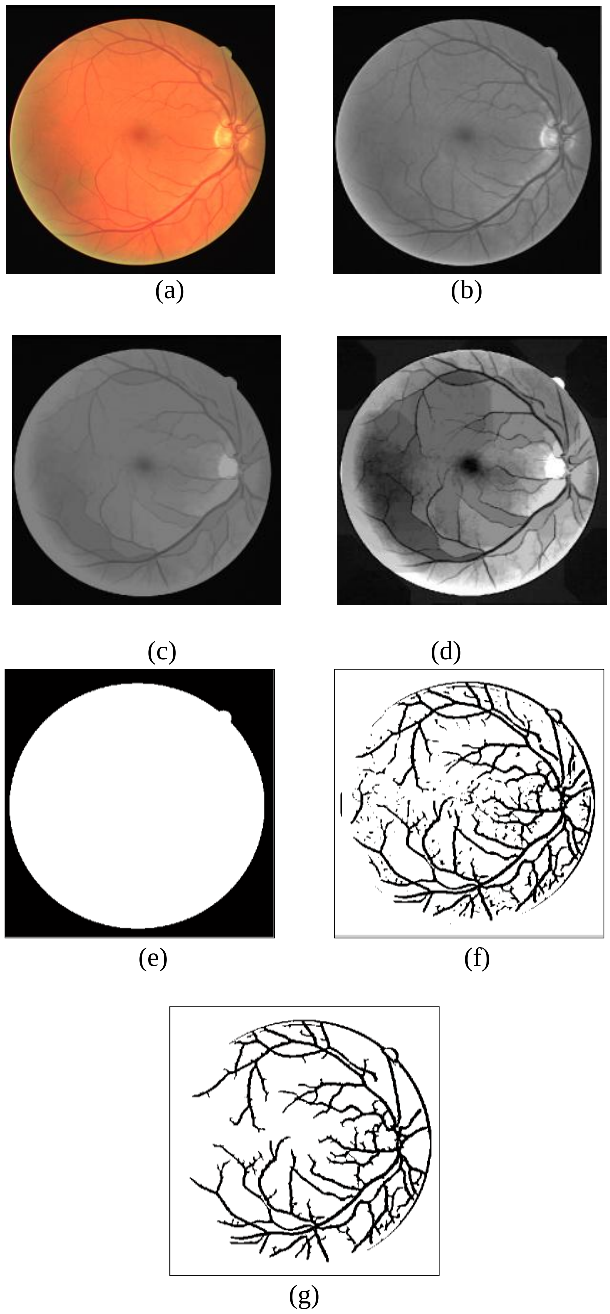

Fig. 3 (a) Original retinal image. (b) Green channel of greyscale image. (c) Result of opening by reconstruction. (d) Top-hat transformation (e) Mask generation. (f) local entropy thresholding. (g) Length filtering

V. Results and Discussion

A. Database

The sample of retinal image is obtained from STARE [4] and DRIVE database [5] . DRIVE database is basically obtained from a screening program in the Netherlands. The test subject for this database is between 25-90 years of age. The screening consisted of 400 photographs. In this database, 40 randomly image is selected and shows that 7 shows sign of mild early diabetic retinopathy while the remaining 33 people do not show any sign of it. Another retinal images is obtained from STARE database which provided by the Shiley Eye Center at the University of California, San Diego, and by the Veterans Administration Medical Center in San Diego[4]

B. Performance of Proposed Method

On Window &,CPU 2.13GHZ, using MATLAB R2011b, the computational time for the whole process is less than 1minute which is basically faster compared to manual that took almost 2hours to executed and other method. The execution time for other methods is shown in Table 1.

TABLE I
TIME TAKEN TO EXTRACT BLOOD VESSEL

Method	Execution Time
Manual	2 hours
Wang and Bhalerao[10]	7.0 minutes
Soares et al.[12]	3.0 minutes
Chanwimaluang and Fan [10]	2.5 minutes
Proposed method	Less than 1 minutes

The performance for this method is calculated by sensitivity and accuracy. The true positive (TP), true negatives (TN), false positives(FP), and false negatives(FN) is basically four outcomes of single prediction for a two-class with classes “1” as “YES” while “0” as “No”. Table 2 shows how it works. The true positive and true negatives are a correct classification while a false negative is when the result is incorrectly classified. Basically sensitivity will tell how well the test predicts the vessel pixels. Accuracy is use to measure how well the test predict both vessel and non vessel pixels. The formula for sensitivity and accuracy is given as in equation (6) and equation (7).

$$\text{Sensitivity}=\frac{TP}{TP+FN} \tag{6}$$

$$\text{Accuracy}=\frac{TP+TN}{TP+TN+FP+FN} \tag{7}$$

TABLE 2
PREDICTED CLASS AND ACTUAL CLASS

		Predicted Class	
		YES	NO
Actual Class	YES	TP	FN
	NO	FP	TN

Based on the result, it have been discovered that this proposed method for improvement does not exactly improve the previous method. Out of sixty sample images, only three images show that the accuracy is actually improved, one from Stare database (image 03) and two from DRIVE database(image 23 and 31).The average value for accuracy is 0.89 and 0.71 for sensitivity. Even though this proposed method appeared to be extracted more vessel than previous results, it actually only referring on how human’s eyes see roughly without any proper calculation have been made. Since this is a medical matter, it is important to determine how good the extracted result was. However, the result does show some improvement for sensitivity. The accuracy and the sensitivity for this proposed method is obtained by comparing the proposed result with the hand-labelled manual1 from DRIVE database and a hand-labelled vessel network provided by Valentina Kouznetsov for STARE database. In this paper, the result gained from Adam Hoover and their proposed match spatial filter probing algorithm is compared with the results provided by Valentina Kouznetsov. Adam Hoover hand-labelled results are proven the best among the rest.

TABLE 3
DATA OF TP, FP, FN AND TN COLLECTED FROM MATLAB SIMULATION FOR STARE DATABASE

Image	TP	FP	FN	TN
im0001	27721	37815	11450	346514
im0002	18557	59481	4958	340504
im0003	18831	38535	5576	360558
im0004	20631	40284	9971	352614
im0005	30560	39174	13925	347041
im0044	31711	33618	16670	341501
im0077	32467	12946	22545	355542
im0081	30663	21200	27527	344110
im0082	34765	21018	17129	350588
im0139	39096	20854	25619	337931
im0162	31355	15294	17147	359704
im0163	35061	11473	14044	362922
im0235	40824	18303	18933	345440
im0236	42441	41934	13781	325344
im0239	39022	21937	14049	348492
im0240	47606	42232	16978	316684
im0255	28422	11182	27112	356784
im0291	21461	33890	4689	363460
im0319	18720	24211	7861	372708
im0329	33100	41051	9109	340240

TABLE 4
DATA OF SENSITIVITY COLLECTED FOR STARE DATABASE

Image	Sensitivity			
	Original	**Propose**	**Adam Hoover**	**Match Filter**
im0001	0.65	**0.71**	0.99	0.97
im0002	0.86	0.79	0.98	0.97
im0003	0.77	0.77	0.98	0.96
im0004	0.58	**0.67**	0.97	0.95
im0005	0.65	**0.69**	0.98	0.97
im0044	0.66	0.66	1.00	0.97
im0077	0.68	0.59	1.00	0.99
im0081	0.69	0.53	1.00	0.99
im0082	0.64	**0.67**	1.00	0.98
im0139	0.58	0.60	1.00	0.98
im0162	0.66	0.65	1.00	0.99
im0163	0.67	**0.71**	1.00	0.98
im0235	0.62	**0.68**	1.00	0.98
im0236	0.74	**0.75**	1.00	0.99
im0239	0.60	**0.74**	1.00	0.99
im0240	0.52	**0.74**	0.99	0.99
im0255	0.64	0.51	0.99	0.99
im0291	0.73	**0.82**	0.99	0.96
im0319	0.63	**0.70**	1.00	0.94
im0329	0.51	**0.78**	0.99	0.96

TABLE 5
DATA OF ACCURACY COLLECTED FOR STARE DATABASE

Image	Accuracy			
	Original	**Propose**	**Adam Hoover**	**Match Filter**
im0001	0.90	0.88	0.96	0.93
im0002	0.86	0.85	0.97	0.95
im0003	0.88	**0.90**	0.96	0.94
im0004	0.94	0.88	0.95	0.93
im0005	0.92	0.89	0.95	0.93
im0044	0.90	0.88	0.95	0.92
im0077	0.94	0.92	0.95	0.93
im0081	0.93	0.88	0.93	0.92
im0082	0.93	0.91	0.95	0.93
im0139	0.91	0.89	0.92	0.90
im0162	0.93	0.92	0.95	0.93
im0163	0.95	0.94	0.96	0.94
im0235	0.93	0.91	0.94	0.91
im0236	0.92	0.87	0.95	0.92
im0239	0.94	0.92	0.95	0.93
im0240	0.92	0.86	0.94	0.91
im0255	0.93	0.91	0.95	0.92
im0291	0.97	0.91	0.98	0.95
im0319	0.95	0.92	0.97	0.92
im0329	0.93	0.88	0.95	0.92

TABLE 6
DATA OF TP, FP, FN AND TN COLLECTED FROM MATLAB SIMULATION FOR DRIVE DATABASE

Image	**TP**	**FP**	**FN**	**TN**
01_test	24994	37379	4446	263141
02_test	25041	12256	8749	283914
03_test	20099	8331	12794	288736
04_test	23762	190858	6592	280548
05_test	22651	15154	8261	283894
06_test	20937	10203	11179	287641
07_test	22485	24770	7667	257038
08_test	19486	12999	8903	288572
09_test	21794	27714	4947	275505
10_test	21223	22122	5933	280682
11_test	20229	13808	9310	286613
12_test	20887	12204	7603	289266
13_test	24803	23743	7456	273958
14_test	20364	15129	6313	288154
15_test	13166	38528	10448	267818
16_test	19813	12934	9978	287235
17_test	22545	27383	5307	274725
18_test	21694	24847	4450	278969
19_test	18711	12974	8660	289615
20_test	19371	18573	4894	287122
21_training	18576	15885	6082	289417
22_training	20651	9759	9158	290392
23_training	15980	28055	5743	280182
24_training	23876	8995	14353	282736
25_training	23383	21349	8286	276942
26_training	18405	20411	9186	281976
27_training	20713	13792	8360	287095
28_training	23276	17086	8952	280646
29_training	19098	20286	8653	281923
30_training	11064	11050	14820	293026
31_training	12216	7594	7682	302468
32_training	22197	33194	4787	269782
33_training	21384	21475	5302	281799
34_training	24344	51534	7943	246139
35_training	22150	18542	6462	282806
36_training	26127	21384	9757	272692
37_training	22236	18812	6605	282307
38_training	22212	20405	6265	281078
39_training	20229	13184	8119	288428
40_training	20944	31236	4057	273723

TABLE 7
DATA COLLECTED FOR DRIVE DATABASE

Image	Sensitivity		Accuracy	
	Original	**Proposed**	**Original**	**Proposed**
01_test	0.82	**0.85**	0.94	0.87
02_test	0.74	0.74	0.94	0.94
03_test	0.65	0.61	0.94	0.94
04_test	0.66	**0.78**	0.95	0.92
05_test	0.69	**0.73**	0.95	0.93
06_test	0.62	**0.65**	0.94	0.94
07_test	0.68	**0.75**	0.94	0.90
08_test	0.66	**0.69**	0.93	0.93
09_test	0.63	**0.82**	0.94	0.90
10_test	0.65	**0.78**	0.95	0.91
11_test	0.56	**0.68**	0.94	0.93
12_test	0.65	**0.73**	0.95	0.94
13_test	0.71	**0.77**	0.94	0.91
14_test	0.73	**0.76**	0.95	0.94
15_test	0.85	0.56	0.90	0.85
16_test	0.68	0.67	0.94	0.93
17_test	0.60	**0.81**	0.94	0.9.
18_test	0.56	**0.83**	0.95	0.91
19_test	0.86	0.68	0.93	0.93
20_test	0.62	**0.80**	0.95	0.93
21_training	0.65	**0.75**	0.95	0.93
22_training	0.69	**0.71**	0.94	0.93
23_training	0.81	0.74	0.87	**0.90**
24_training	0.47	**0.62**	0.93	0.93
25_training	0.71	**0.74**	0.93	0.91
26_training	0.68	0.67	0.95	0.91
27_training	0.44	**0.71**	0.94	0.93
28_training	0.62	**0.72**	0.94	0.92
29_training	0.73	0.69	0.95	0.91
30_training	0.61	0.43	0.95	0.92
31_training	0.86	0.61	0.89	**0.95**
32_training	0.72	**0.82**	0.95	0.88
33_training	0.75	**0.80**	0.94	0.92
34_training	0.71	**0.75**	0.89	0.82
35_training	0.79	0.77	0.94	0.92
36_training	0.52	**0.73**	0.93	0.91
37_training	0.71	**0.77**	0.94	0.92
38_training	0.69	**0.78**	0.94	0.92
39_training	0.64	**0.71**	0.95	0.96
40_training	0.84	0.84	0.94	0.89

Fig. 5 First row: Results from hand-labelled manual1 from DRIVE database

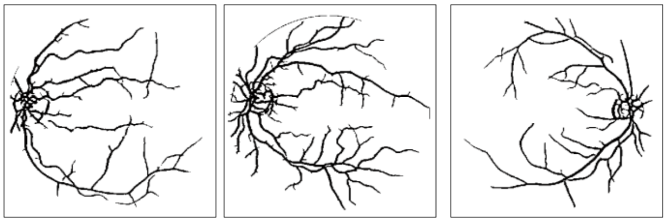

Fig.6 Results from original local entropy thresholding

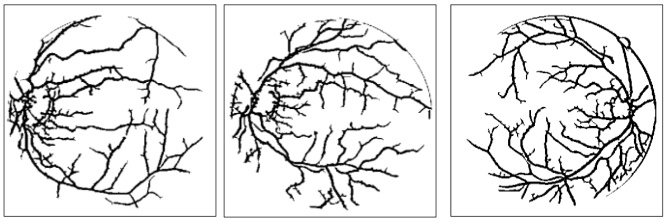

Fig. 7 Results from proposed method

Instead of only improving this method, other approaches have been tested. One of the tested algorithm is by applying opening by reconstructing, Bottom-Hat transform and followed by intensity thresholding which include manual, polynomial and Otsu's method. However those methods are not enough in producing a good result. The vessels extracted are quite weak. There are limitations in this method because of simple thresholding. Since thresholding does not consider the spatial relationship between pixels, there is no guaranteed that the threshold pixels will be contiguous. The results from this approach are shown in Fig.8.

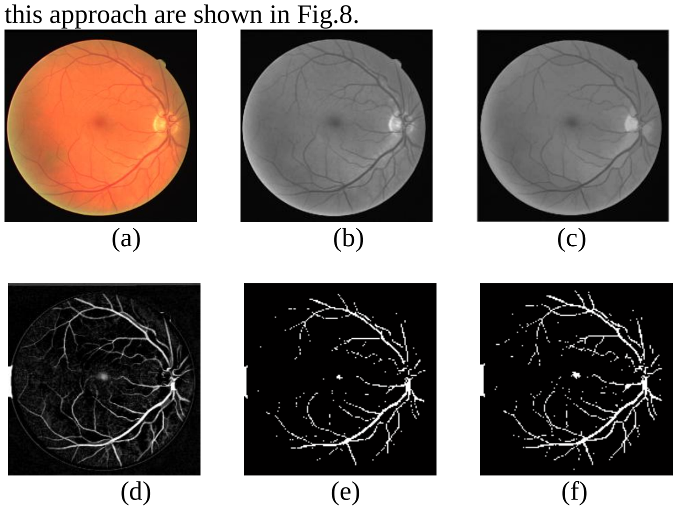

Fig.8 (a) Retinal image. (b) Greyscale of green channel. (c) Result of opening by reconstruction. (d) Bottom-hat transformation (e) Result of Polynomial threshold (d) Result of Otsu's method.

Another approach for blood vessel detection is by using greyscale erosion and dilation with flat structuring elements. This morphological gradient works by replacing a given pixel by the minimum or maximum value in the local neighbourhood defined by the structuring element will effect little or no change in smooth regions of the image [11]. The step is then followed by enhancing the image using Top-Hat transform. Fuzzy-c means thresholding is applied to the enhanced image for blood vessel extraction. This method took quite a long time for iteration and does not extract small blood vessel and the image is not clean enough. The result from this approach is shown in Fig.9

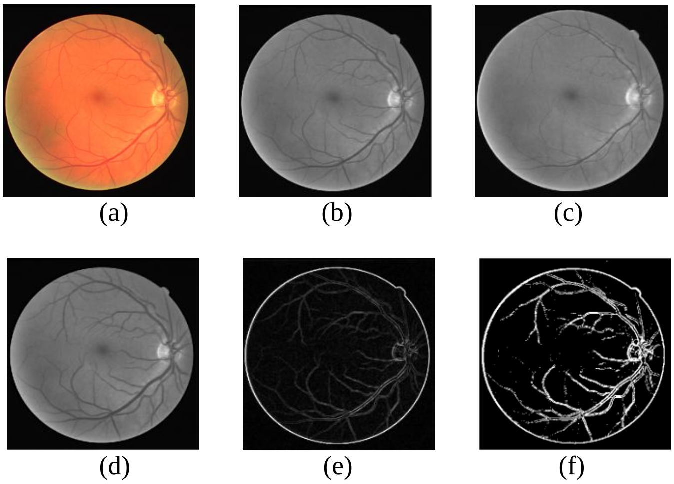

Fig.9 (a) Retinal image. (b) Greyscale of green channel. (c) Result of dilation (d) Result of erosion (e) Result of Top-Hat transformation (f) Result of fuzzy thresholding

VI. CONCLUSION

In this paper, an attempt to do some improvement has been made to the previous method which is a local entropy thresholding. The step is first employed by extracting the green channel of greyscale image from RBG since it gives better contras for blood vessel. Compared to previous method, the process is added up by performing the morphological process which is opening by reconstructing and followed by applying Top-Hat transformation. However, based on the results which obtained by comparing it with hand-labelled images from both database, the proposed method did not actually improving the accuracy. Even though this proposed method does not actually give better result in extracting the blood vessel in retinal image when compared to other previous method, it does extract the main blood vessel of the retinal image. Some images do appear to be improved in naked eye. However, since this is a medical matter, it is important to be able to do a computational analysis. Moreover, the sensitivity is proven to be improved by using this method. For future prospect, we might as well improve the method by differentiating the lesion so that the image accuracy and sensitivity can be improved. Another approach for comparing the results can also be implemented by using Receiving Operating Characteristic, ROC curve.

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