DETECTION OF MICROANEURYSMS TO INDICATE THE DIABETIC RETINOPATHY DISEASE

By

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FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved:

_____

A.P. Dr. Tang Tong Boon
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Nursyarmimi Liyana Binti Mohd Aris

ABSTRACT

Early detection of diabetic retinopathy is essential to avoid blindness. By detecting the early signs of the disease which is the microaneurysms, the progress of the disease can be better controlled. However, there is lack of ophthalmologists to screen hundreds of retina images. Hence, a computer-aided system is developed to help in detecting the microaneurysms in the fundus images. The objectives of this project is to develop a MATLAB coding to detect the microaneurysms which are the early signs of diabetic retinopathy disease and to evaluate between the retina images having microaneurysms and those of not having microaneurysms. The fundus images are retrieved from the online public database that supplies the fundus images for research purpose. This project will focus on detecting only microaneurysms. Thresholding, shade correction, morphological operation and rule-base classifier have been developed in this project. The experiment results demonstrated that microaneuryms could be detected in the fundus images. However, not all microaneurysms are detected.

ACKNOWLEDGEMENTS

I would like to express my gratitude to Allah S.W.T for His blessing and guidance to complete my final year project entitled “Detection of Microaneurysms to Indicate the Diabetic Retinopathy Disease”. I am very grateful to my dearest family for giving me great support along my journey at Universiti Teknologi PETRONAS (UTP). I would also like to thank my project supervisor A.P. Dr. Tang Tong Boon for his continuous support and guidance throughout completing my final year project. Thank you and God bless.

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LIST OF ABBREVIATIONS

DR	Diabetic Retinopathy
FYP	Final Year Project
GUI	Graphical User Interface
CHT	Circular Hough Transform

CHAPTER 1
1 PROJECT BACKGROUND

1.1 Background of Study

Diabetic retinopathy (DR) is an eye disease that is commonly suffered by patients with diabetes. The disease is caused by the changes in blood vessels of the retina. There are four stages of diabetic retinopathy. The stages are as stated below:

- First stage: Mild non-proliferative retinopathy
- Second stage: Moderate non-proliferative retinopathy
- Third stage: Severe non-proliferative retinopathy
- Fourth stage: Proliferative retinopathy

The early signs of diabetic retinopathy consist of microaneurysms, small hemorrhages, cotton wool spot and exudates. Research proven that these signs can be identified by analyzing the retina images. Currently, eye screening by the ophthalmologists is carried out to detect the diabetic retinopathy. However, there are several barriers in achieving the goals of detecting the disease. One of the barriers is lack of ophthalmologists to screen hundreds of the retina images. Hence, many researches have been carried out on digital imaging in detecting the disease in order to overcome the barriers of detecting the disease.

1.2 Problem Statement

Early detection of diabetic retinopathy is essential in order to manage the disease. With the increase number of people having diabetic retinopathy and other eye diseases nowadays, the number of ophthalmologists to examine the eyes and screen the retina images is lacking. Furthermore, it involves a very high cost to provide training for the ophthalmologists in order to cater the number of patients. Thus, there is a need in clinical practice to have a convenient and economical way to detect the early signs of the disease.

1.3 Objectives and Scope of Study

1.3.1 Objectives

- To develop a software program to detect the microaneurysms that indicates the early stage of diabetic retinopathy disease.
- To evaluate between the retina images having microaneurysms and those of not having microaneurysms.

1.3.2 Scope of study

The early detection of diabetic retinopathy will be accomplished by developing a software program that can perform image segmentation. This project is to use MATLAB software to develop the program needed to carry out the image segmentation. The images that need to be segmented are the fundus images of the retina which can be retrieved from the online public database, DIARETDB1 – Standard Diabetic Retinopathy Database Calibration level 1 [1] which is available for research purpose. This project will focus on detecting the microaneurysms of the retina images which are the first stage of diabetic retinopathy. The second stage and beyond which consist of small hemorrhages, cotton wool spots and exudates will not be considered in this project.

1.4 Relevancy of the Project

This project is relevant to the current situation where the number of people suffered from diabetes is increasing. Based on a research done by Lorraine L. Lipscombe and Janet E. Hux [2], the diabetes occurrence has ascended from 1995 to 2005 which is from 5.2% to 8.8% respectively. Diabetes is the cause of the diabetic retinopathy. As the number of individuals with diabetes increase, the number of individuals with diabetic retinopathy will also increase. Moreover, many people do not know that they have diabetes. They are not well aware of their health. By monitoring the diabetic retinopathy disease among the people through public screening, they can prevent the disease from worsen and also prevent sight loss. With addition of other individuals suffered from other eye diseases, the man power available for examining the eyes at hospitals may not cater this large number of patients. Hence, this project will

help in the detection of the diabetic retinopathy disease to be carried out conveniently and efficiently.

1.5 Feasibility of the Project

This project is feasible to the author as the software needed for the project is available at the author's place of study, Universiti Teknologi PETRONAS (UTP). The sample for the fundus images of the retina is also available for the author as there is online database of the images. The Gantt chart in the Methodology section shows that this project can be completed within the given timeframe.

CHAPTER 2
2 LITERATURE REVIEW

2.1 Diabetic Retinopathy Disease

Diabetic retinopathy is a disease caused by the damage in blood vessels of the retina. Diabetes is the cause of the damage of the blood vessels. This disease will lead to blindness as one's sight might deteriorate with time. As mentioned in Section 1, there are four stages of diabetic retinopathy which are mild non-proliferative retinopathy, moderate non-proliferative retinopathy, severe non-proliferative retinopathy and the last stage, proliferative retinopathy. For the first stage of DR, small swellings of the tiny blood vessels of the retina called microaneuryms occurred. As these microaneurysms increase, some of the blood vessels of the retina will be blocked and the disease is now at the second stage. Then, when the number of blood vessels that are blocked keeps increasing, signals will be sent to the brain for growth of new blood vessels. This is the third stage of DR. In the fourth stage of DR, there will be new blood vessels growth in the retina which are abnormal and fragile. These new blood vessels have fragile thin walls which can cause severe vision loss if they are to leak blood [3].

The early stage of the diabetic retinopathy which is the non-proliferative diabetic retinopathy consists of microaneurysms, small hemorrhages, cotton wool spot and exudates [4]. These signs can be seen in the fundus images of the retina which is used by the ophthalmologists to study on eye diseases. Microaneurysms are the small red dots found in the fundus images of the retina. Microaneurysms can lead to blood clots which are the hemorrhages. The bright yellow lesions seen in the retina images are the exudates which are yellow lipid deposits [5]. These signs can be used to determine the severity of diabetic retinopathy. Figure 1 shows the example of fundus images of the retina [5].

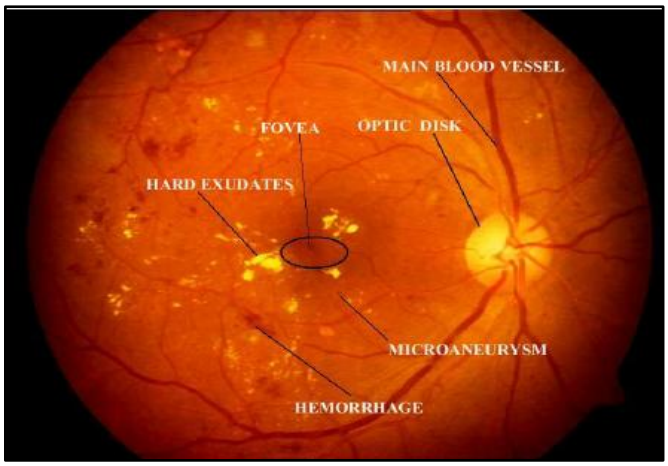


Figure 1 Fundus image of the retina

Early detection of these signs is one way to manage the disease. It is a chance to prevent sight loss. By carrying out public screening for diabetic retinopathy, people will be more aware of the disease. Based on the research [2], the number of individuals suffered from diabetes is increasing which also increase the number of individuals having diabetic retinopathy. It is shown in Figure 2 that the diabetes prevalence is increasing from year to year.

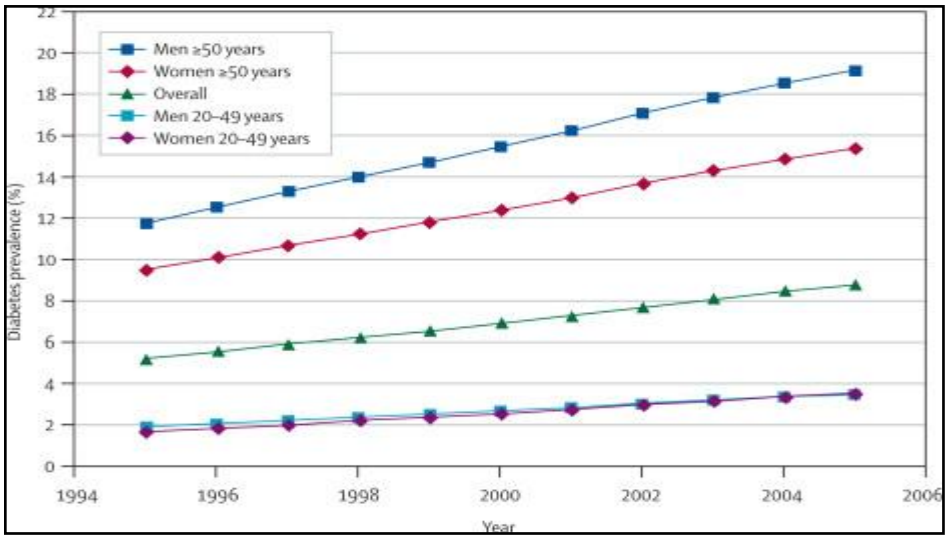


Figure 2 Yearly diabetes prevalence rates, by sex and age-group from 1995 to 2005 [2]

With this large number of people having the disease, there are some difficulties regarding the eye screening process. These difficulties include insufficient referrals, socioeconomic factor and poor geographic access [6].

2.2 Previous Research on Digital Imaging in Detecting Diabetic Retinopathy

This has lead to numerous researches on digital imaging to aid in detecting the early signs of diabetic retinopathy disease. One of the researches done by Hussain F. Jaafar, Asoke K. Nandi and Waleed Al-Nuaimy [7], a technical paper entitled "Automated Detection of Red Lesions from Digital Colour Fundus Photographs" proposed an automated method for red lesion detection by using a morphological technique to perform the image segmentation. There are 3 stages of the method which are stated below:

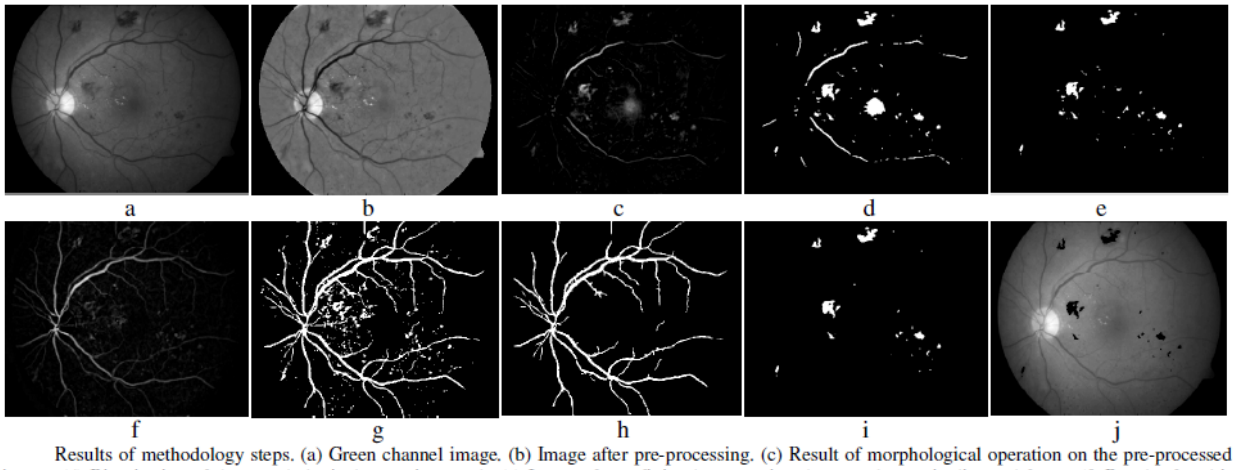
1. First stage: To perform shade correction and normalization of the green channel image
2. Second stage: To serve in refining red lesion candidates
3. Third stage: To detect red lesion based on candidate segmentation, blood vessel removal, feature extraction and categorization.

The first stage started with resizing the fundus image and viewing it in the green channel as the retinal features are more contrasted from the background in the channel. Then, a median filter is used to perform shade correction to the green channel image. The image filtered is then subtracted from the original image leaving red lesions and blood vessels in the background. The last step of the first stage is normalizing the output image.

The second stage is to serve in refining red lesion candidates by extracting the blood vessels from the background. Firstly, candidate segmentation is carried out. Flood-fill operation is used to extract red lesions from the background of the image. The pre-processed image from the first stage is the subtracted from the output image from the flood fill operation. This operation will distinguish the red lesions from the blood vessels. A threshold value, a_1, is set to convert the image to binary image. The next step

is to detect the features of blood vessels in the image. To do this, morphological closing operation is applied twice to the image that has been converted to binary. Different sizes of disk-shaped structuring elements are used. The closed image of the smaller structure elements will be subtracted from that of larger structure element hence, distinguish the blood vessels from the background.

The last stage of the operation is to classify the candidates of red lesions into the actual red lesions or the spurious red lesions. This is achieved by using a rule-based classifier. The Figure 3 shows the results of methodology steps of this paper.



Results of methodology steps. (a) Green channel image. (b) Image after pre-processing. (c) Result of morphological operation on the pre-processed image. (d) Binarisation of the morphological operation result. (e) Image after refining by removing the vascular, optic disc and fovea. (f) Result of multi-scale thresholding technique. (g) Binarisation of multi-scale technique result. (h) Final blood vessel image after classification. (i) Image after classification (final binary image of red lesion detection). (j) The binary result superimposed on the original gray image.

Figure 3 Results of methodology steps [7]

Another research done by Kanika Verma, Prakash Deep and A. G. Ramakrishnan [8], a technical paper entitled “Detection and Classification of Diabetic Retinopathy using Retinal Images”, proposed an improved method of blood vessel extraction, hemorrhages detection and categorize the retinal cases using an advanced non-parametric method provided higher categorization accuracy. The first operation is the blood vessel extraction. As the previous research paper, green channel image is used because of the higher contrast. 3 by 3 median filter is used to remove unwanted noise

from the image. After the filtering, blood vessels are detected in the image which is the converted to binary image with a threshold value of 0.1490 empirically determined. Blood vessel is determined if the pixel gray level of the binary image multiplied by a factor is greater than the threshold value.

After the blood vessels are detected, the next step is to detect the hemorrhage in the image. Smoothening filter is used to smoothen two images of different window sizes. Both images are then compared to extract blood vessels and detect hemorrhage candidates. The hemorrhages are detected by calculating the ratio of major axis length and the minor axis length of each segment. Figure 4 shows the result of the methodology steps of this paper.

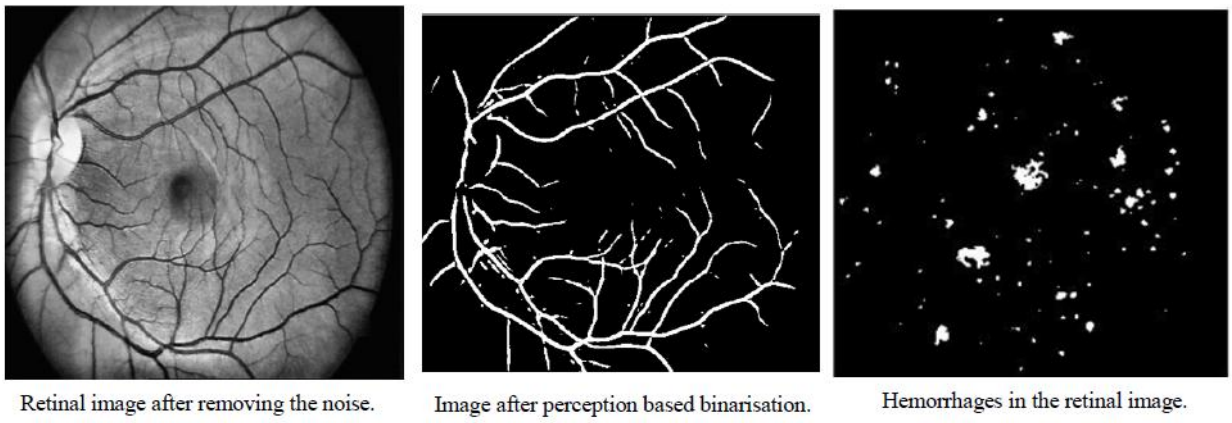


Figure 4 Result of methodology steps [8]

The next research entitled "Automated Feature Extraction for Early Detection of Diabetic Retinopathy in Fundus Image" [5] is done by Saiprasad Ravishankar, Arpit Jain and Anurag Mittal. The operation of detecting the disease consists of 4 steps which starts with multi-scale blood vessel extraction followed by exudates localization and detection, optic disk detection and detection of microaneurysms and hemorrhages. The first step is the same as the previous papers which green channel image is used, closing operation and morphological operation are executed and 2 by 2 median filter is used to filter the image. The second step is focusing on the exudates which are described as bright lesions with sharp edges. To detect the exudates, boundary detection is carried out using

morphological operation. From step 1, the thicker blood vessels are extracted from the background. These blood vessels are used to detect the optic disk which is by using the convergence of the vessels. Lastly, the detection of microaneurysms and hemorrhages are executed by using blood vessel based colour model and detecting and removing the fovea. The fovea is identified by using the location of the optic disk obtained from the previous step and curvature of the main blood vessels. Figure 5 shows the microaneurysms and hemorrhages detection result.

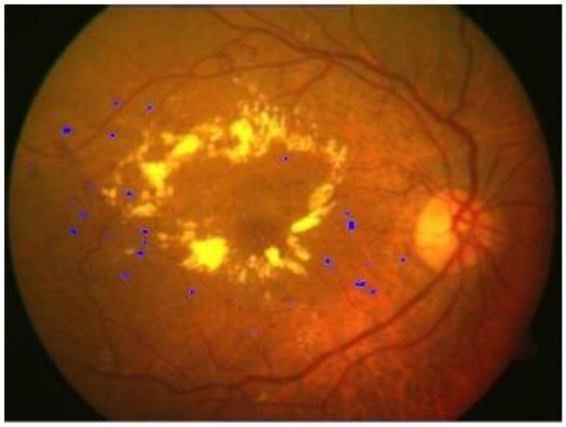
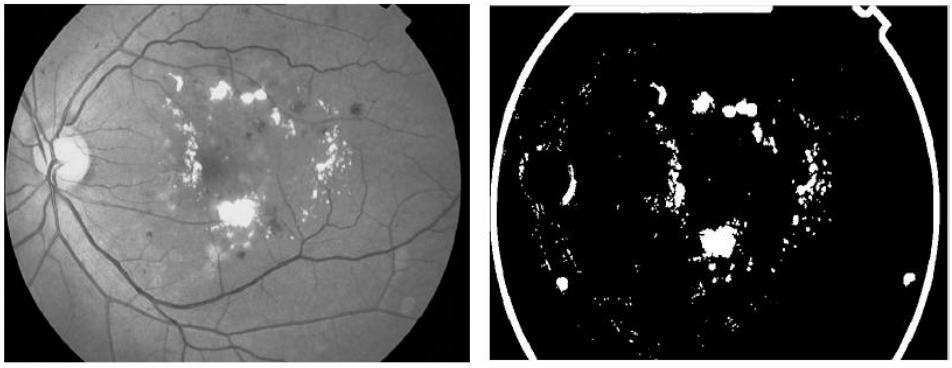


Figure 5 Microaneurysms and hemorrhages detection result [5]

A research entitled "Feature Extraction for Early Detection of Diabetic Retinopathy" done by V. Vujaya Kumari, N. Suriyanarayanan and C. Thanka Saranya proposed extraction of blood vessels with varying thickness using morphological operations, detection of exudates using open and close operations of different scales and detection of optic disk by subtracting the extracted blood vessel image and exudates detected image. The operation of detecting the exudates is almost the same as the first and second research papers but the only difference is that they used Laplacian and Gaussian (log) operator to detect the edge of the exudates. Figure 6 shows the results of the operation.



Green channel image. Detected Exudate Patches

Figure 6 Results of the operation [9]

CHAPTER 3

3 METHODOLOGY

3.1 Research Methodology

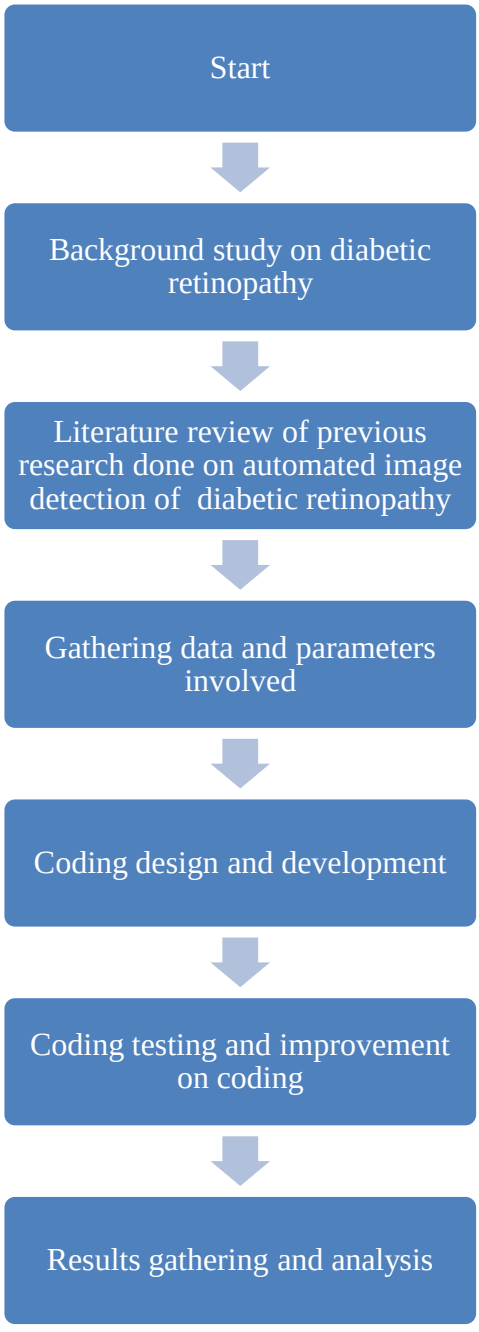


Figure 7 Research methodology

3.2 Project Activities

3.2.1 Background study and literature review of previous research

Study on diabetic retinopathy and previous research on automated image detection of the disease is done to obtain understanding on the disease and the technology. This is to help the author to identify and manage the tasks that are needed to be done to complete this project.

3.2.2 Gathering data and parameters involved

Data needed for this project are the fundus images of the retina of individuals having diabetic retinopathy and also those of not having the disease. This can be retrieved from the online public database which is meant for research. The author also needs to have knowledge on image processing and the MATLAB software.

3.2.3 Coding design and development

Referred to the research [7] and the information [9], the first revision of the coding has been developed after all the data needed is gathered. The first part of the coding is the pre-processing of the image. A threshold value is set each for the red lesions and the blood vessels which is 0.4 and 0.1 respectively. Then the fundus image of the retina is resized to a standard size, 640x480 pixels. The feature of the fundus image is more contrasted when the image is viewed in the green channel of the image. Hence, the green channel image is used for the coding. The green channel image is shown in the Figure 8(a). The image is then filtered by using the 2D median filtering to extract shade. Shade-correction is executed by subtracting the filtered image from the resized image and then it is adjusted to increase the contrast of the image. The output image is the shade-corrected image shown in Figure 8(b).

For the feature extraction, flood fill operation is executed on the shade-corrected image to fills holes which is the red lesions candidates of the image. After that, the shade-corrected image will be subtracted from the result of the filling operation. Then the image will be converted to binary image. The image is shown as the pre-processed image in Figure 8(c). To create a mask to remove the blood vessels, 2 flat disk-shaped structure elements are created which is used to perform closing operation to the pre-

processed image. This operation is executed twice with two different radii of the structure elements. The purpose of this operation is to extract the blood vessels from the background of the image. On the other hand, the bright lesions and the optic disk are filtered out by using the thresholding operation. However, in order to block the fovea, a mask is created based on the [x, y] coordinates of the fovea. The image in Figure 8(d) shows the blood vessels that have been extracted from the background.

The next step is to index the parameters of each microaneurysm candidate by using the 'bwconncomp' command which specifies desired connectivity for the connected components. After all the parameters have been indexed, the rule-based classifier is set to remove the blood vessels leaving the microaneurysms. Figure 8(e) shows the microaneurysms that have been detected in the fundus image. Figure 8(f) shows that the microaneurysms that have been detected are highlighted in blue colour in the green channel image of the fundus by using the command 'imoverlay'. Figure 8 shows the stages of microaneurysms detection.

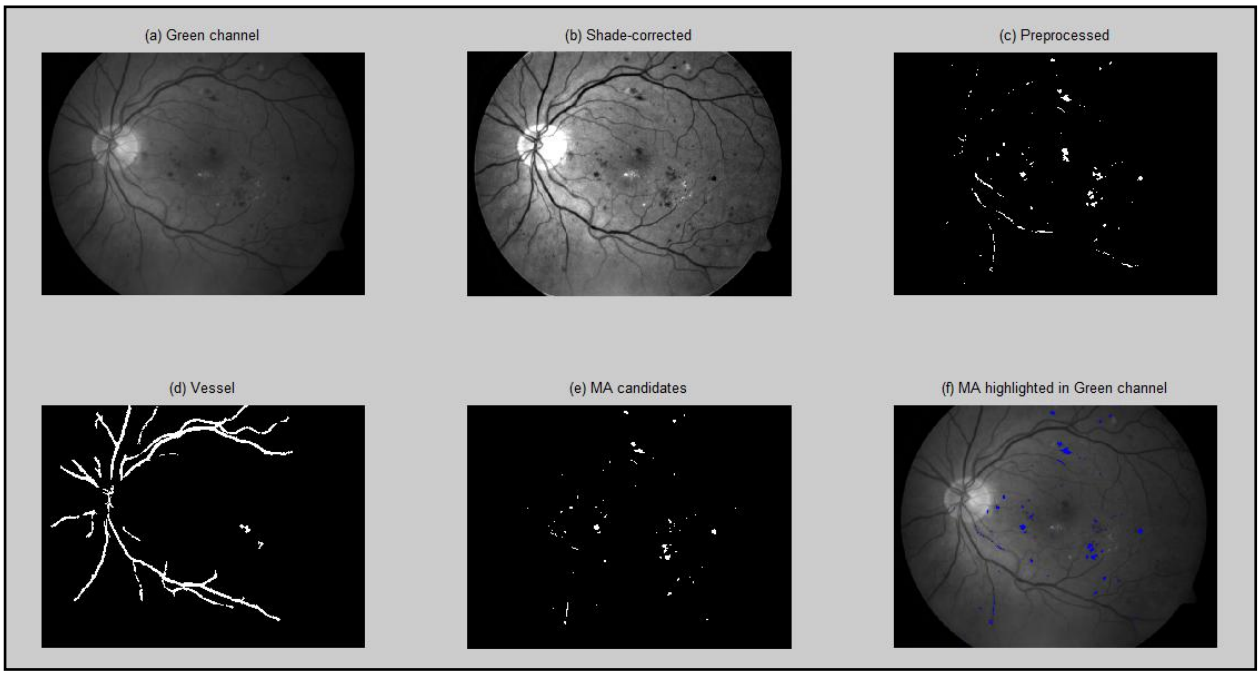


Figure 8 The stages of microaneurysms detection of Image_5

The coding is made to read all the images in the folder specified. For testing purpose, 10 images are read from a folder.

To aid the users of this coding, a GUI interface has been developed. The GUI interface is made that one can insert the threshold value for the red lesions and the blood vessels to control the sensitivity of the image processing. Figure 9 shows the GUI interface that has been developed.

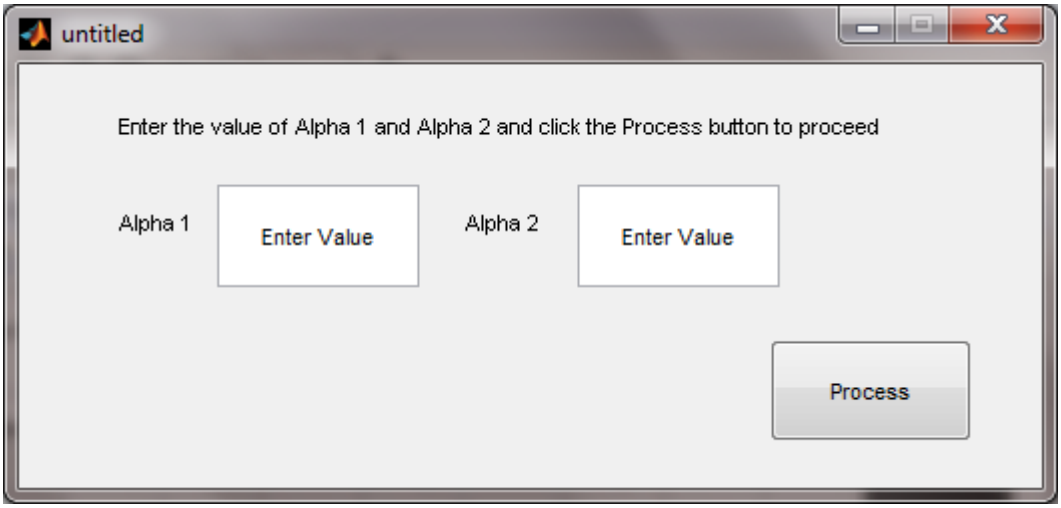


Figure 9 GUI interface

3.2.4 Coding testing and improvement on coding

The coding that has been developed is tested. Continuous improvement is needed to achieve the objectives of the project.

3.3 Key Milestone

Key milestone that needed to be achieved in completing the project

- Completion of review on previous research on automated image detection of diabetic retinopathy.
- Implementation of data gathered in developing the coding.
- Coding testing and data collection afterwards.
- Improvement on coding developed.

3.4 Tool

Tools needed for the project

- MATLAB software
- Database of fundus images of the retina

3.5 Gantt Chart

Table 1 Gantt Chart for FYP 1

No	ITEM	WEEK													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of the project topic														
2	Preliminary research work on diabetic retinopathy, automated image detection, image processing and MATLAB														
3	Extended proposal submission														
4	Experiment Design														
5	Submission of Interim Draft Report														
6	Submission of Interim Report														

Table 2 Gantt Chart for FYP II

No	ITEM	WEEK														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Selection of the project topic															
2	Coding testing															
3	Result gathering and analysis															
4	Submission progress report															
5	Pre – EDX															
6	Submission of draft report															
7	Submission of dissertation (soft bound)															
8	Submission of Technical Paper															
9	Oral presentation															
10	Submission of project dissertation (hard bound)															

CHAPTER 4

4 RESULTS AND DISCUSSION

In FYP 1, the first revision of the coding has been developed. The images are analyzed for the presence of microaneurysms one at a time. There are some problems occurred in the process such as the fovea in the fundus image is not properly blocked and some blood vessels are detected as microaneurysms. These problems will be investigated further in FYP II. The objective of FYP II is to overcome the problems by improving the sensitivity of the coding developed. Apart from that, the coding will be improved as to read and analyzed multiple images at a time. In addition, a GUI interface will be developed as to give easy access to the user to control the sensitivity of the microaneurysms detection and also to display the output of the coding.

Figure 10 shows another fundus image that has been segmented to detect the microaneurysms. This shows that the coding developed can be used to detect microaneurysms in other fundus images. Figure 10(e) shows the microaneurysms that have been detected in the image and again in Figure 10(f), the microaneurysms are highlighted in blue colour. Same goes for Figure 11.

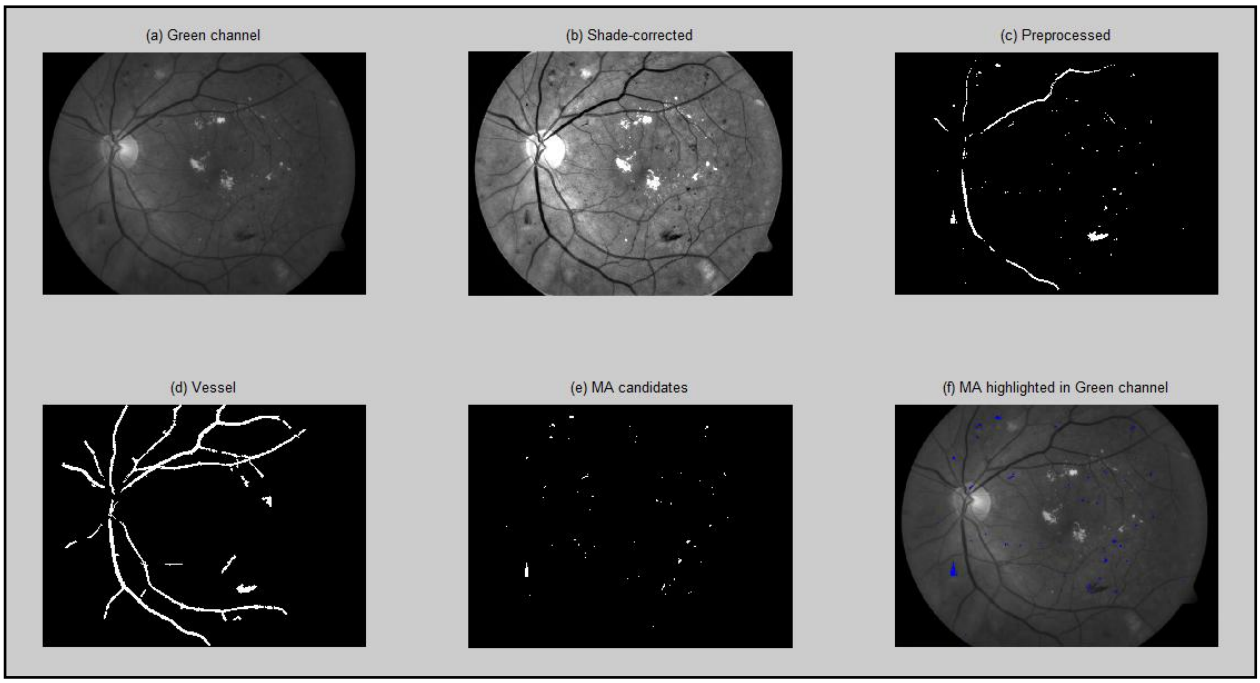


Figure 10 The stages of microaneurysms detection of Image_1

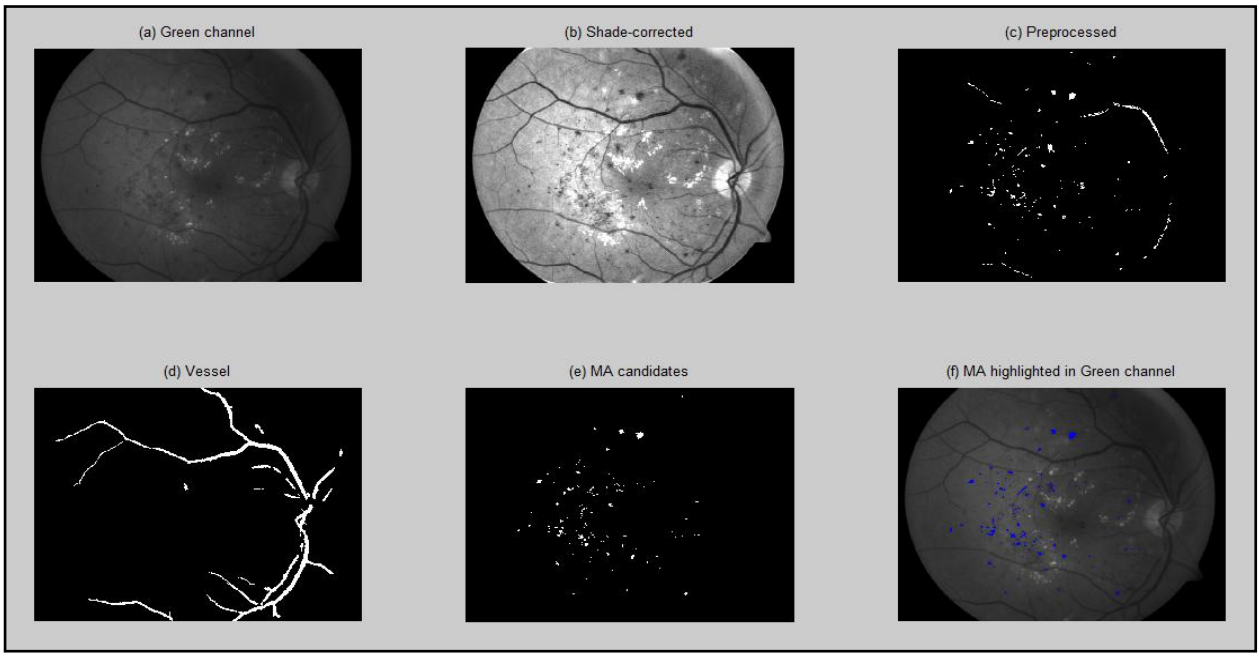


Figure 11 The stages of microaneurysms detection of Image_2

However, in Figure 12(e), it can be seen that among the microaneurysms detected, some part of the blood vessels is also detected as microaneurysms. It can also be seen in Figure 17 and Figure 18. This is one of the problems that need to be solved. This shows that the coding developed need more sensitivity in detecting the microaneurysm candidates.

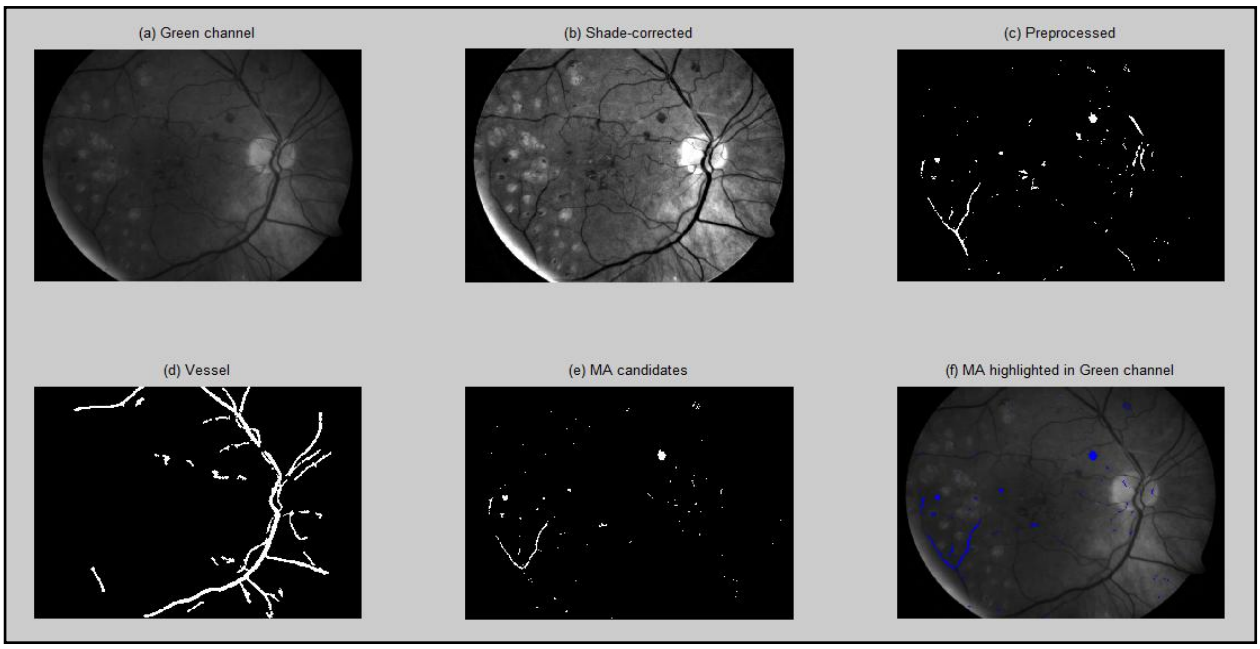


Figure 12 The stages of microaneurysms detection of Image_3

Figure 13 shows the stages of microaneurysms detection of another fundus image. The microaneurysms detected in this image are less compared to the previous images. However, in Figure 13, it can be seen that the microaneurysms detected are actually the fovea of the retina. This problem is resolved by creating a mask to block the fovea. Previously, the mask for the fovea is created by manually clicking the image to obtain the [x, y] coordinates of the fovea. The coding has been improved by firstly identified the [x, y] coordinates of the fovea in all the images. Then the coordinates are inserted in the coding and when it runs, the mask will be created automatically for all the images. It can be seen from Figure 14 that the microaneurysms detected previously in the fovea area are not detected in the image.

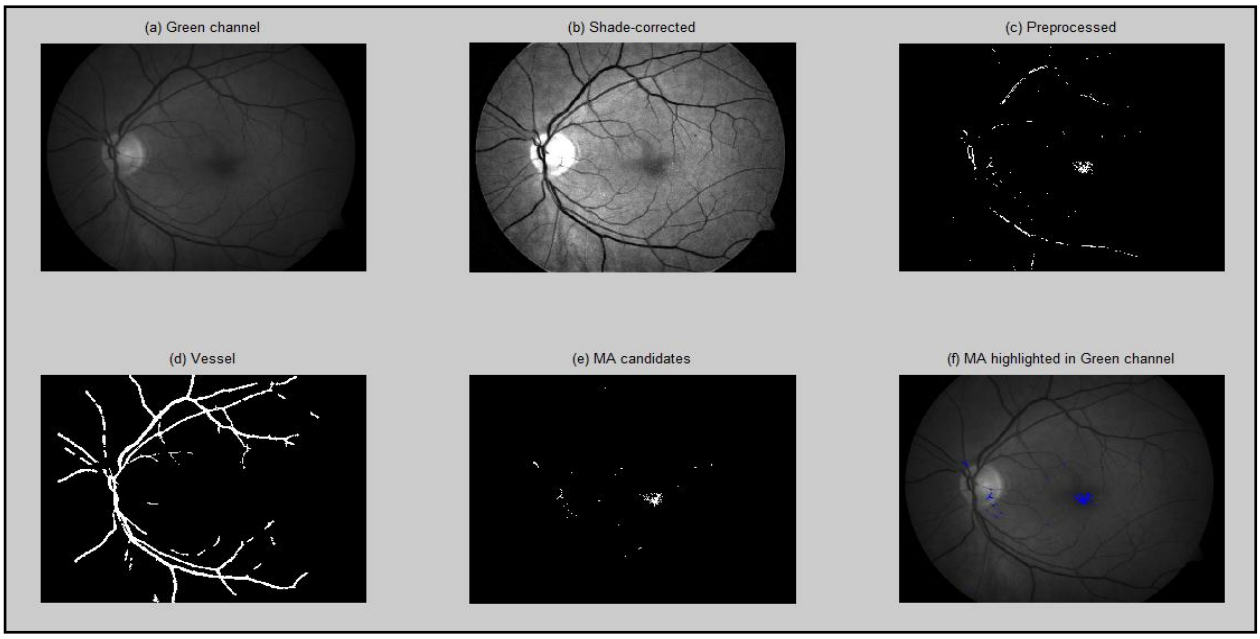


Figure 13 The stages of microaneurysms detection of Image_4 in FYP 1

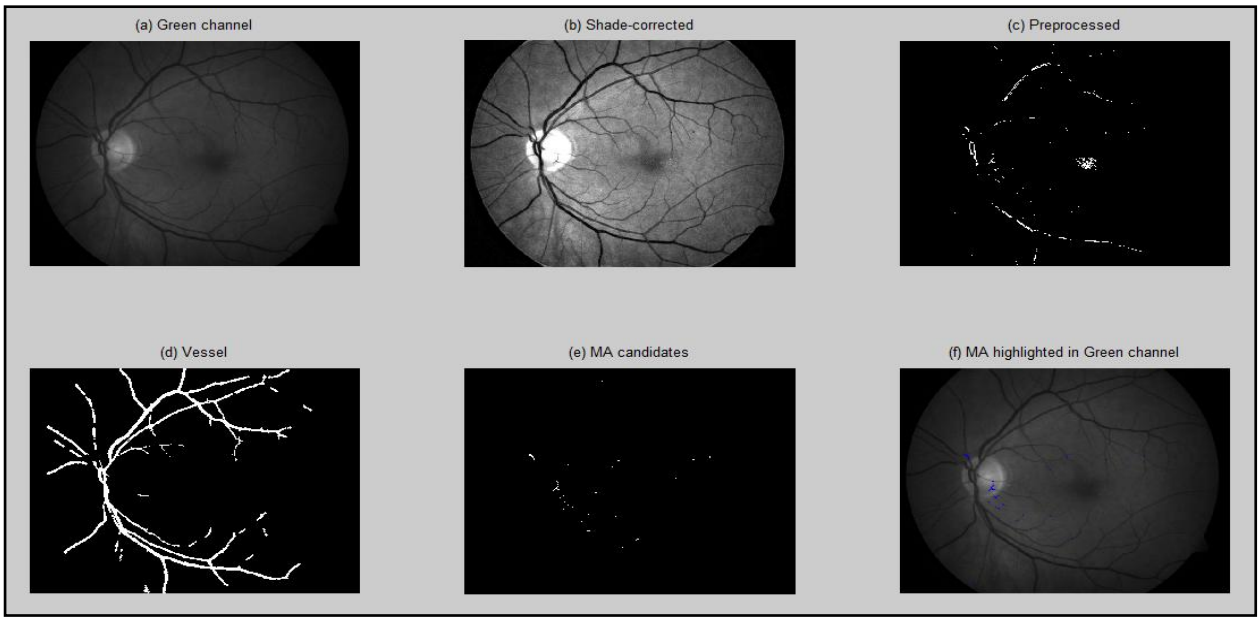


Figure 14 The stages of microaneurysms detection of Image_4 in FYP II

Below are the other images that are analyzed for the presence of microaneurysms which sum up to ten images including the previous images.

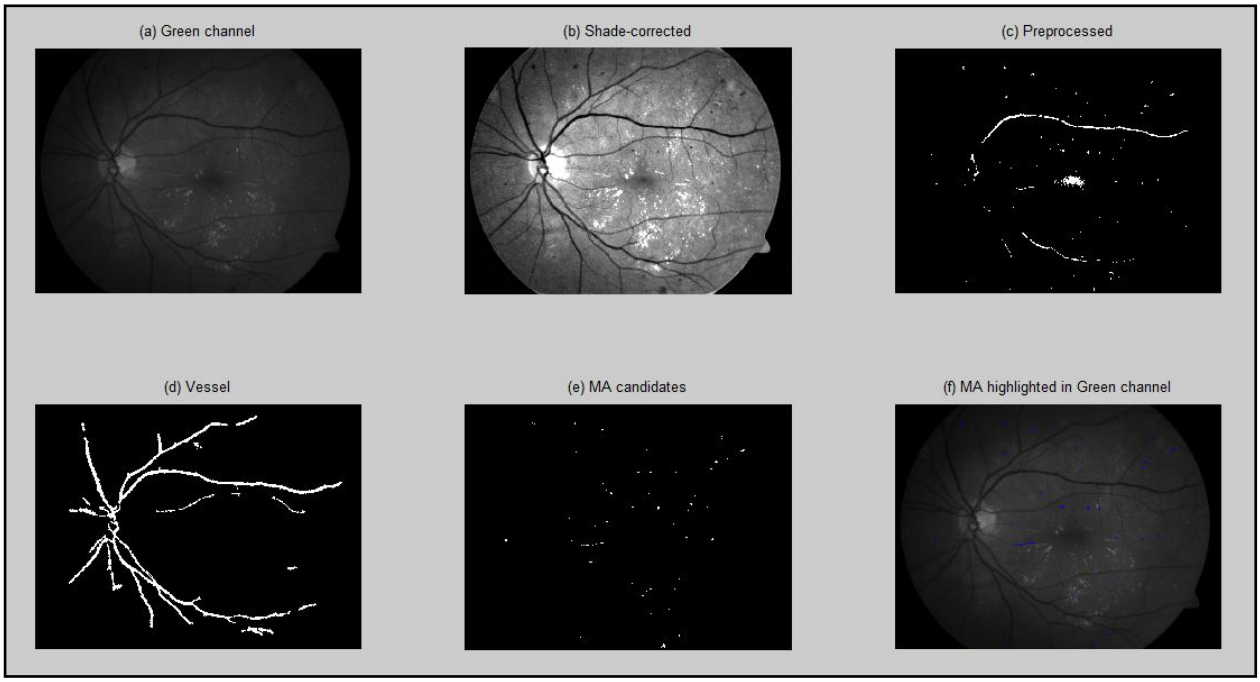


Figure 15 The stages of microaneurysms detection of Image_6

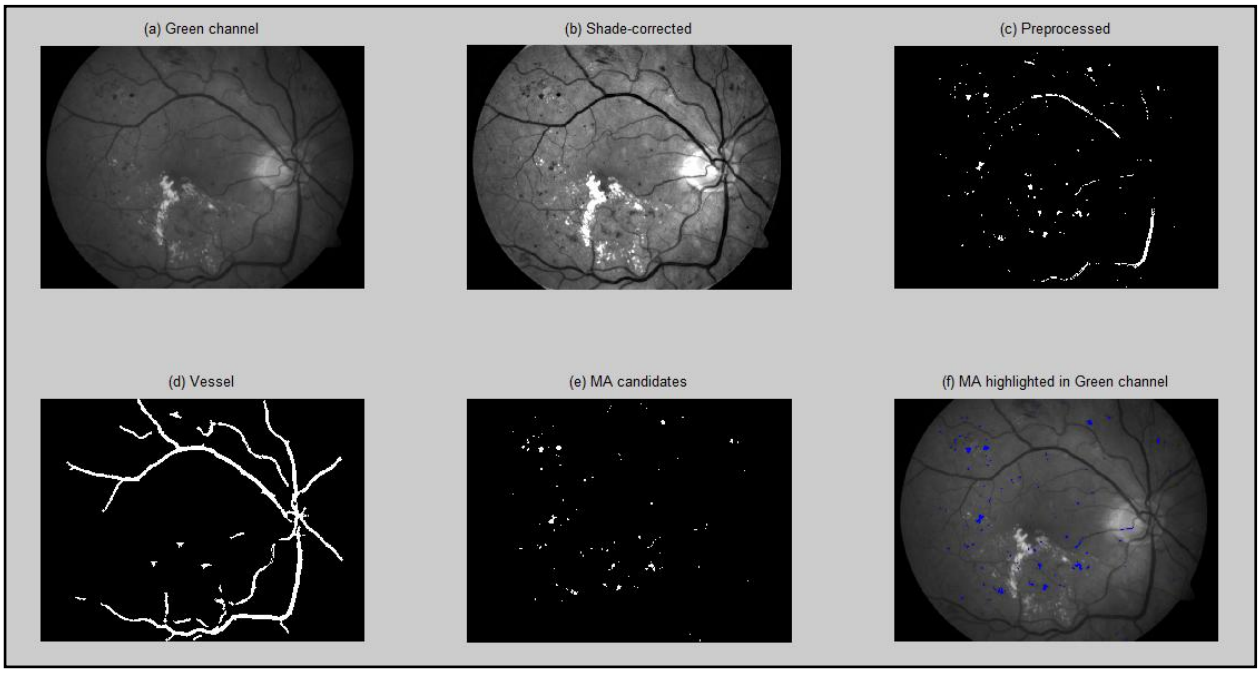


Figure 16 The stages of microaneurysms detection of Image_7

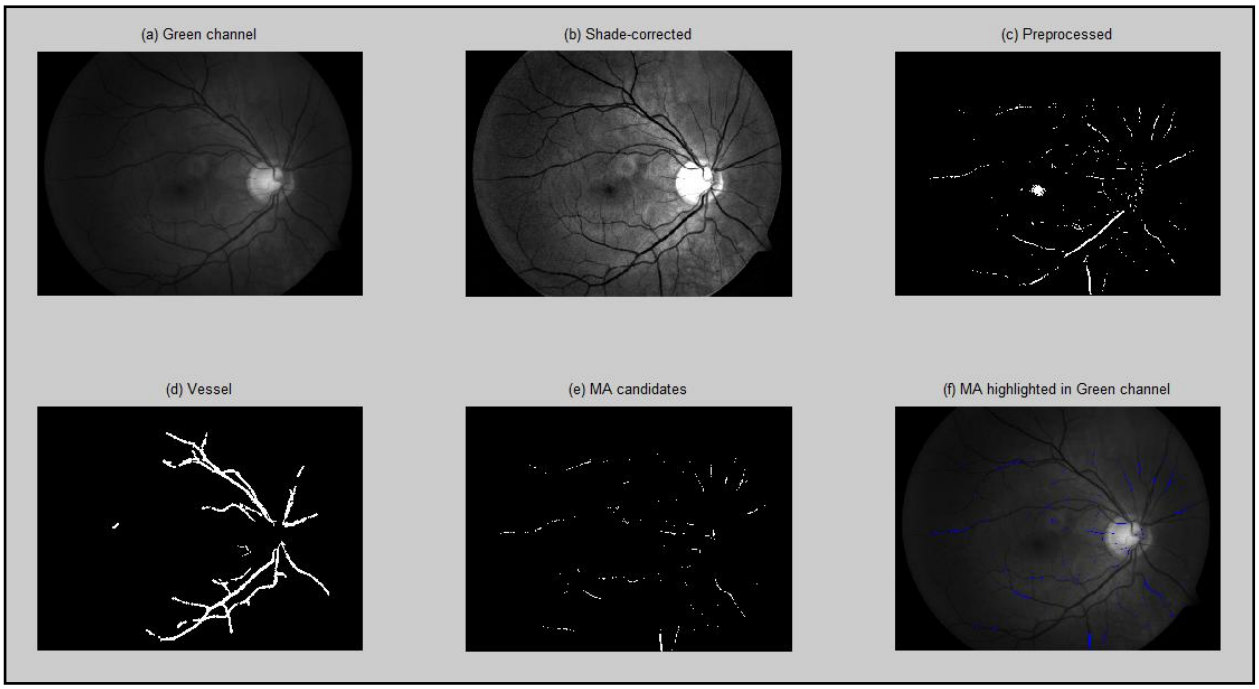


Figure 17 The stages of microaneurysms detection of Image_8

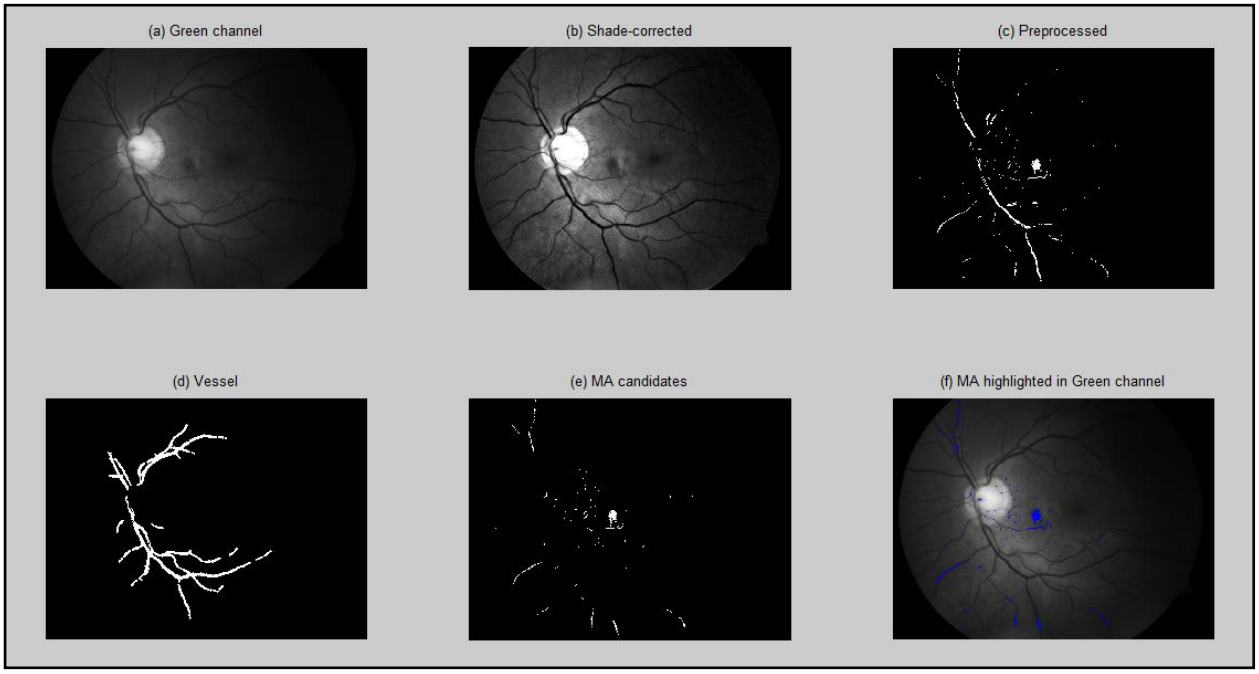


Figure 18 The stages of microaneurysms detection of Image_9

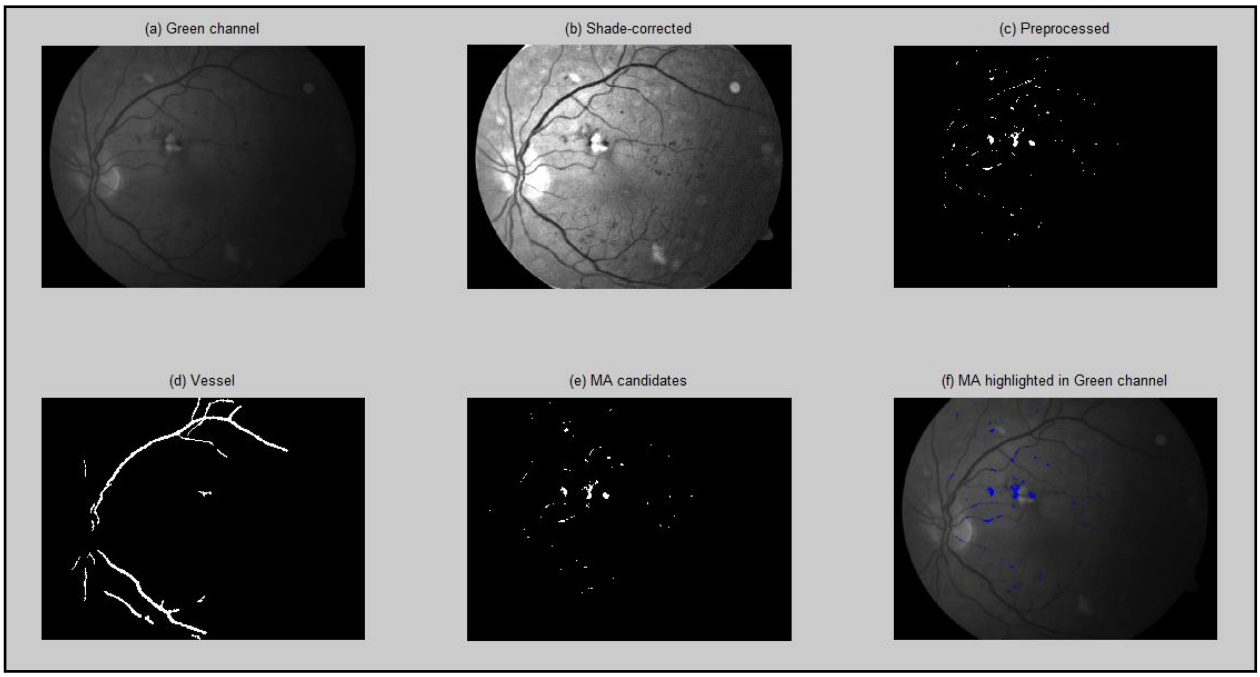


Figure 19 The stages of microaneurysms detection of Image_10

Table 3 below summarizes the results of microaneurysms detection in all the images.

Table 3 Table of results

IMAGE	RESULTS
Image_1	▪ Many microaneurysms detected ▪ No blood vessels detected as microaneurysms
Image_2	▪ Many microaneurysms detected ▪ No blood vessels detected as microaneurysms
Image_3	▪ Some microaneurysms detected ▪ A few blood vessels detected as microaneurysms
Image_4	▪ Less microaneurysms detected ▪ No blood vessels detected as microaneurysms
Image_5	▪ Many microaneurysms detected ▪ No blood vessels detected as microaneurysms
Image_6	▪ Many microaneurysms detected ▪ No blood vessels detected as microaneurysms
Image_7	▪ Many microaneurysms detected ▪ No blood vessels detected as microaneurysms
Image_8	▪ Less microaneurysms detected ▪ Many blood vessels detected as microaneurysms
Image_9	▪ Some microaneurysms detected ▪ Some blood vessels detected as microaneurysms
Image_10	▪ Many microaneurysms detected ▪ No blood vessels detected as microaneurysms

Apart from the coding to detect the presence of microaneurysms in the fundus images of retina, a GUI interface is to be developed which will include the control for the threshold value and the display of the output. The GUI interface consists of two edit text to enter the threshold value for red lesions and blood vessels which are Alpha 1 and Alpha 2 respectively and a push button to initiate the image processing. Figure 20 shows the GUI interface that has been developed.

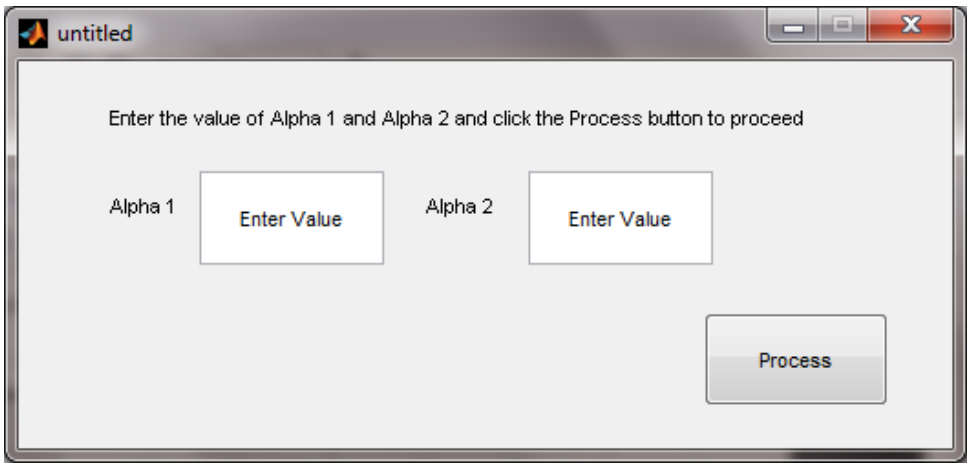


Figure 20 GUI interface

The value entered in the both edit textboxes are set not to exceed 1. If the value entered exceeds 1, an error dialog box will appear as shown in Figure 21.

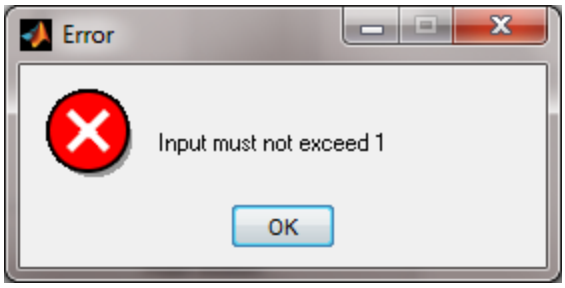


Figure 21 Error dialog box

It is also made that if the user of the program entered non-numeric value, an error dialog will also appear as shown in Figure 22.

Figure 22 Error dialog box

The GUI interface is developed with the purpose of aiding the users of the program. The users can control the threshold value without the need to go through the complicated coding of the program. In other words, the GUI interface is to be made as a user-friendly tool. More things can be added to the GUI interface to further ease the users of the program. In the near future, the program will be further improved to comply with the requirements.

CHAPTER 5

5 CONCLUSION AND RECOMMENDATIONS

In conclusion, the coding that has been developed is almost complete. There are still some improvements that can be done in order to exactly detect the microaneurysms in the fundus images of the retina. Despite the limitation in the coding developed, the objectives of the project have mostly been achieved. A program coding has been developed to detect the microaneurysms that indicate the early stage of diabetic retinopathy disease even though the program coding is not yet perfect. Hence, for future work expansion and continuation, some improvement is needed for the program coding that has been developed. The objective is to improve the sensitivity of microaneurysms detection by using Circular Hough Transform (CHT) method. By using this method, the microaneurysms can be detected even when the number is small. Other research is focusing on the presence of microaneurysms in the fundus image. Some of the microaneurysms may be eliminated from the fundus image before the classification stage. The purpose of the improvement is to detect all the microaneurysms present in the fundus image if possible. Other than that, the GUI interface can be further improved. The interface can be made to show the average number of microaneurysms detected in each of the fundus image as the microaneurysms detected have been indexed in the coding.

REFERENCES

[1] V. Kalesnykiene, J. K. Kamarainen, L. Lensu, *et al.* (2007, June). *DIARETDB1 - Standard Diabetic Retinopathy Database.* [Online]. Available: http://www2.it.lut.fi/project/imageret/diaretdb1/

[2] J. E. Hux and L. L. Lipscombe, "Trends in diabetes prevalence, incidence, and mortality in Ontario, Canada 1995–2005: a population-based study," *THE LANCET*, vol. 369, no. 9563, pp. 750-756, March 2007.

[3] (2012, June). *National Eye Institute.* [Online]. Available: http://www.nei.nih.gov/health/diabetic/retinopathy.asp

[4] M. J. Cree and H. F. Jelinek, Ed., *Automated Image Detection of RETINAL PATHOLOGY*. Boca Raton, Florida: CRC Press, 2010.

[5] A. Jain, A. Mittal and S. Ravishankar, "Automated feature extraction for early detection of diabetic retinopathy in fundus images," Indian Institute of Technology Madras, Madras, Tech. Rep. 2009.

[6] R. M. Davis and S. Garg, "Diabetic retinopathy screening update," *Clinical Diabetes*, vol. 27, no. 4, pp. 140 - 145, 2009.

[7] A. K. Nandi, W. Al-Nuaimy and H. F. Jaafar, "Automated detection of red lesions from digital colour fundus photographs," The University of Liverpool, UK, Tech. Rep. 2011.

[8] P. Deep, A. G. Ramakrishnan and K. Verma, "Detection and classification of diabetic retinopathy using retinal images," Indian Institute of Science, India, Tech. Rep.

[9] (2013). *MathWorks.* [Online]. Available: http://www.mathworks.com/help/images/

[10] N. Suriyanarayanan, C. T. Saranya and V. V. Kumari, "Feature extraction for early detection of diabetic retinopathy," V.L.B. Janakiammal College of Engineering and Technology, Coimbatore, Tech. Rep. 2010.