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AUTOMATIC DIAGNOSIS OF DIABETIC RETINOPATHY USING FUNDUS IMAGES

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Declaration

This thesis report is submitted to the Department of Signal Processing, School of Engineering, Blekinge Institute of Technology in partial fulfilment of the requirements for the award of Master of Science in Electrical Engineering (M.Sc.E.E) with emphasis on Signal Processing. This work is equivalent to 20 weeks of full time studies.

This work has been carried out under the supervision, recommendation and advice from Mikael Nilsson from February 2006 to October 2006.

Mikael Nilsson

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The product of any research work depends so much on: the quality of education received, the quality of the teachers, research resources and enabling and encouraging environment. Studying in Blekinge Institute of Technology, Sweden provides all these aforementioned conditions which have made possible the successful outcome of this research work.

Firstly, our gratitude goes to our supervisor, Mikael Nilsson, who was our source of encouragement and motivation during the whole work. His advice, suggestions and solution to bottleneck problems encountered during this work are just immensurable and un-parallel in the history of our education in our different countries. He is more than a supervisor to us, in fact, we all look to be like him in the not long future.

Also we shall like to express our appreciation to Benny Lövström for all his support, encouragement and active role in seeing to the provision of research materials needed for this work. Also to Victor Adolfsson of Optimum Biometric Labs who have been our liaison officer with the Ophthalmologist, to him also, we say ‘’tack’’.

To Dr. Jack Bergen, the main behind the wheel, who not only gives his time in the hospital but also spend some of his time with us in the laboratory during this research work. We really appreciate his effort and assistance in the development of this algorithm and his aim of making the place a better place to live. He has dedicated most of his life time to the treatment of diabetic patient.

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Abstract

Keywords: Diabetic Retinopathy, Fundus Image, Digital Image Processing, Segmentation, Retina, Classifier.

This thesis applies the process and knowledge of digital signal processing and image processing to diagnose diabetic retinopathy from images of retina.

The Pre-Processing stage equalizes the uneven illumination associated with fundus images and also removes noise present in the image. Segmentation stage clusters the image into two distinct classes while the Disease Classifier stage was used to distinguish between candidate lesions and other information. Method of diagnosis of red spots, bleeding and detection of vein-artery crossover points were also developed in this work using the colour information, shape, size, object length to breadth ration as contained in the digital fundus image in the detection of this disease.

In addition to diagnosis of Diabetic Retinopathy (DR), two graphical user interfaces (GUI's) were also developed during this work, this first is for collection of lesion data information and was used by the ophthalmologist in marking images for database while the second GUI is for automatic diagnosing and displaying the diagnosis result in a more friendly user interface and is as shown in chapter three of this report.

The algorithm was tested with a separate set of 25 fundus images. From this, the Receiver Operating Characteristics (ROC) was determined for red spot disease and bleeding, while cross over points were only detected leaving further classification as part of future work needed to complete this global project. Sensitivity (classify abnormal fundus images as abnormal) and specificity (classify normal fundus image as normal) was calculated for the algorithm is given as 98% and 61%.

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Chapter One

Introduction

1.0 Introduction

In recent times, Sweden and other parts of the world have been faced with an increase in age and society related diseases like diabetes. According to recent survey [1], 4% of the country population has been diagnosed of diabetes disease alone and it have been recognize and accepted as one of the main cause of blindness in the country if not properly treated and managed. Early detection and diagnosis have been identified as one of the way to achieve a reduction in the percentage of visual impairment caused by diabetes with more emphasis on routine medical check which the use of special facilities for detection and monitoring of the said disease [1]. The effect of this on the medical personnel need not be over emphasized, it has lead to increase work load on the personnel and the facilities, increase in diabetes screening activities just to mention a few. A lot of approaches have been suggested and identified as means of reducing the stress caused by this constant check up and screening related activities among which is the use medical digital image signal processing for diagnosis of diabetes related disease like diabetic retinopathy using images of the retina.

Diabetes is a disorder of metabolism. The energy required by the body is obtained from glucose which is produced as a result of food digestion. Digested food enters the body stream with the aid of a hormone called insulin which is produced by the pancreas, an organ that lies near the stomach. During eating, the pancreas automatically produces the correct amount of insulin needed for allowing glucose absorption from the blood into the cells. In individuals with diabetes, the pancreas either produces too little or no insulin or the cells do not react properly to the insulin that is produced. The build up of glucose in the blood, overflows into the urine and then passes out of the body. Therefore, the body loses its main source of fuel even though the blood contains large amounts of glucose [2].

Basically there are three types of diabetes, Type 1 Diabetes, is caused as a result of auto immune problem. The immune system of the body destroys the insulin producing beta cells in the pancreas leading to no or less production of the required insulin by the pancreas. Type 2 Diabetes is a result of malfunctioning of the beta cell itself. This malfunction includes non production of insulin or a situation known as insulin resistance. In insulin resistance, the muscles, fat and other cells do not respond to the insulin produced. Type 3 is known as gestational diabetes and only occurs during pregnancy. During this stage, the body resist the effect of insulin produced.

The effect of diabetes on the eye is called Diabetic Retinopathy (DR). It is known to damage the small blood vessel of the retina and this might lead to loss of vision. The disease is classified into three stages viz: Background Diabetic Retinopathy (BDR), Proliferate Diabetic Retinopathy (PDR) and Severe Diabetic Retinopathy (SDR). In BDR phase, the arteries in the retina become weakened and leak, forming small, dot-like haemorrhages. These leaking vessels often lead to swelling or edema in the retina and decreased vision. In the PDR phase, circulation problems cause areas of the retina to become oxygen-deprived or ischemic. New fragile, vessels develop as the circulatory system attempts to maintain adequate oxygen levels within the retina. This phenomenon is called neovascularisation. Blood may leak into the retina and vitreous, causing spots or floaters, along with decreased vision. In the SDR phase of the disease, there is continued abnormal vessel growth and scar tissue, which may cause serious problems such as retinal detachment and glaucoma and gradual loss of vision.

This research work is one of the method of applying digital image processing to the field of medical diagnosis in order to lessen the time and stress undergone by the ophthalmologist and other members of the team in the screening, diagnosis and treatment of diabetic retinopathy. This work determine the presence of BDR and PDR or otherwise in a patient by applying techniques of digital image processing on fundus images taken by the use of medical image camera by a medical personnel in the hospital.

1.1 Aims and Objective

The primary aim of this project is to develop a system that will be able to identify patients with BDR and PDR from either colour image or grey level image obtained from the retina of the patient. These types of images are called fundus images. The different diabetic retinopathy diseases that are of interest include red spots, microaneurysm and neovascularisation and they fall between BDR and PDR stages of the disease. While SDR types are expected to be referred to the ophthalmologist.

The secondary aim includes developing a MATLAB based Graphic User Interface (GUI) tool to be used by the ophthalmologist in marking fundus images. The marked images are to be used for the development of DR grading and database system for this present and future work.

1.2 Thesis Overview

The thesis overview is as shown in Figure 1-1, the input fundus image is analysed by the system and the output contains the grading and the result with the co-ordinates of the detected abnormality shown on the GUI.

The input image to the Pre-Processing stage can be a colour or a grey level image. The Pre-Processing stage corrects the problem of Illumination variation that occurred when taken the pictures. Other problems corrected by this process include the enhancement of the contrast between the exudates and vein network and the background to aid in segmentation and detection of the abnormalities. Process involves in this stage include Colour Space Conversion, Zero Padding of Image Edges, Median Filtering and Windowed Based Adaptive Histogram Equalization with Overlap Mean.

The output of this stage is passed to the Segmentation stage. This stage segments the background pixel from the exudates and the vein networks using K-mean clustering algorithm with two cluster class centres. The exudates and the vein networks class centres also contain some noisy pixels that were over enhanced

during the Pre-Processing stage and will be removed during the next stage called Disease Classifier stage.

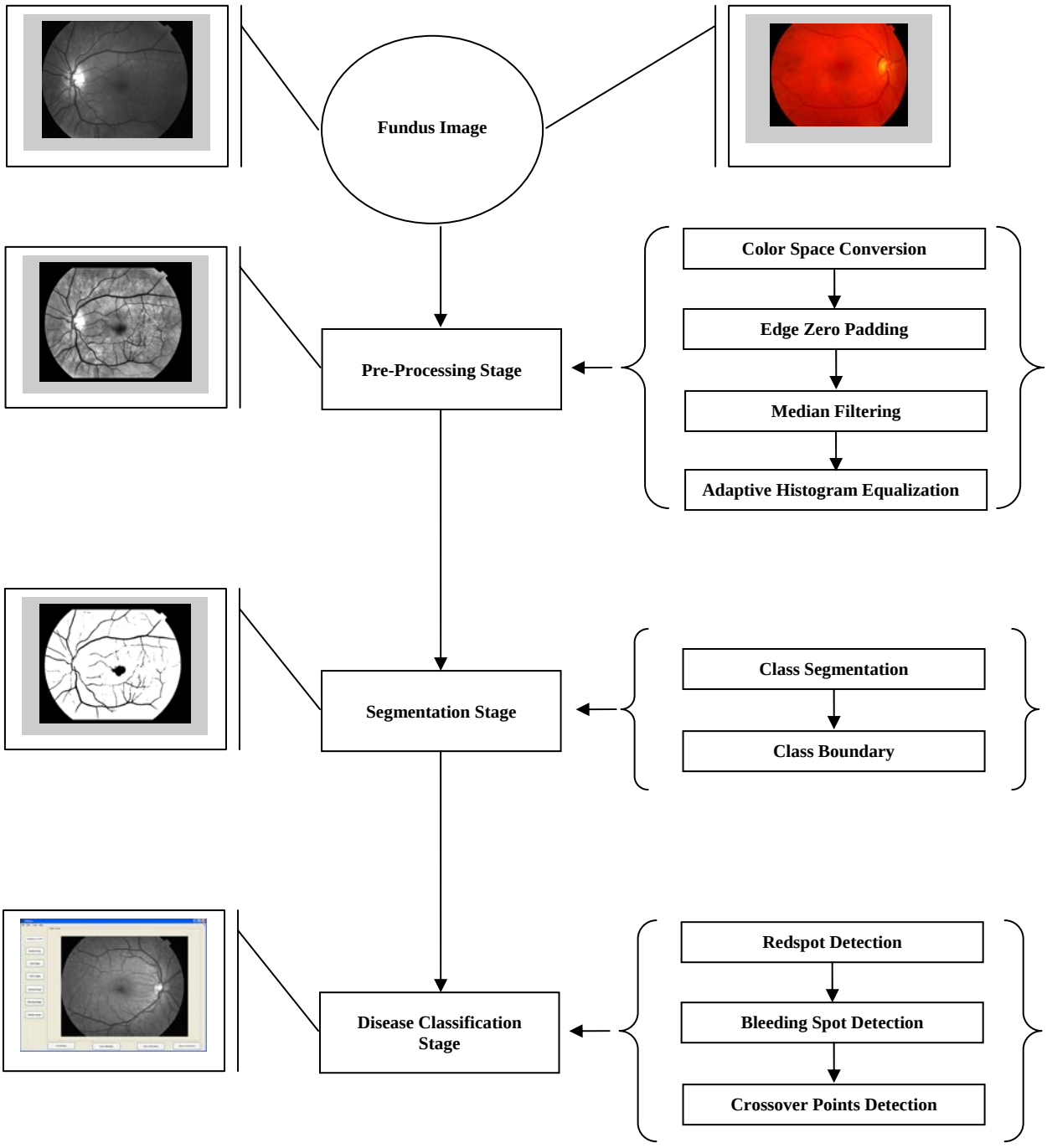


Figure 1-1, *Block Diagram of Automatic Diagnosis of Diabetic Retinopathy using Fundus Images*

The Disease Classification/Abnormality Detection consists of a series of classifiers and differentiating parameters with set of conditions in detecting and diagnosis of exudates, microaneurysm, red spots, and crossover points. The criteria used for detecting image background based disease like exudates, microaneurysm and red spots include Object Ratio Test, Compact Ratio Test, Length Test, Pixel Count Test and Region Hole Test. After detecting and removing these background based diseases, the image is then passed to the Vein-Processing stage for crossover points detection using Modified Crosspoint Number Method (MCNM).

1.3 Thesis Structure

This thesis is structured as explained below

Chapter 2:

This section start with a brief discussion on the eye‘s structure and DR in relation to the eye and shortly followed by review of some of the past work done on detecting and classifying DR into crossover points, red spots and bleedings.

Chapter 3:

This chapter starts with introduction to basic image processing techniques used in this work, these include Colour Space Conversion, Histogram Equalization, K-mean Classification, Median Filtering and Morphological Operation on retinal fundus images. This section also talks about the development of the Graphical User Interface (GUI) used for data analysis for this project.

Chapter 4:

In this chapter the stages involve in DR diagnosis are discussed. These stages include Pre-processing, Segmentation, Disease Classifiers/Abnormalities Detection.

Chapter 5:

Results of this work are presented in this chapter.

Chapter 6:

In this chapter recommendation and suggestions on future works are discussed.

Chapter Two

Literature Review

2.0 Introduction

This chapter start with discussion on the structure of the eye, some of the abnormalities associated with the eye and shortly followed by review of methods used in the not too long a past in the diagnosis of DR under two main sections, vessels and background information.

2.1 The Eye Structure

Eye is an organ associated with vision. It is housed in socket of bone called orbit and is protected from the external air by the eyelids [3]. The cross section of the eye is as shown in Figure 2-1 while that of retina is as shown in Figure 2-2 below

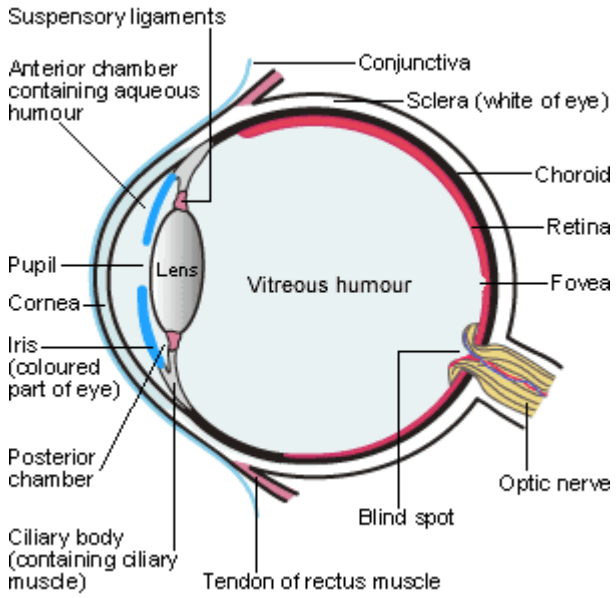
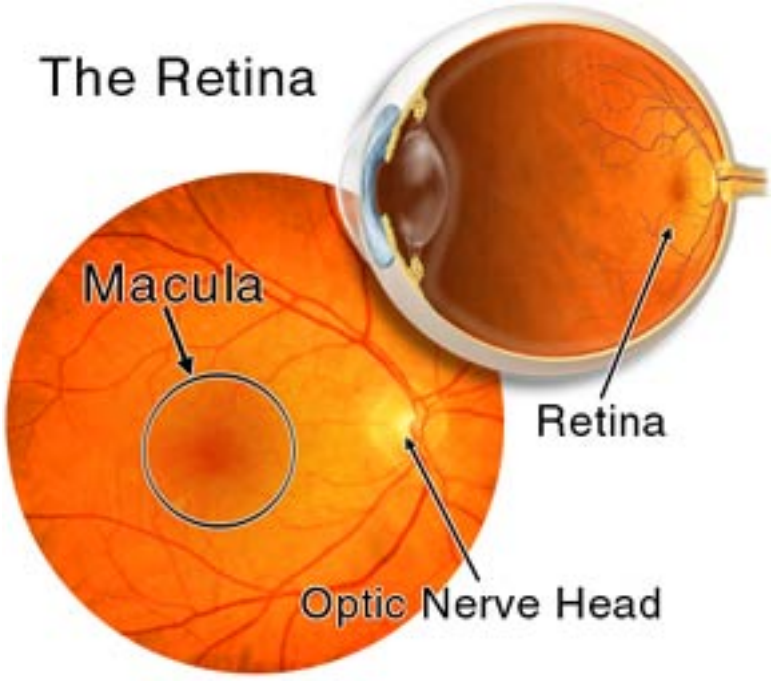


Figure 2-1, Structure of eye

Light enters the eye through the pupil and is focused on the retina. The lens assists in focusing images from different distance. The amount of light entering the eye is controlled by the iris, by closing when light is bright and opens when light is dim. To the outside of the eye is a transparent white sheet called conjunctiva. Ciliary muscles in ciliary body control the focusing of lens automatically. Choroids form the vascular layer of the eye supplying nutrition to the eye structures. Image formed on the retina is transmitted to brain by optic nerve. Optic disk is brighter than any part of the retina image and is normally circular is shape. It is also the entry and exist point for nerves entering and leaving the retina to and from the brain. Near to the centre of the retina is an oval shape object called macula. The fovea is near the centre of the macula and it contains packed cone cells. Due to high amount of light sensitive cells, the fovea is responsible for the most accurate vision [3] [4].



[Image from website: http://www.myeyeworld.com]

Figure 2-2, *Retina Image*

The retina is a multi-layered sensory tissue that lines the back of the eye. It contains millions of photoreceptors that capture light rays and convert them into electrical impulses. These impulses travel along the optic nerve to the brain where they are turned into images. There are two types of photoreceptors in the retina: rods and

cones. The retina contains approximately 6 million cones. The cones are contained in the macula, the portion of the retina responsible for central vision. They are most densely packed within the fovea, the very centre portion of the macula. Cones function best in bright light and allow us to appreciate colour [5].

2.2 Abnormalities Associated with the eye.

Abnormalities associated with the eye can be divided into two main classes, the first being disease of the eye, such as cataract, conjunctivitis, blepharitis and glaucoma. The second group is categorized as life style related disease such as hypertension, arteriosclerosis and diabetes [6].

When the retina is been affected as a result of diabetes, this type of disease is called Diabetic Retinopathy (DR), if not properly treated it might eventually lead to loss of vision. Ophthalmologists have come to agree that early detection and treatment is the best treatment for this disease [1]. DR occurrence have been generally categorise into three main form viz, BDR, PDR, SDR. These were explained in chapter one of this report. These Three classes can occur in any of the form described below as related to this research work.

Microaneurysms: These are the first clinical abnormality to be noticed in the eye. They may appear in isolation or in clusters as tiny, dark red spots or looking like tiny haemorrhages within the light sensitive retina. Their sizes ranges from 10-100 microns i.e. less than 1/12th the diameter of an average optics disc and are circular in shape [7], at this stage, the disease is not eye threatening.

Haemorrhages: Occurs in the deeper layers of the retina and are often called ‘blot’ haemorrhages because of their round shape.

Hard exudates: These are one of the main characteristics of diabetic retinopathy and can vary in size from tiny specks to large patches with clear edges. As well as blood, fluid that is rich in fat and protein is contained in the eye and this is what leaks out to form the exudates. These can impair vision by preventing light from reaching the retina.

Soft exudates: These are often called ‘cotton wool spots’ and are more often seen in advanced retinopathy.

Neovascularisation: This can be describe as abnormal growth of blood vessels in areas of the eye including the retina and is associated with vision loss. This occurs in response to ischemia, or diminished blood flow to ocular tissues. If these abnormal blood vessels grow around the pupil, glaucoma can result from the increasing pressure within the eye. These new blood vessels have weaker walls and may break and bleed, or cause scar tissue to grow that can pull the retina away from the back of the eye. When the retina is pulled away it is called a retinal detachment and if left untreated, a retinal detachment can cause severe vision loss, including blindness. Leaking blood can cloud the vitreous (the clear, jelly-like substance that fills the eye) and block the light passing through the pupil to the retina, causing blurred and distorted images. In more advanced proliferate retinopathy; diabetic fibrous or scar tissue can form on the retina [8].

2.3 Literature Review

There have been an increase in the use of digital image processing techniques for the screening of DR after it was recommended as one of the method for screening DR at the conference on DR held in Liverpool UK in 2005 [1] . With this increase more work have been done to improve some of the existing screening method while new methods have also been introduced in order to really increase the sensitivity and the specificity of this method. Sensitivity refers to the percentage of abnormal fundus image classified as abnormal by the method while specificity can be defined as percentage of normal fundus image classify as normal. The higher these two factors the better the method. Most of the available work done can generally be categorised into screening of BDR and PDR while diagnosis of SDR have been left for the ophthalmologist. However only few work have really been done in the detection of microaneurysm and exudates, most work done are in vascular abnormalities detection using colour fundus images. In this section, some of these past works are review and the results obtained are also discussed.

Vallabha et al in their work titled automated detection and classification of vascular abnormalities in diabetic retinopathy [8] applied the use of scale and orientation of selective Gabor filter to detect and classify the retina images into mild or severe case. Scale and angle analysis were used because of its ability to distinguish images by virtues of its variation across scales and orientation. The input image is first filtered through Gabor filter banks. The banks consist of several filters tuned to specific scales and orientation and the operation is performed in Fourier domain. The output of which is then analysed. Detection of NPDR (PDR) is done by analysing the width of the blood vessels. The presence of one local maxima in the plot of energy vs. orientation for more than 100 test images signify the presence of mild to NPDR (PDR) while the presence of more than one local maxima signify severe PDR. This method only signifies the presence of BDR and PDR but does not specify the co-ordinates nor the actual spots or actual disease type. The specificity and sensitivity of this method were not discussed in work done nor do they use a full scale image, instead part of the images of size 256 x 256 pixels were used.

In the work done by Chanwimaluang and Fan [9] as an improvement to the tracking-based method done by Zhou et al , [The detection and quantification of retinopathy using digital angiograms [10]] proposed a four step algorithm Matched filtering, local entropy thresholding, length filtering and vascular intersection detection for detection and extraction of blood vessel in retina images. The blood vessel was first enhanced by the use of Matched filtering, based on the assumption that blood vessels usually have lower reflectance compared with the background. Entropy based thresholding was then used to distinguished between background and vessels in the generated Matched Filter Response [MFR] image of step one. Length filtering was then employed to eliminate misclassified pixels before the application of a 3 X 3 and 11 X 11 neighbourhood windows to probe for branching points and intersection or crossovers. The Algorithm work very well with normal fundus images without lesions but perform poorly with images with lesions.

In [11], a computational model to extract vasculature from fundus images and detect bifurcation and crossover points was presented by the use of six (6) different steps. Naka Rushton filters; Cluster filter, Hyperbole filter, Median filter and Skeletonization were used in order to remove noise and produced an optimised skeleton version of

the veins. The sixth step was used for detecting and classifying crossover and bifurcation points. Naka Rushton filtering method uses the non-linear retinal features to correct the problem of unequal illumination. The vein networks were extracted using the Cluster filter, which is similar to K-means algorithm. Impulsive noise that was still present in the binary segmented image was removed by the use of hyperbole filter and this is then reduce to one pixel thick by the Skeletonization which uses the method of Zhang-Suen [12]. In the bifurcation and crossover detection, Crosspoint Number Method was used and certain conditions were defined for bifurcation and crossover points. Presence of noise affects this system and the test was only done on twelve images. Recommended method of improvement includes the use of and hybrid approach which combine genetic and heuristic method for detection of crossover points.

In work done by Xiaohui, Z., and Chutatape, O [13], a three step approach for detection and classification of bright lesions in colour fundus images was presented. The aim of the work was to detect and classifying bright lesion alone. The fundus image is first passed through a local contrast enhancement as a Pre-Processing stage, and then an improved fuzzy C- Means (IFCM) is applied to the Luminance/Chrominance (LUV) colour space to segment all candidate bright lesions. This segment all possible bright lesions as well as false positives due to clusters overlapping, non uniformity of colour distribution and noise [13], the third is hierarchal Support Vector Machine (SVM) that distinguish true bright lesions from non lesions.

Hayashi et al [6] developed a more similar system like ours titled ‘’A Development of Computer Aided Diagnosis (CAD) system using fundus images’’ which assist physician in detecting abnormalities associated with fundus images of the retina. An improvement to a four step diagnosis for red spot recorded fairly good result on tested 230 images on which 17 has red spots disease. 10 were detected correctly while 40 were false positive and 7 were not detected. The initial four steps involve converting and RGB fundus image to monochrome; from this areas of low density were extracted using Binarization method. This is followed by deletion of vascular regions and the last stage involves deletion of unnecessary elements. The method listed above suffered from lots of misdetection and it necessitate improvement.

Despite the improvement implemented, it only manages to achieve the above stated result.

In detecting white spots related abnormalities, the same method applied for the red spots were used on the negative of the monochrome image. However there were some huge differences in the way the two detection methods yield misdetection [13]. Improvement method suggested on misdetection around the optic disk offers improvement only for fundus images with visible optic disk while misdetection that occurred around areas with multiple blood vessels were left unresolved.

Chapter Three

Principles and Application of Image Processing

3.0 Introduction

This section discusses some of the principles applied in this research work. These principles include: Colour Space Conversion, Histogram Equalisation, K-mean Clustering Algorithm, Classification, Image Morphological Operations and Skeletonization. Also in this chapter, the development of GUI's for both fundus images marking and diagnosis of DR are also discussed.

3.1 Some of the Principles of Digital Image Processing

3.1.1 Colour Space Conversion

In digital image processing, images are either indexed images or RGB (Red, Green, Blue) images. An RGB image is an M x N x 3 array of colour pixels, where each colour pixel is a triplet corresponding to red, green and blue components of RGB image at specified special location. The range of value of an RGB is determined by its class. An RGB image of class double, has value in the range of [0 1], while class of uint8 is [0 255], similarly for the range [0 65535] is called class uint16.

There exist other colour spaces or models in some applications other than the two models mentioned above, these include NTSC (luminance(Y), hue(I), saturation (Q) colour model), HIS (luminance(H), hue(I), saturation (S)) colour model), YCbCr (luminance(Y), hue(I), saturation (Q)) colour model), HSV (hue(H), saturation(S), Value(V)) colour model), CMY(cyan(C), Magenta(M), Yellow (Y) colour model) and CMYK(cyan(C), Magenta(M), Yellow (Y), black(K)) colour model. Image processing toolbox provides conversion functions from RGB to any above listed colour spaces except HIS which will be discussed later in this section and is based on Gonzalez et al method [14].

a) NTSC colour spacing: NTSC (luminance(Y), hue (I), saturation (Q)) colour system is used in television in United States. One of the advantages of this method is that the greyscale information is separate from colour data. The percentage of RGB components are given as red 29.9%, green 58.7% and blue 11.4%. The image data consists of three components luminance (Y), Hue (I) and Saturation (Q). The transformation matrix is as given below.

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.211 & -0.523 & 0.312 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

The appropriate MATLAB function to use is: rgb2ntsc (RGB IMAGE NAME).

b) The YCbCr colour spacing: In YCbCr (luminance(Y), hue (I), saturation (Q)) colour spacing, the luminance information is represented by a single component Y while the colour information is stored as two colour difference components Cb, Cr. The difference between the blue component and reference value component is called Cb while the difference between the red component and reference value is referred to as component Cr [14]. This colour model is widely used in digital video.

Convert from RGB to YCbCr uses the transformation matrix below

$$\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 16 \\ 128 \\ 128 \end{bmatrix} + \begin{bmatrix} 65.481 & 128.553 & 24.966 \\ -37.797 & -74.203 & 112.000 \\ 112.000 & -93.786 & -18.214 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Appropriate MATLAB function for converting from RGB to YCbCr is: rgb2ycbcr (RGB IMAGE NAME)

c) The HSV colour space: HSV (hue (H), saturation(S), Value (V)) colour space is generated by looking at the RGB colour cube along the grey axis (the axis joining the black and white vertices) resulting in a hexagonally shaped colour palette. This colour system is based on the cylindrical coordinates, thereby making conversion from RGB

to HSV similar to a mapping RGB coordinate values to cylindrical coordinates function.

Appropriate MATLAB function for converting RGB to HSV is: rgb2hsv(RGB IMAGE NAME)

d) The CMY and CMYK colour spaces: Secondary colours of light are Cyan, magenta, and yellow. Cyan pigment subtracts the red light from reflected white light, which it self is composed of equal amounts of red, blue and green light. The conversion matrix is as below

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

MATLAB function for conversion is: imcomplement (RGB IMAGE NAME)

e) HSI colour space: HSI means hue saturation and intensity. In this colour model space, the intensity component is decoupled from colour carrying information (hue and saturation) in colour image, hence an ideal tool for the development of image processing algorithms. The HSI space consists of a vertical intensity axis and the locus of colour points that lie on a plane perpendicular to this axis, as the plan move up and down the intensity axis [14]. The important components of HSI colour space are the vertical intensity axis and the length of the vector to the colour point and the angle this vector makes to the red axis.
The transformation equations used in the conversion of RGB to HSI are

$$\text{H} = \begin{cases} \theta & if\ \text{K}\ B \le G \\ 360 - \theta & if\ \text{K}\ B \ge G \end{cases}$$

where

$$\theta = \cos^{-1}\{ \tfrac{1}{2}[(\text{R-G})+(\text{R+B})]/[(\text{R-G})^2 + (\text{R-B})(\text{G-B})]^{1/2}\}$$

and the saturation component is given by

$$S = 1 - [3/(R+G+B)][\min(R, G, B)].$$

Finally, the intensity component is given by

$$I = 1/3\ (R+ G+ B).$$

3.1.2) Histogram Equalisation

Histogram equalisation is nothing but a finding of cumulative distribution function for a given probability density function. Modelling of the histogram is usually done by the use of continuous process functions rather than discrete process functions.

Suppose for a given image the intensity levels are continuous quantities and is normalized to the range **[0 1]**. According to Gonzalez and Woods [2002], transformation can be performed on the probability density function of the intensity levels input image $P_r(r)$ is to obtain S as shown below

$$S = T(r) = \int_0^r P_r(\omega) d\omega$$

where ω is the dummy variable of integration.

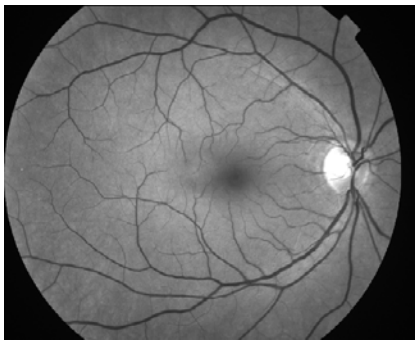
After the transformation, the image will have an increased dynamic range, high contrast and the probability density function of the output will be uniform, which can be regarded as a Cumulative Distribution Function (CDF).

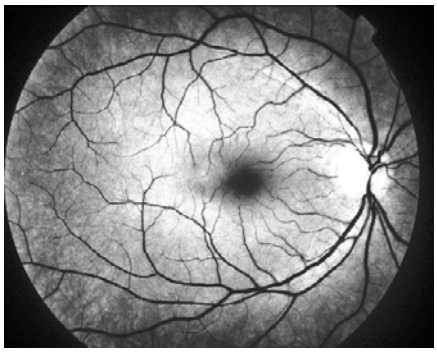
$$Ps\ (s) = 1 \text{ for } \quad 0 \leq s \leq 1, \text{ else zero}$$

In digital images, the intensity levels are discrete in nature, so the method above is often referred to as histogram equalisation method, though the output image histogram is not uniform due to the discrete nature of the variables. For discrete value data, the summations and equalisation methods above become

$$S_k = T(r_k) = \sum_{j=1}^{k} P_r(r_j) = \sum_{j=1}^{k} \frac{n_j}{n}$$

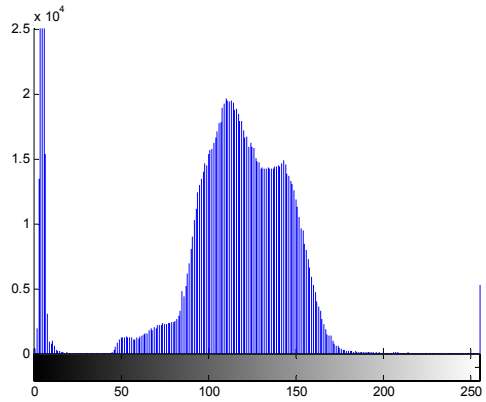
for **j = 1,2,…….L**, where $\mathbf{s}_k$ is the intensity value in the out put (processed) image corresponding to the value $\mathbf{r}_k$ in the input image. Example of this is as shown below

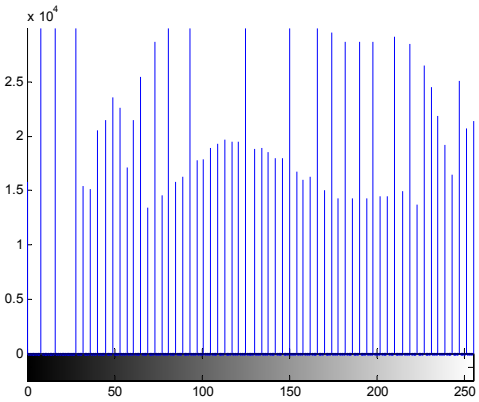




3-1 3-2

Figure 3-1, Original Image
Figure 3-2, Image after Histogram Equalisation





3.3 3.4

Figure 3-3, Histogram of Original Image
Figure 3-4, histogram of Image after Histogram Equalisation

Cleary Figure 3-1, shows an image with low dynamic range which can be seen in histogram Figure 3-3 the most important features like veins intersections and nodes can hardly be seen, most of the image intensity is concentrated in the range around 100 to 150 so it needs an enhancement. Figure 0-2 shows an enhanced image while Figure 0.4, shows the same image with considerable spread of the histogram over the entire intensity scale.

3.1.3) Simple Threshold Method of Segmentation

Simple thresholding is a simple method and highly intuitive method of segmenting image based on the pixel intensity value. It is based on the assumption that the intensity value of the image can be group into two non-overlapping groups namely object and background based on the perceived histogram of the image.

Suppose the intensity of an object is denoted by f(x,y) and the histogram is as shown in Figure 3. In this image, it can be seen that the image intensity can be group into two non-overlapping classes based on the value of threshold T in the histogram. This help in distinguishing the any pixel with value below this threshold, i.e. f(x,y) < T into a class called Background Information and any pixel with intensity value greater than T i.e. f(x,y) > T into another class called Object. In the segmented binary image, background pixels have value of zero while object pixels have value 1.

That is

$$g(x,y) = \begin{cases} 1 \text{ , if } f(x,y) > T \\ 0 \text{ if } f(x,y) < T \end{cases}$$

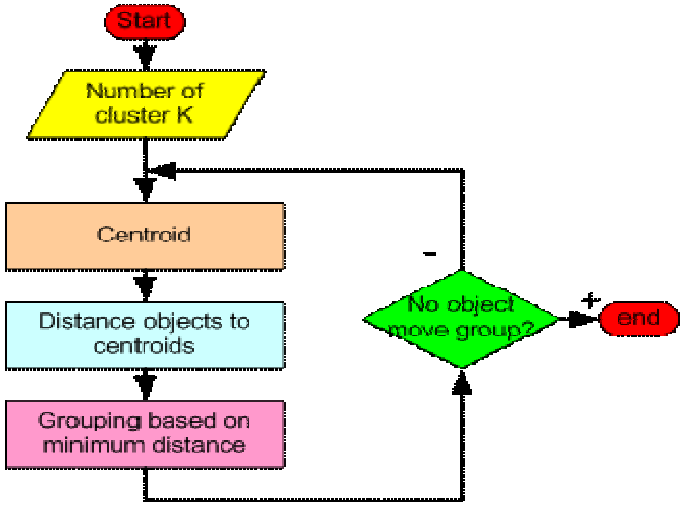
When the value of threshold T is constant, this is called Global Thresholding. Global thresholding often fails when the background illumination is uneven. When the histogram of the figure is not easily grouped or segregate, thresholding becomes difficult as compared to the last example, hence a need for another method of segmentation like Local Thresholding method or K-mean Thresholding mcan be used.

3.1.4) K-mean Clustering Algorithm of Segmentation

The K-means is another simple algorithm of segmenting or classifying images into k different clusters based on feature, attribute or intensity value. It is computationally efficient and does not require the specification of many parameters as compared to other method of segmentation. Unlike local thresholding, which can only group into two main classes while K-mean Algorithm can group into k different classes and that is part of the reason why we chosen as segmentation method for this work. The classification is done by minimizing the sum of the squares of distances between data and the corresponding clustering centroid. Type of distance calculation compatible with K-means Algorithm includes Manhalanobis and Euclidean distance etc.

The basic K-means Algorithm is as given in Figure 3.5:

Algorithm for K-means Segmentation
Step 1: Input data and number of clusters
Step 2: Calculate cluster (group) centroids based on initial guess value
Step 3: Calculate distance of each pixel from Class centroid
Step 4: Group pixels into k clusters based on minimal distance from centroids
Step 5: Calculate new centroid for each cluster
Step 6: Classify into groups based on new centroid and distance
Step 7: Test if any of centroid changes its position.
Step 8: If there are changes repeat step 3- 8, else step 9
Step 9: end



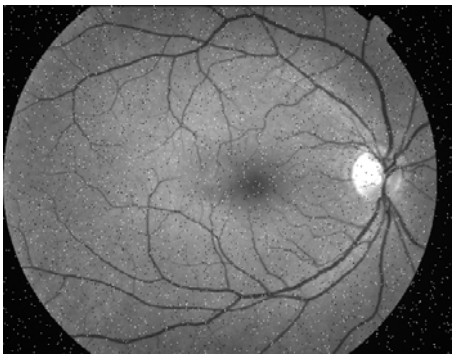
[Image source] http://people.revoledu.com/kardi/tutorial/kMean/NumericalExample.htm

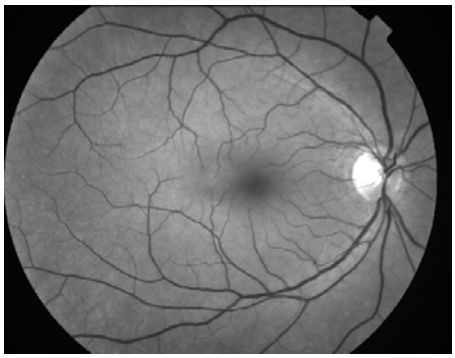
Figure 3-5, K-Mean Flow Chart

3.1.5) Median Filtering

The median filter is a nonlinear filter, which can reduce impulsive distortions in an image and without too much distortion to the edges of such an image. It is an effective method that of suppressing isolated noise without blurring sharp edges.

Median filtering operation replaces a pixel by the median of all pixels in the neighbourhood of small sliding window. It gives better results then the neighbourhood averaging in the case where noise is of impulsive nature. The advantage of a median filter is that it is very robust and has the capability to filter only outliers and is thus an excellent choice for the removal of especially salt and pepper noise and horizontal scanning artefacts. The median filter is realized in MATLAB by the function medfilt2.





3.6 3.7

Figure 3-6, Original Image before Median Filtering
Figure 3-7, Image after Median Filtering

3.1.5. Morphological Operations

Morphological operations play a key role in digital image processing with special application in the field of machine vision and automatic object detection. The morphological operations include dilation, erosion, opening, closing and skeletonization etc.

a) Dilation

Dilation is a process that thickens objects in a binary image. The extent of this thickening is controlled by the Structuring Element (SE) which is represented by a matrix of 0s and 1s.

Mathematically, dilation operation can be written in terms of set notation as below

$$A \oplus A_s = \{z|(A'_s)_z \cap A \neq \Phi \}$$

Where Φ is an empty element and A_s is the structuring element. The dilation of A by A_s is the set consisting of all structuring element origin locations where the reflected and transmitted A_s overlaps at least some portions of A. Dilation operation is commutative and associative.

b) Erosion

Erosion shrinks or thins the objects in a binary image by the use of structuring element. The mathematical representation of erosion is as shown below.

$$A \ominus A_s = \{z|(A_s)_z \cap A^c \neq \Phi \}$$

Erosion is performed in MATLAB using the command imerode (Image Name, SE).

c) Opening and Closing

In image processing, dilation and erosion are used most often and in various combinations. An image may be subjected to series of dilations and or erosions using the same or different SE. The combination of this two principles leads to morphological image opening and morphological image closing.

Morphological opening can be described as an erosion operation followed by a dilation operation. Morphological opening of image X by Y is denoted by X ^{O} Y, which is erosion of X by Y followed by dilation of the result obtain by Y closing and opening

$$X \circ Y = (X \ominus Y) \oplus Y$$
$$X \bullet Y = (X \oplus Y) \ominus Y$$

Morphological closing can also be described as dilation operation followed by erosion operation. Morphological Closing of Image X by Y is denoted by X $^{\copyright}$ Y, which is dilation of X by Y followed by erosion of the result obtained by Y.

Image opening and image closing and are implemented in MATLAB by the use of imopen(image name) and imclose(image name) respectively.

d) Skeletonization:

Skeletonization is another way to reduce binary image objects to a set of thin strokes that can display important information about the shape of the original objects. Skeletonization is similar to thinning, except that it maintains more information about the internal structure of objects with it being 1 pixel thick.

3.2 Graphical User Interface (GUI)

A graphical user interface (GUI) can be describe as a graphical display that contains devices, or components, that enable a user to perform interactive tasks without creating a script or type commands at the command line [14]. These components can be push buttons menus, toggle buttons, toolbars, checkboxes, radio buttons and sliders etc. Data can also be display in graphical form or plots or groups. The user need not know the details of the task. A simple GUI supported by MATLAB with its rich sets of tools is as shown in Figure 3-10.

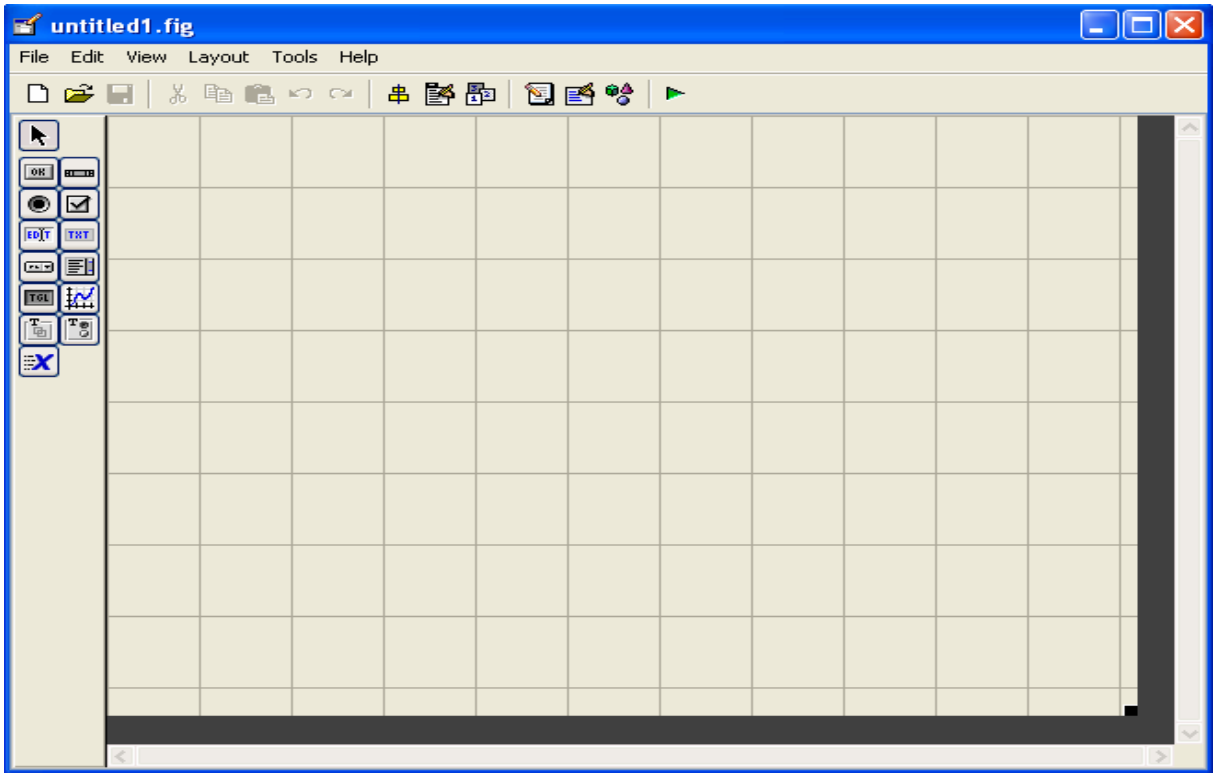


Figure 3-8, GUI Supported by MATLAB

Creating a GUI using MATLAB's Graphical User Interface Development Environment (GUIDE) is divided into two relatively managed and independents tasks, viz:

1) GUI Component layout
2) GUI Programming

In GUI component layout, the GUIDE enables the user to layout the GUI as required. It involves clicking and dragging of the components from the components palette to

the layout area. These components can be aligned, resize, set tab order etc by using other tools are accessible from the Layout Editor [15]. Saving this GUI layout generates an M-Files (MATLAB) file which helps to control how the GUI works. This and subsequent activities constitute the GUI Programming tasks. The generated M-file provides code to initialize the GUI when launched and contains a framework for the GUI callbacks; the routines that execute in response to user-generated events such as a mouse click [16]. Adding codes to the callbacks function using the M-file editor enable the GUI perform intended operations.

Since part of the aim of this research work is to design a GUI to assist in fundus image marking and labelling for this present and future work in this field, two different GUI were created, the first called Fundus Image Data Acquisition GUI (FIDA-GUI) and the second is Diabetic Retinopathy GUI (DR-GUI) titled CVision. FIDA-GUI is to be used for marking and labelling abnormalities in images while CVision is used for diagnosis of DR.

FIDA-GUI as shown in Figure 3.2 consist of 4 different push buttons, 3 different text box, two toggle boxes, and a display area. The user input the fundus image number to the section called ‘’FUNDUS IMAGE NUMBER’’ and the image is loaded into a 9cm by 10 cm display area. The drop down box enable user or ophthalmologist to pick from set of pre define disease type while the section called ‘’XYZ’’ enables the user to define a new set of diseases. To facilitate Ophthalmologist to view clearly even in a dark image it has option to increase the intensity of the any particular area. Colour Conversion can be done by pressing ‘’CONVERSION’’ push button. When the fundus image have been marked, this can be saved by pressing the ‘’SAVED PUSH BUTTON’’ so that the marked image can be loaded again anytime with the intended saves name with the marked points. The save button also create a .inf file that saved the x-y co-ordinates of the marked images with the label name.

Figure 3-9, FIDA-GUI

CVision-GUI is similar to FIDA-GUI, but with added functionalities. It enables the user to automatically diagnose DR by the use of Push Button. The image name to be diagnosed is loaded and type of diagnosis to be run is pressed. Type of diagnosis includes red spots, bleeding, soft and hard exudates and vein-artery crossover points. The output section is made up of two areas, the display section and the result section. The display section displays the fundus image with the disease area highlighted in red, for red spot, green for bleeding and blue for cross over points. Also enclose in a rectangle is the count of this various diseases. The CVision GUI is as shown in Figure 3-10 below.

Figure 3-10, CVision GUI

Chapter Four

Diabetic Retinopathy Diagnosis

4.0 Introduction

In this chapter, the stages involved in the automatic diagnosis of fundus image are discussed. It starts with a brief review of the block diagram of the processes involved in diagnosis of DR and is similar to that contained in Figure 1-1 (Figure 1 is contained in Chapter 1 of this report). This is followed by comprehensive discussion of each of the stages involve with this research work.

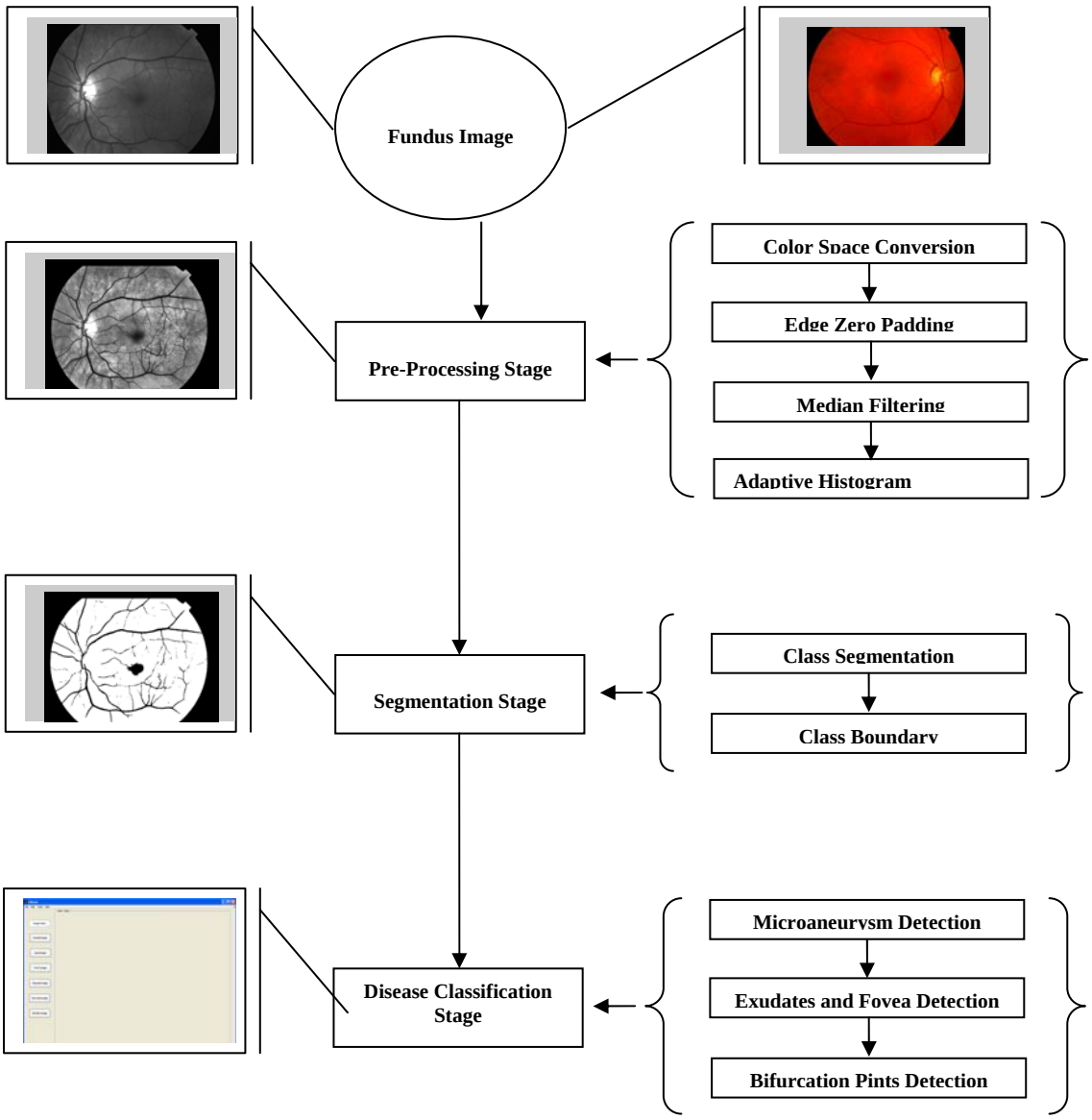


Figure 4-1, Block Diagram of Automatic Diagnosis of Diabetic Retinopathy using Fundus Images

4.1 Pre-Processing Stage (PPS)

In detecting abnormalities associated with fundus image, the images have to be Pre-Processed in order to correct the problems of uneven illumination problem, non-sufficient contrast between exudates and image background pixels and presence of noise in the input fundus image. Aside from aforementioned problems, this section is also responsible for colour space conversion and image size standardization for the system. This section, which is Pre-Processing stage, can be regarded as the bedrock of this research work. The block diagram of the sub sections that constitute the Pre-Processing stage (PPS) is as shown in Figure 4-2.

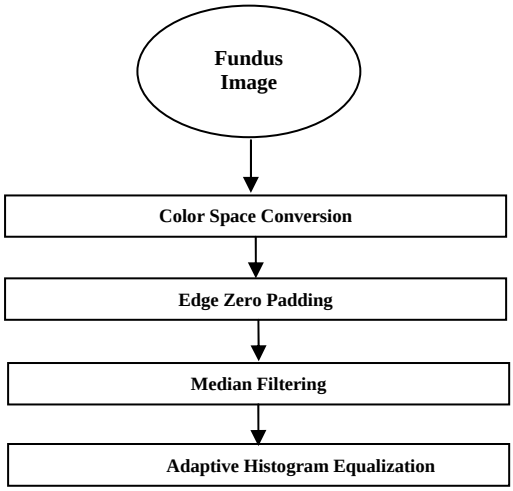


Figure 4-2, Block diagram of Pre-Processing stage.

4.1.1 Colour Space Conversion

The first stage in Pre-Processing stage is the colour space conversion. The input fundus image can be either an RGB or a grey scale image. If it is an RGB image then the system converts it to an intensity image using RGB to HIS conversion based on Gonzalez and Woods (2002) method [14], else the system process the image as double image using image to double MATLAB conversion. Conversion to intensity image has been fully discussed in Chapter 3 of this report. The choice of RGB to HSI is based on the fact that the intensity matrix of the image can be disassociated from other components such as hue and saturation. More so since the information needed for the diagnosis is contained in the intensity matrix alone, dissociation and further processing using the intensity matrix or component alone is enough for the diagnosis

of DR. The input RGB and output intensity image of this is as shown in Figure 4.3 and 4.4 respectively.

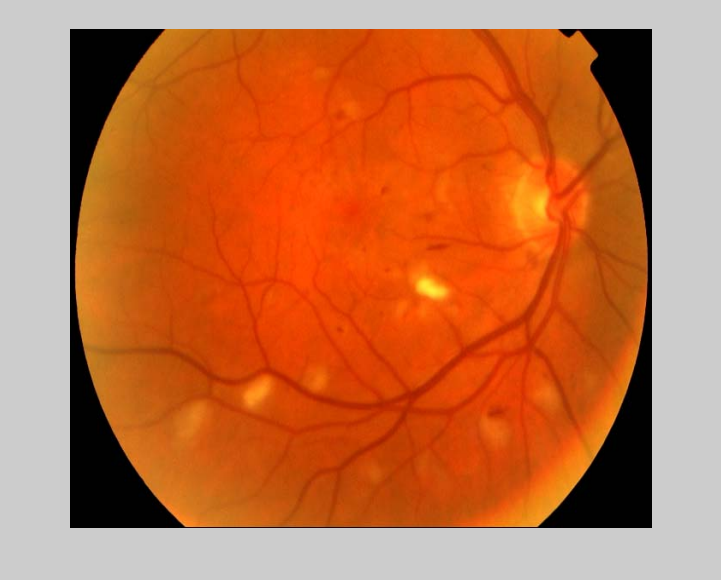


Figure 4-3, Original Image before Colour Space Conversion

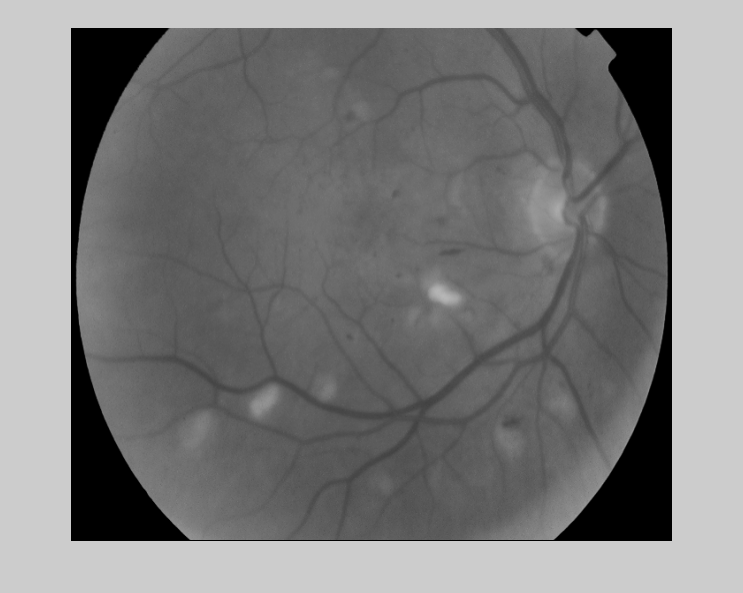


Figure 4-4, Intensity Component of HSI Matrix

4.1.2 Zero Padding

The result of this colour space conversion section is fed to the edge padding section of PPS. In this subsection, the image is padded with zeros so as to remove un-wanted noise that may be introduced during the intensity enhancement and segmentation stage and also to be able to calculate the minimum and maximum intensity value of the whole image. There are four steps associated with this section, viz image intensity thresholding, image fillings, minimum and maximum intensity detection.

Algorithm: Steps involve in zero padding a fundus image and obtaining minimum and maximum intensity value

Step 1: Check for the size of image, zero padding value, and obtain origin co-ordinate

Step 2: Create a zero matrix equal to image size

Step 3: Fix the original image at the appropriate coordinate obtain in 1

Step 4: Fill exterior of the mask with zero

Step 5: Obtain the minimum and maximum intensity within the mask

Step 6: Return the new zero padded image, minimum intensity and maximum intensity values

In image intensity thresholding, the minimum value of the intensity image is used as the threshold in order to detect the boundary of the image, thus generating a binary image with positive 1 in the mask and zeros outside the mask. This is then combined using logical AND operation with the original input image in other to ensure that other areas outside the mask are of intensity value zero. In the image fillings, this involves filling the outside region of the mask with either zero or other values. In obtaining a mask, the outside will be filled with zeros while in the obtaining minimum and maximum intensity, outside of the mask is filled with intensity value of 128. The input and output images for the zero padding step are shown in Figure 4.5 and 4.6 respectively.

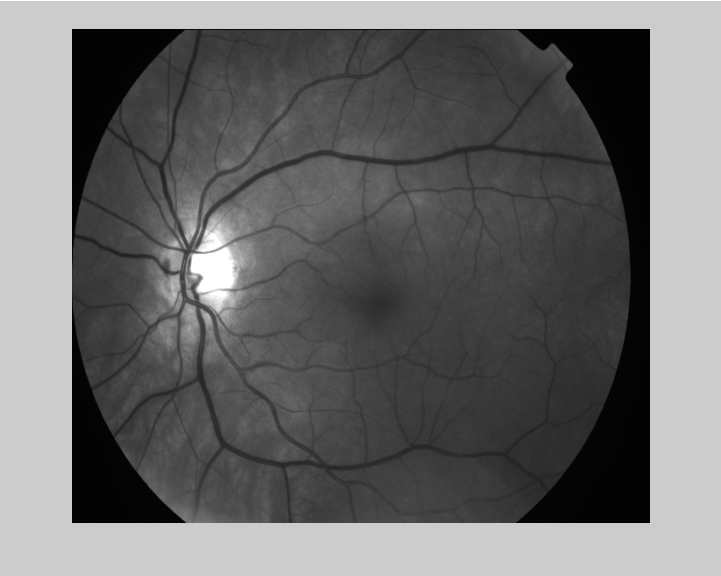


Figure 4-5, Input Image before zero Padding

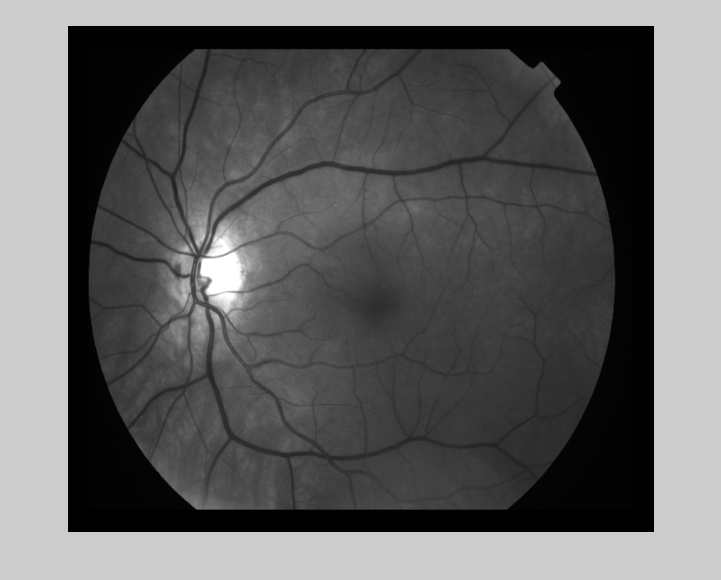


Figure 4-6, Output zero Padded Image

4.1.3 Median Filtering

Applying adaptive histogram equalisation to an image to enhance the contrast between the background pixels and the information contained in the image also lead to enhancement of the noisy pixels. A noisy pixels appears with the background information, therefore there is need to remove noisy pixels before contrast enhancement using a Median filter. Median filtering has been discussed in detail in Chapter 3 hence no need of detail discussion here.

4.1.4 Histogram Equalisation

One of the problems associated with fundus images is uneven Illumination. Some areas of the fundus images appear to be brighter than the other. Areas at the centre of the image are always well illuminated, hence appears very bright while the sides at the edges or far away are poorly illuminated and appears to be very dark. In fact the illumination decreases as distance form the centre of the image increase. Many methods were tried in resolving this problem of un-even illumination, among which are the use of Naka Rushton method and Adaptive Histogram Equalisation Method (AHEM). AHEM gives better performance, higher processing speed and work well for all images of different sizes, hence the reason for it being used as method of correcting un-even illumination. Nevertheless the two methods will be discussed in this sub section.

a) Naka Rushton Method

Bevilacqua [1] in their work titled 'A combined method to detect retinal fundus features' take advantage of the non-Linear filtering effect of the eye in order to correct the impulsive noise created during the acquisition of fundus images and produced an image with uniform intensity. The filtering effect is based on the method called Naka Rushton method and the equation is as given below

$$O(i,j) = \frac{I(i,j)}{I(i,j) + \mu_{window}}$$

where

$O(i,j)$ is the transformation result, $I(i,j)$ is the original image and μ_{window} is the average of the chosen exploration window.

Using this method, a grey level compression of the image was produced with high contrast between the background and the objects information contained there in. The grey level represented in the original image was compressed, though it works well for small parts of image but doesn't perform well for images with complete size. Aside this, a lot of noise was added to the image using this method and this leads to false and poor segmentation stage. Also in the work done by Bevilacqua et all, it was only of interest to find vascular features and not all the features associated with fundus images so a more robust method, with less noisy output and fast processing speed is needed for the large images used for this work hence the need for Adaptive Histogram Equalisation Method (AHEM).

b) Adaptive Histogram Equalisation

The main objective of this method is to define a point transformation within a local fairly large window with the assumption that the intensity value within it is a stoical representation of local distribution of intensity value of the whole image. The local window is assumed to be unaffected by the gradual variation of intensity between the image centres and edges. The point transformation distribution is localised around the mean intensity of the window and it covers the entire intensity range of the image. Consider a running sub image W of N X N pixels centred on a pixel P (i,j) , the image is filtered to produced another sub image P of (N X N) pixels according to the equation below

$$p_n = 255.\left(\frac{[\phi_w(p) - \phi_w(Min)]}{[\phi_w(Max) - \phi_w(Min)]} \right)$$

where

$$\phi_w(p) = \left[1 + \exp\left(\frac{\mu_w - p}{\sigma_w} \right) \right]^{-1}$$

and *Max* and *Min* are the maximum and minimum intensity values in the whole image, while μ_w and σ_w indicate the local window mean and standard deviation which are defined as:

$$\mu_w = \frac{1}{N^2} \sum_{(i,j)\in(k,l)} p(i,j)$$

$$\sigma_w = \sqrt{\frac{1}{N^2} \sum_{(i,j)\in(k,l)} \left(p(i,j) - \mu_w\right)^2}$$

The size of the window chosen for this work is as given in the appendix.

As a result of this adaptive histogram equalisation, the dark area in the input image that was badly illuminated has become brighter in the output image while the side that was highly illuminated remain or reduces so that the whole illumination of the image is same. It is worthy of mentioning that this method also used overlap mean in the final build up of the image. The input and output images are shown in Figure 4-7 and Figure 4-8 respectively.

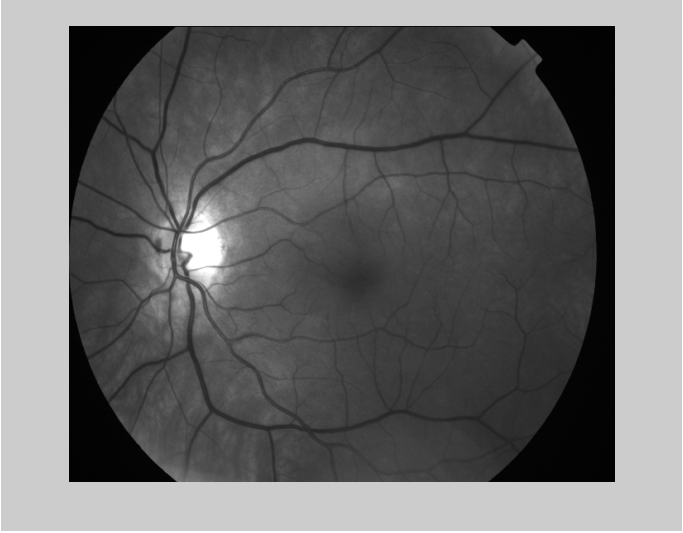


Figure 4-7, Original Grey Image

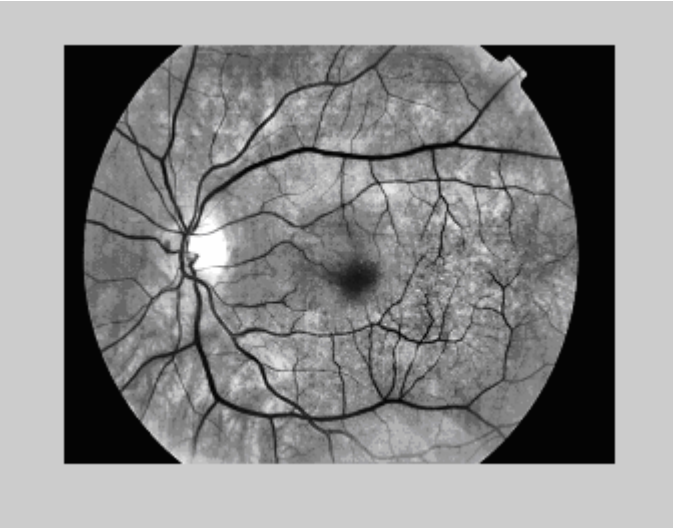


Figure 4-8, Pre-Processed Image

All the aforementioned processes constitute the Pre-Processing sections and the output image of this PPS is as shown in Figure 4-8 above.

4.2 Segmentation

The main objective of segmentation is to group the image into regions [14] with same property or characteristics. It plays a major role in image analysis system by facilitating the description of anatomical structures and other regions of interest. Method of image segmentation include: simple thresholding, K-means Algorithm and Fuzzy C-means. Some of these methods were as discussed in Chapter 3.

In this research, segmentation by K-means with two non-overlapping classes are found to be better than segmentation by simple thresholding. Background and noisy pixels were segmented into one class and the fundus image features which consist of the spots, exudates veins and features of the fundus images were segmented into another class without any pixel belonging into two classes. The non-overlapping of this method made it suitable for this particular research work where it is only of interest to distinguish between the background and the main fundus image features. The algorithm for the segmentation is as shown in table 3.3

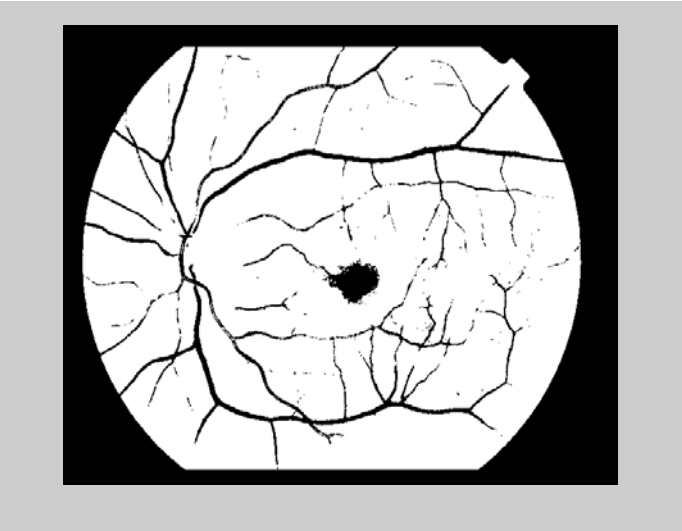


Figure 4-9, Segmented Image

The output of the Segmentation stage is as shown in Figure 4-9 above

4.3 Disease Classification/Abnormalities Detection

There are three distinct stages involved in detecting microaneurysm, exudates and crossover points in fundus images in this research work. The block diagram of which is as shown in Figure 4-10.

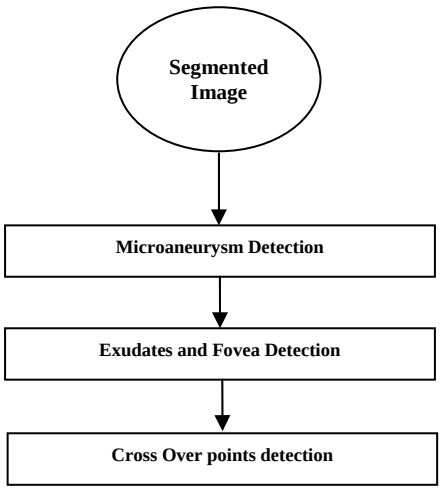


Figure 4-10, Block Diagram of Abnormalities detection

4.3.1 Microaneurysm Detection

This is the first stage of work involved in abnormalities detection. The input is a segmented fundus binary image with candidate lesions, vein network and

microaneurysm, which is as shown in Figure 4.9 above. A set of decision criteria is made in this section. This include: pixel counts, ratio of minor to major axes, robustness test, length test and holes test. All these assist in distinguishing microaneurysm from non-microaneurysm.

Pixel Counts: This involves counting the number of pixel that constitutes a candidate microaneurysm. From analysis and experiment, the pixel count for candidate microaneurysm ranges from 30 (called *MinPixelCount*) to 5000 pixels for a (1320x1024) image. A region or candidate less than *MinPixelCount* is regarded as a background noise while a region greater than the maximum pixel counts of 5000 pixels is regarded as a non-microaneurysm.

Ratio of Minor to Major Axes: The ratio of the length of the minor axes to the major axes is determined for a candidate lesion. These lengths are determined as shown in Figure 4.11. The longer axis is termed major axes while the shorter is called minor axis.

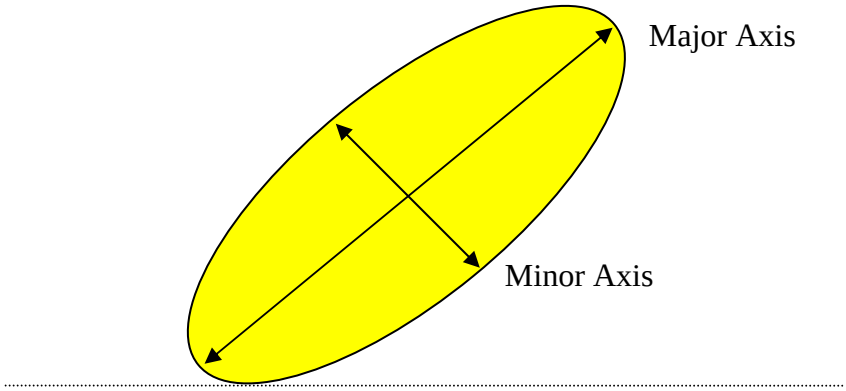


Figure 4-11, Major and Minor Axis

In diagnosing microaneurysm, a threshold is set for this criterion with the assumption that microaneurysm or red spots are cylindrical or circular in shape. So it is assumed that the ratio of minor to major axes should not be less than *MinObjRation* (with a value of 0.5).

MinObjRation = Minor Axis/Major Axis

Compactness Test: If a candidate region is enclosed in a rectangle, the ratio of the filled area to the total area is also used as a criterion for distinguishing between microaneurysm and others. The threshold of which is called *MinRedSpotCompactRatio* and *MinBleedingCompactRatio* for red spots and bleeding respectively.

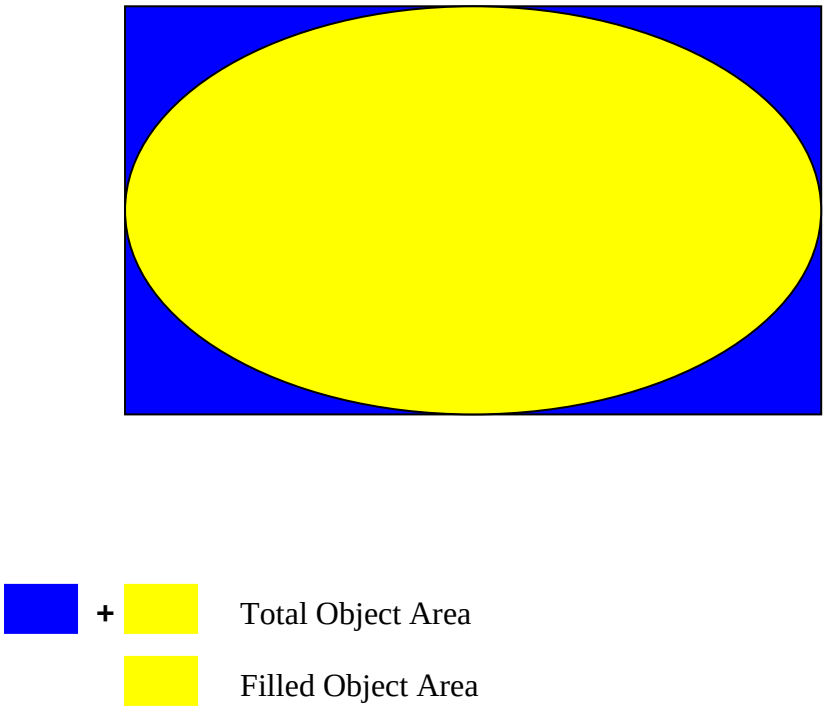


Figure 4-12, Compactness Test

MinRedSpotCompactRatio = Filled Area/Total ObjectArea

Length Test: The length test is a criteria used to distinguished between a vein that was cut due to segmentation and a microaneurysm. The length of a region is determined and a threshold set for this.

Hole Test: The solidity of a region is also tested in order to finally accept it as a microaneurysm or not. It is assumed that an object with a hole (off pixel) cannot be regarded as a candidate red spot but can be a bleeding or other non vein related information.

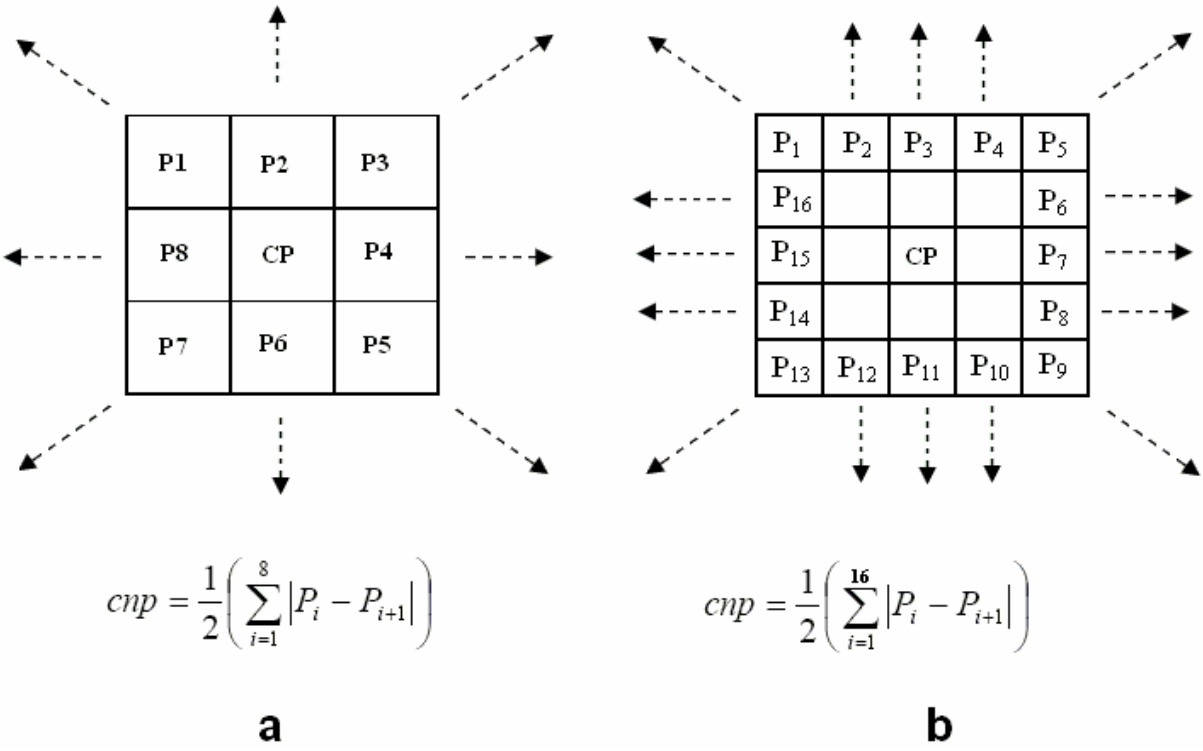
4.3.2 Crossover Points Detection

This involves accurately determining crossover or vein intersection points in a fundus image. After removing all the candidate microaneurysms, red spots, fovea and noise, the image is ready for crossover points detection.

Vein-artery crossover points were detected by using two different approaches, viz:
A) Simple Cross-point Number (SCN) method.
B) Modified Cross-point Number (MCN) method.

Simple and Modified Crosspoint Number Methods for Crossover Detection:

In the Simple Cross-point Number (SCN) method a window of 3x3 is used with 8 neighbouring pixels to the central pixel while Modified Cross-point Number (MCN) method uses a 5x5 window with 16 surrounding pixels to the central pixel, while the upper limit of the summation equation being 8 and 16 respectively for the both methods. This is as shown in the Figures below.



4.13 4.14

Figure 4-13, Simple Cross-point Number Method

Figure 4-14, Modified Cross-point Number Method

A point is regarded as a cross-point or intersection in both methods if cnp = 4 as shown in Figure 4-15 below.

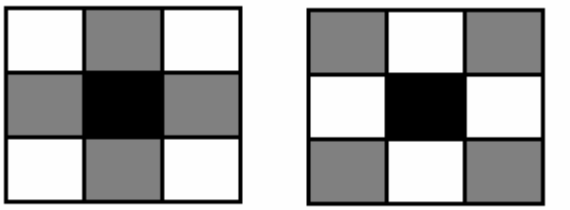


Figure 4-15, Cross Point Number Method

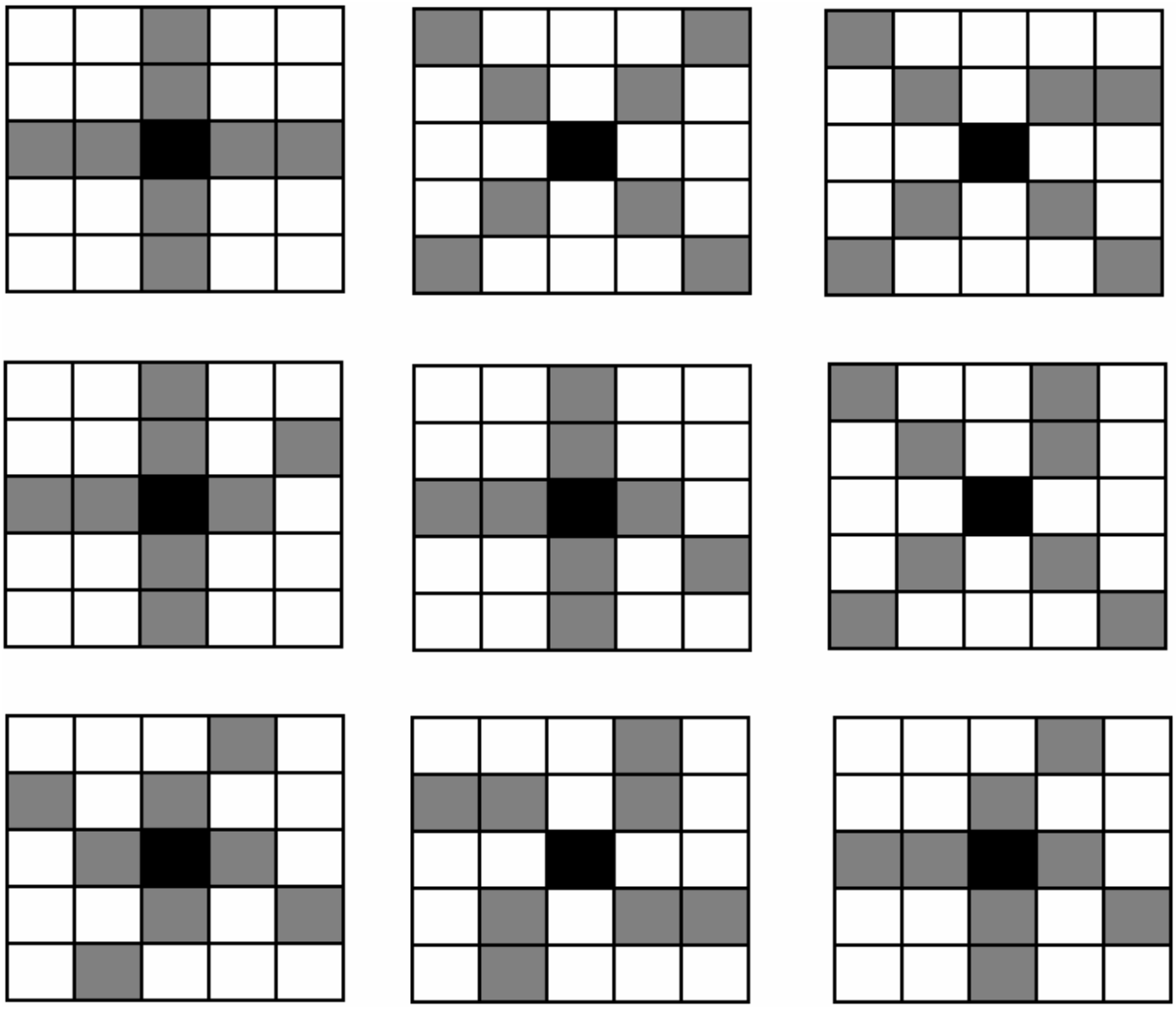


Figure 4-16, Crossover point examples in the Modified Cross Point Number Method

Advantages of the Modified Cross Point Number Method:

Skeletonization or thinning process some times converts some of the crossover points into a pair bifurcation points depending on the angle and thickness of veins as shown in the Figure 4-17, this affected the detection of cross-points in the previous work done, hence a need to modified this method in a more efficient way, so as to reduce this phenomenon.

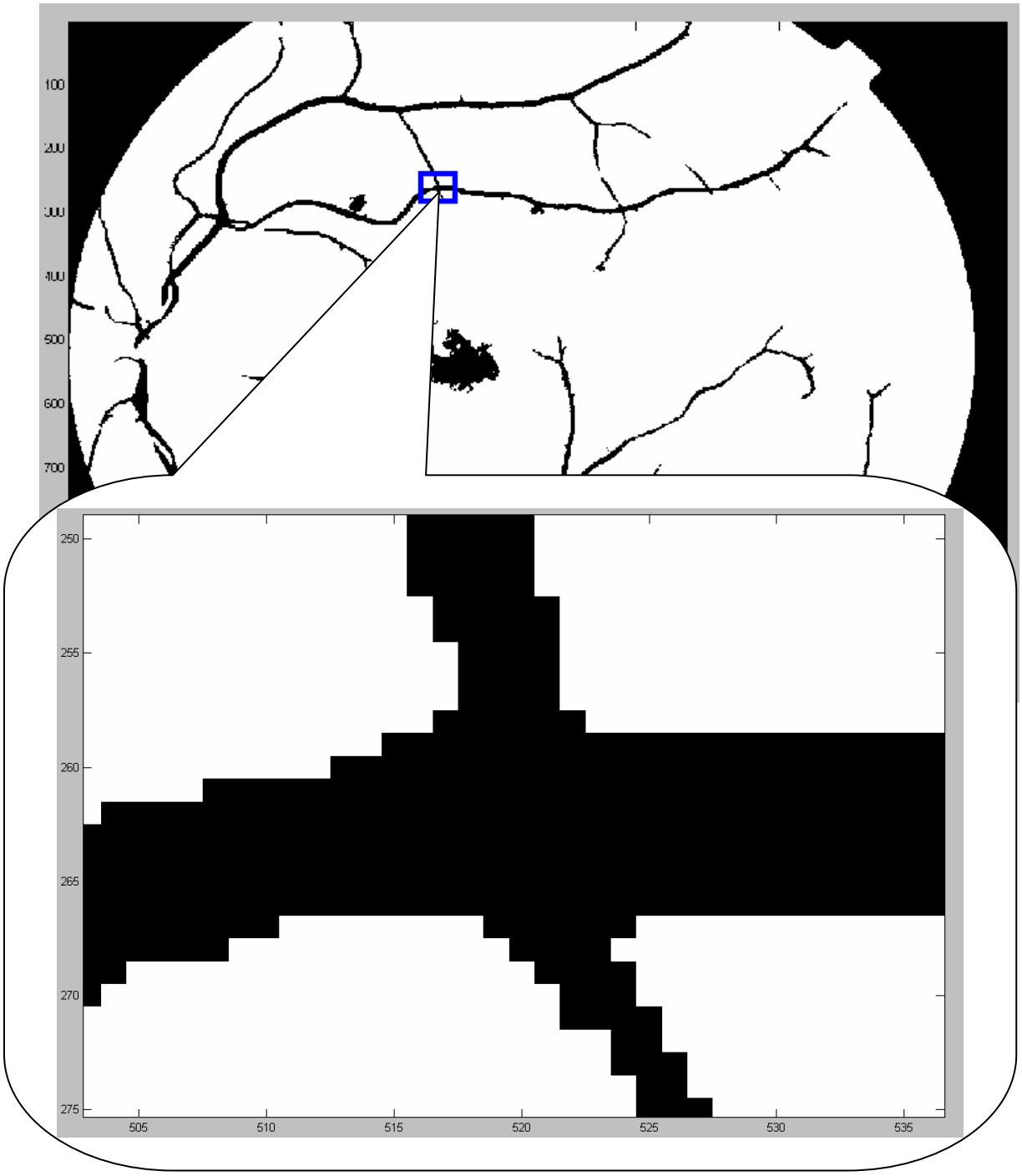


Figure 4-17, Segmented Fundus Image with Enhanced view of a simple crossover

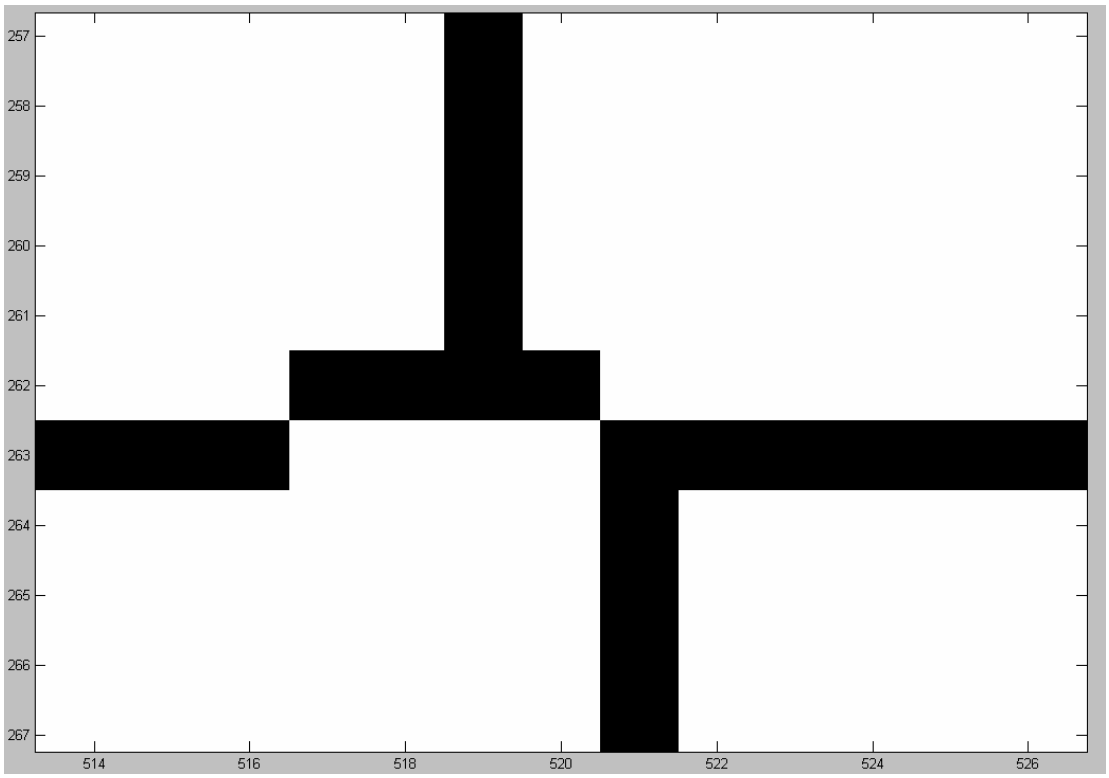


Figure 4-18, Skeletonization sometimes convert crossover into two bifurcation points

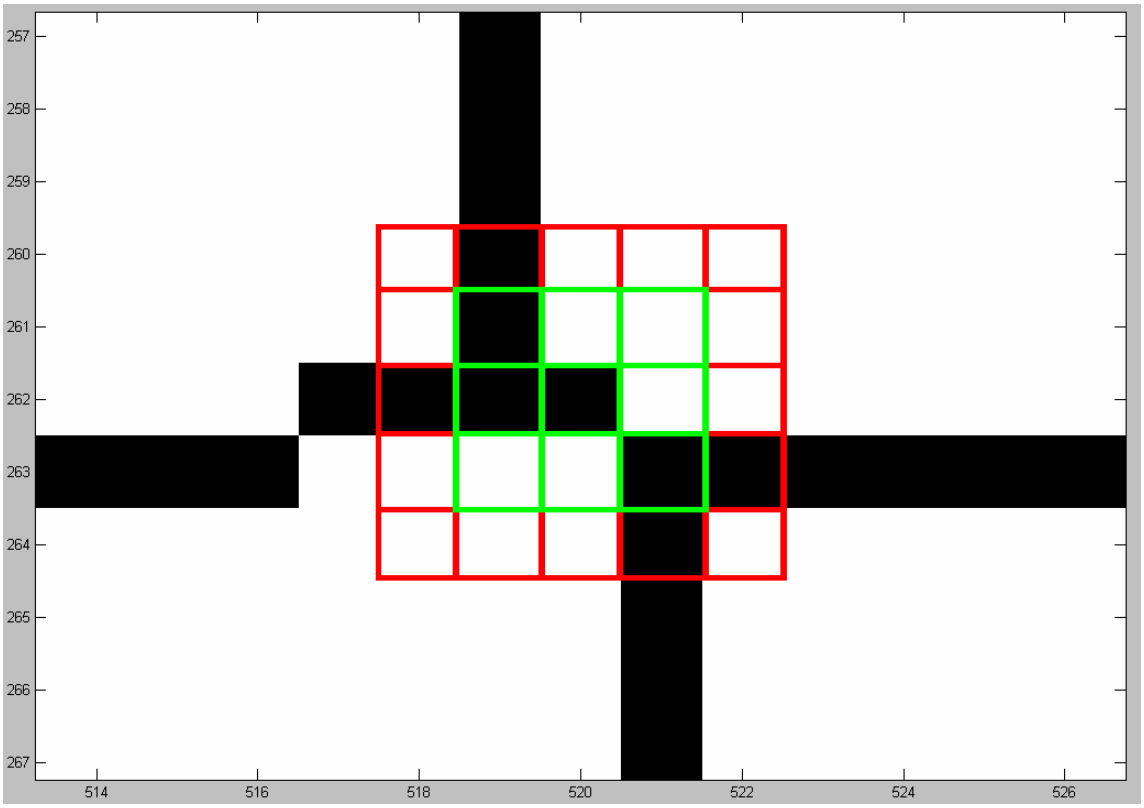


Figure 4-19 cnp = 2 (green) for the Cross point Method and cnp = 4 (red) for Modified Cross Point Number Method

With the use of MCN method, detection of some of the crossover points which changed to bifurcations points can easily be detected and it subsequently reduced error associated with SCN method.

The use of the 5x5 window instead of 3x3, introduces two new errors if care is not taken. These errors are false detection due to the traces of other non-intersecting veins in the 5x5 window and detection of one crossover point at more than one pixel. These problems were resolved as:

To prevent false positive detections due to the traces of non-intersecting veins, all unconnected pixels to the central pixels were removed before further processing, as shown in Figure 4-20 and Figure 4-21 below.

To prevent more than one detections for a single crossover point, we eroded the crossover image which re-connected the crossovers points into one detected by the algorithm which in fact belong to the same crossover point then selected of one pixel from each label as the crossover point. This is as shown in Figure 4-22.

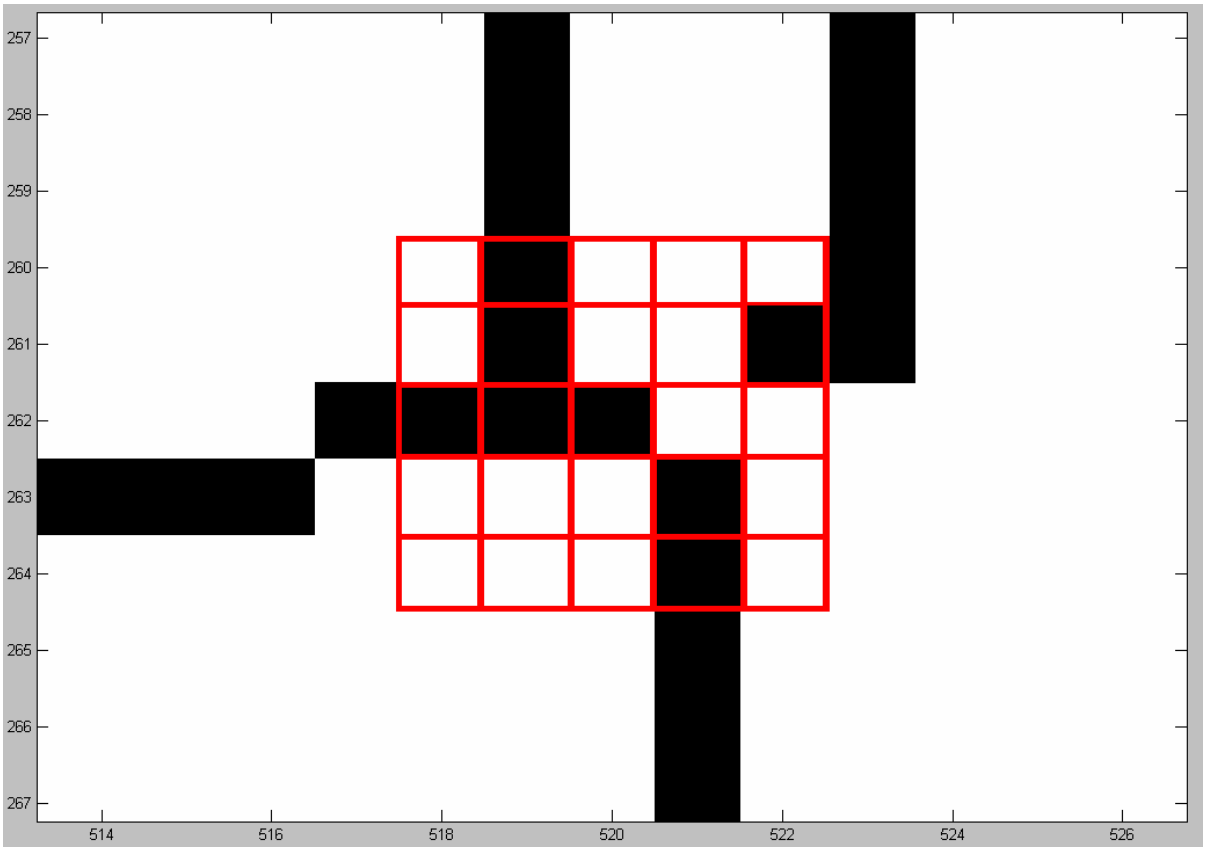


Figure 4 -20, cnp = 4 but this not a crossover point

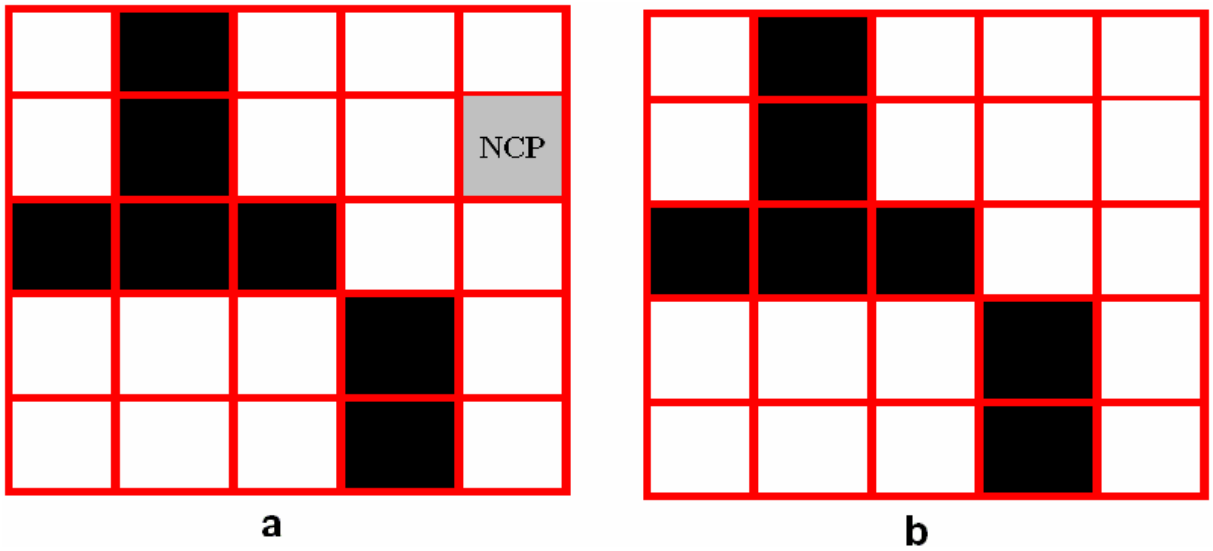


Figure 4-21, (a) 5x5 windows with cnp = 4. (b) Non connected pixel removed cnp = 3.

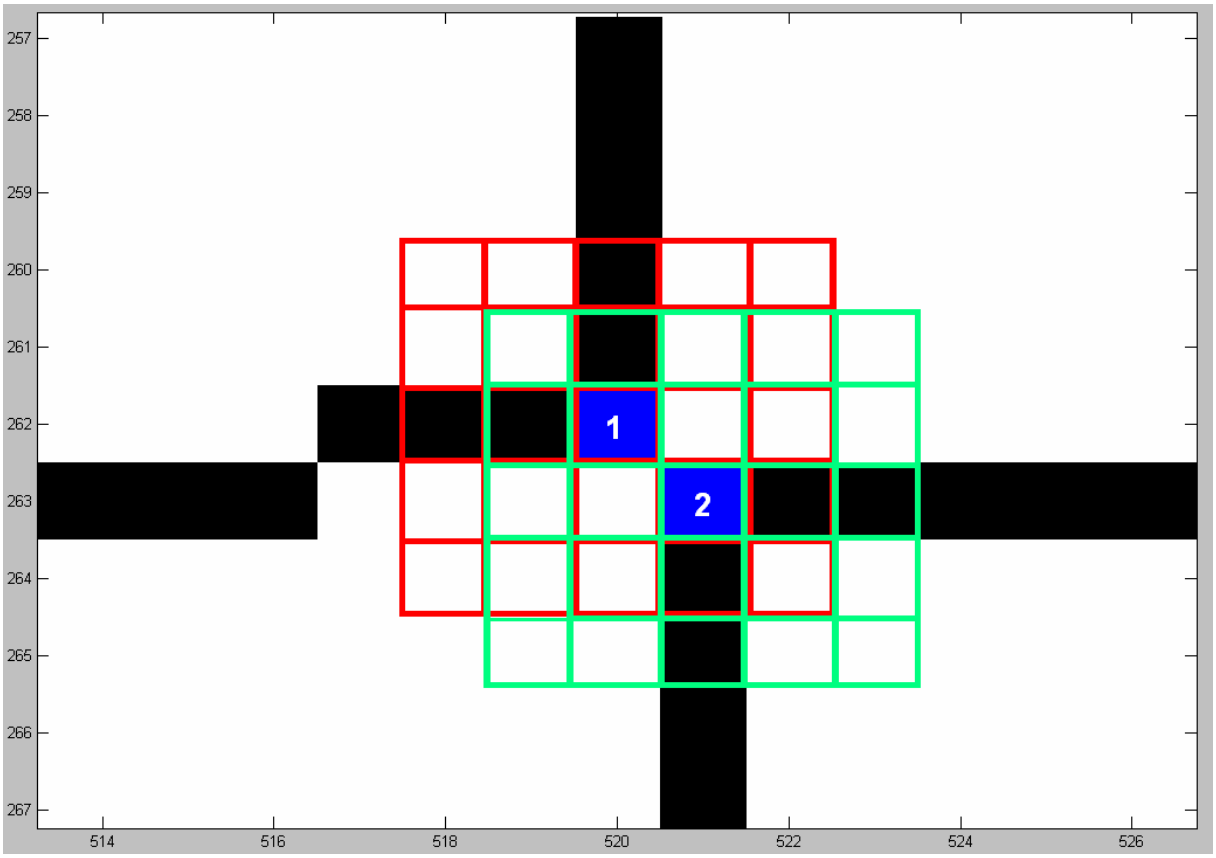


Figure 4-22, Two time detection of one crossover point

Chapter Five

Results and analysis

This chapter starts with presentation of result obtained from diagnosis of twenty five (25) fundus images which were used for detection and diagnosis. For each set of data, the Receiver Operator Characteristics (ROC) curve is also presented and this is shortly followed by the analysis of the result and some of the thresholds used in obtaining the ROC.

5.1 Result and Analysis

5.1.1 Result Obtained

The result obtained from the diagnosis of DR by this research work is as shown in the different ROC. Twenty-five images (10 normal images and 15 abnormal images). Detection for abnormalities is centred on detecting red spot disease and bleeding.

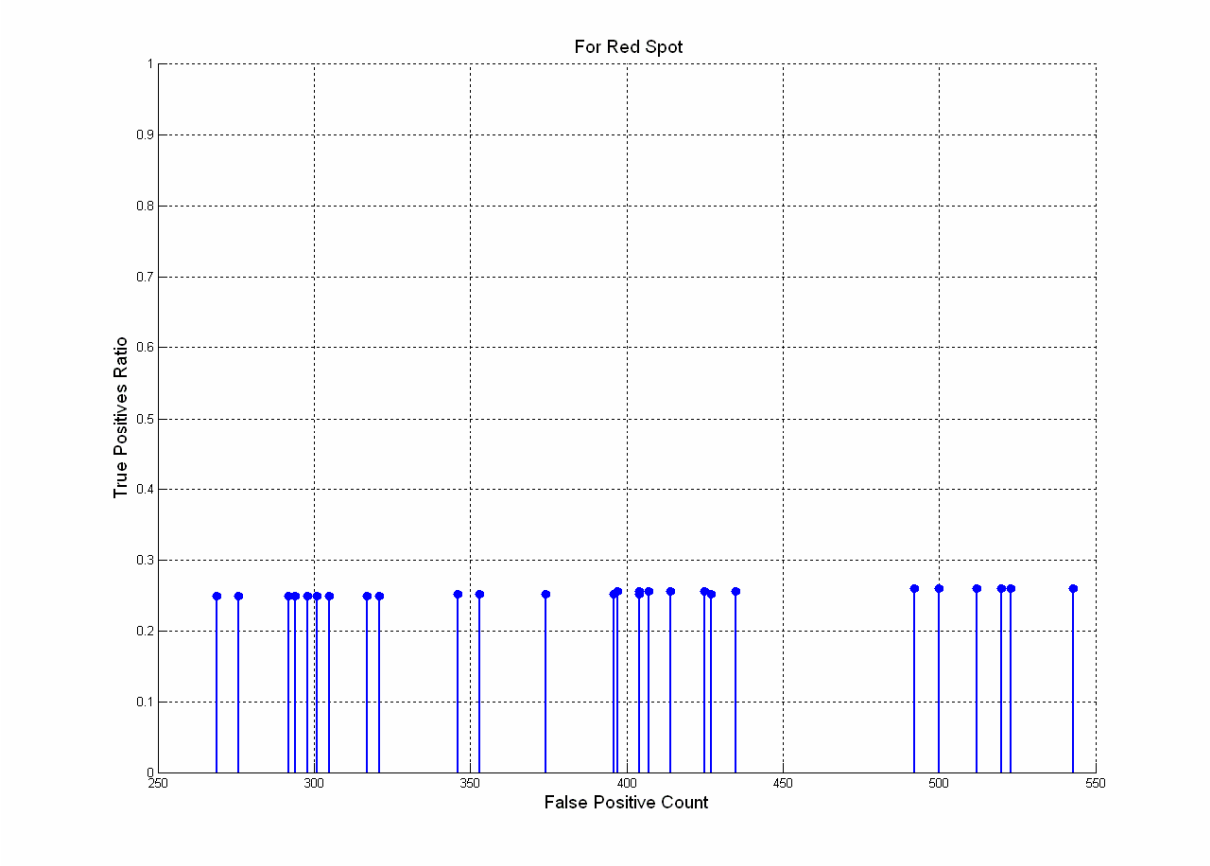


Figure 5-1, Red Spot ROC

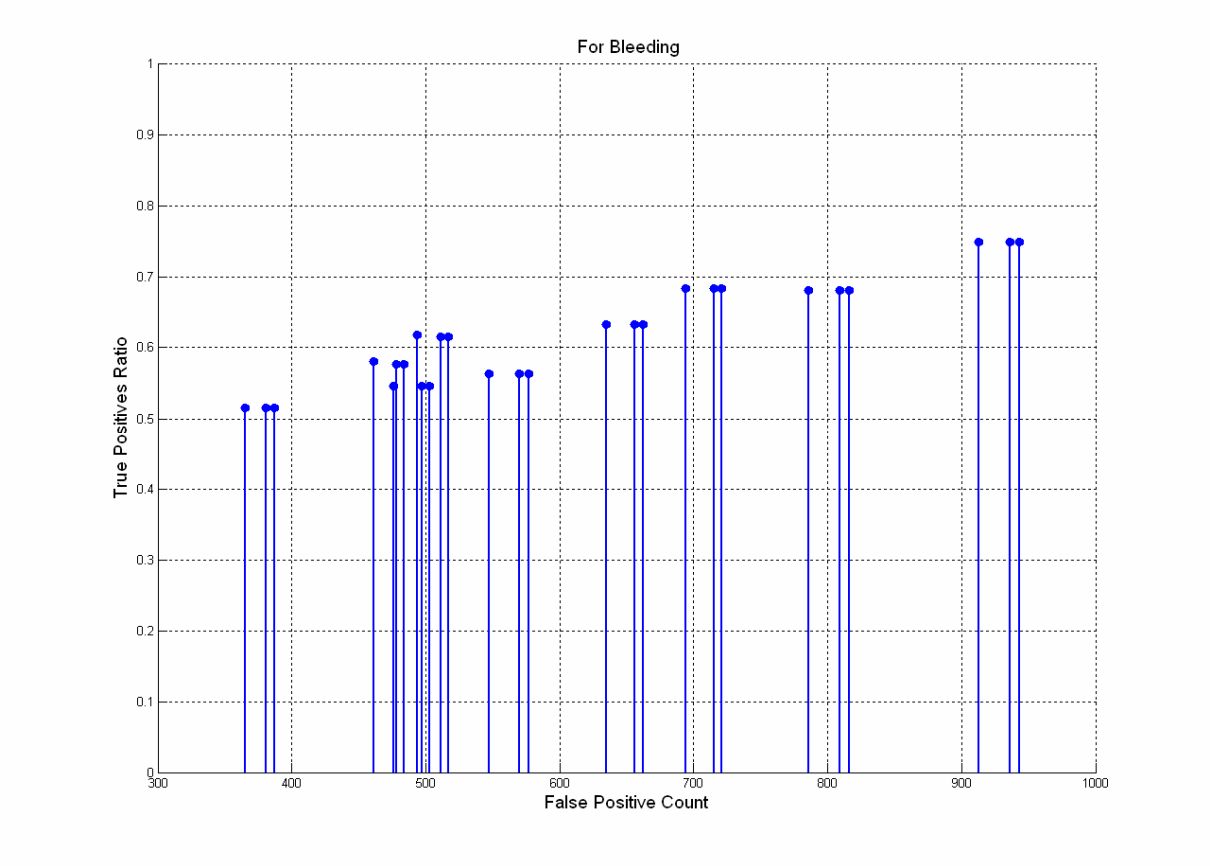


Figure 5-2, Bleeding ROC

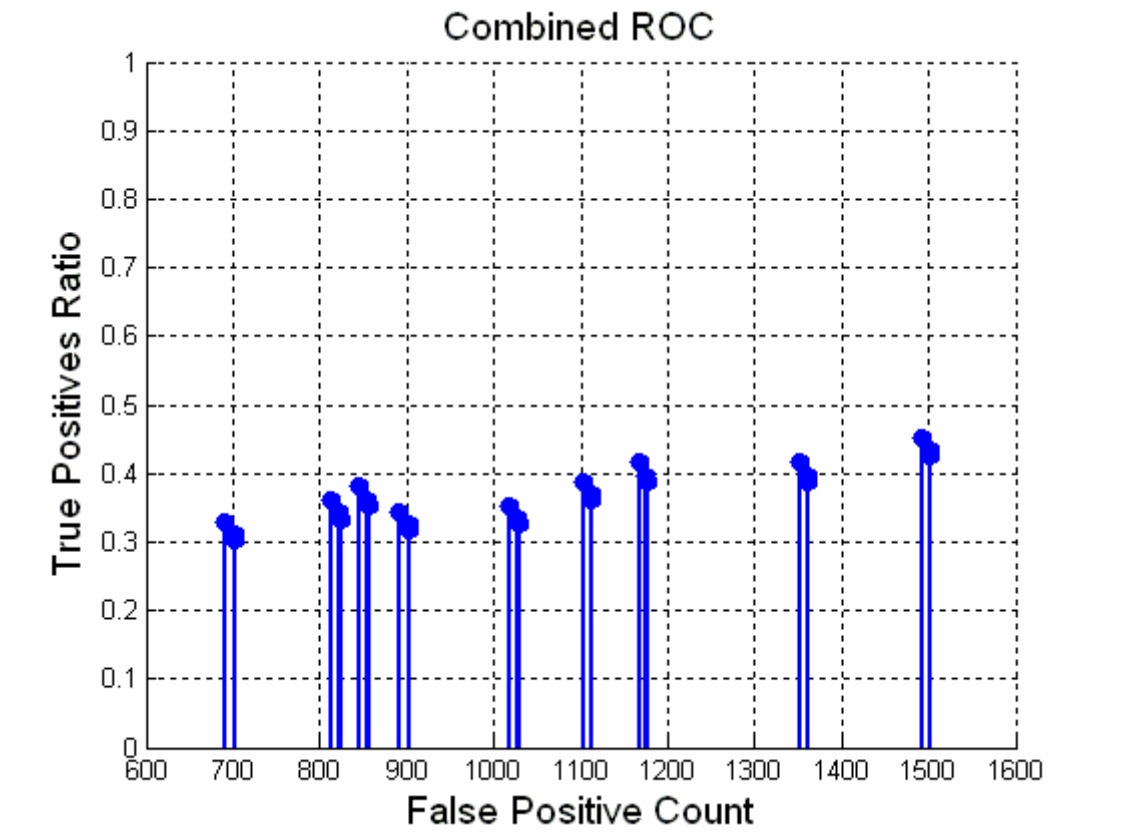


Figure 5-3, Combined ROC

5.1.2 Analysis

5.1.2.1 Classifier Performance for Red Spots Detection and Classification.

In this section, red spot detection will be analyzed, the set and values of classifiers used are:

a) Object Ratio
b) Red Spot Compact Ratio
c) Bleeding Compact Ratio

Discussion:
Each of the points in the ROC Figure 5.1 represent a set of classifier values used in the determining the best threshold value to be used for our algorithm.

5.1.2.2 Classifier Performance for Bleeding Detection and Classification

In the detection of bleeding from fundus image as carried out during this research work, the following are the set of thresholds used for the classifier:

d) Object Ratio
e) Red Spot Compact Ratio
f) Bleeding Compact Ratio

Discussion:
Each of the points in the ROC in Figure 5.2 represent a set of classifier values used in the determining the best threshold value to be used for our algorithm.

5.1.2.3 Combined Classifier Performance

In the detection of both red spots and bleeding from fundus image as carried out during this research work, the following are the set of thresholds used for the classifier:

g) Object Ratio
h) Red Spot Compact Ratio
i) Bleeding Compact Ratio

Discussion:
Each of the points in the ROC in Figure 5.3 represent a set of classifier values used in the determining the best threshold value to be used for our algorithm.

5.1.2.4 General Classifier Performance:

General classification involves classifying an image as normal or abnormal. This involves the presence or otherwise of any of the disease mentioned in the previous sections above. From this the specificity and sensitivity of the system is determined. Sensitivity refers to the percentage of abnormal fundus image classified as abnormal by the method while specificity can be defined as percentage of normal fundus image classify as normal.

Sensitivity for this algorithm is calculated to be 98% while specificity value is 61%

Discussion:
In detecting abnormalities or otherwise, the presence of at least, quantity five of the sum of the disease analyzed above, i.e. red spot or/and bleeding points in an image leads to the image being classified as abnormal image. The only exception to this is the crossover points, there are two types of vein artery crossover in fundus images, one is regarded as normal crossover point while the other is regarded as abnormal crossover. The abnormal crossing occurs when and artery crosses a vein and during the high blood pressure it presses the vein and causes a stop of the blood flow in vein. Because of this type of abnormal crossing of vein and artery bleeding can occur from vein at that point. All other types of vein-artery crossings are normal. In this work, vein artery crossings were detected only but further probing need to be done for classification.

Chapter Six

Conclusion and Recommendation

The summary of the work done is contained in this section of the report and future work to be done is also recommended in this section. The first section, section 6.1 is titled conclusion while section 6.2 is tilted recommendation.

6.1 Conclusion

As stated earlier in Chapter 1 of this report the aims of this work are:

a) Development of a system that will be able to identify patients with BDR and PDR from either colour image or grey level fundus image
b) The different diabetic retinopathy diseases that are of interest include red spots and bleeding both falls between BDR and PDR stages of the disease. While SDR types are expected to be referred to the ophthalmologist.
c) Development of a MATLAB based Graphic User Interface (GUI) tool to be used by the ophthalmologist in marking fundus images. The marked images are to be used for the development of DR grading and database system for this present and future work.

In line with the aims and objectives of this research work, this research group is able to develop a MATLAB GUI based system called CVision which is able to detect DR with a specificity of 61% and sensitivity of 98%.

Furthermore, two MATLAB based GUI's were developed for this work, the first one was used my ophthalmologist in marking images for database while the second one was used for the DR diagnosis.

Equalisation of uneven illumination of the set of provided fundus image is one of the key successes of this research work. The quality of the images provided and used in the hospital is very low and very difficult for visual manual grading by the ophthalmologists. The quality of which is firstly improved by our method of Illumination equalisation.

The second achievement of this research work include the detection of red spots and bleeding in this work, though more work still need to be done in order to reduce the error due to over enhancement of noise and misdetection in this work. This is a very good result in the diagnosis process and it shows how far the use of image processing can replace the tedious and strenuous work at our various hospitals.

6.2 Recommendation

Despite the success of this research work, more work still need to be done on

a) Crossover Points Classification: The present research work detect crossover points of various type leaving the classification as part of future work. The classification involve probing the nature of crossover points because not all crossover points are really abnormal and it only becomes a crossover points when artery is pressing the vein down and causing a blockage in flow of blood.

b) Other Diseases: Other diseases are also to be incorporated into this research work in order to complete the whole DR diagnosis. Ours only focus on red spot and bleeding, diseases like new vein growth, microaneurysm and intra retina microaneurysm will still need to be diagnosed as part of future work.

c) Research Facilities for Image Processing work: The school has to provide more research facilities for this particular work so as to complement this existing research facilities needed for this work especially provision of faster computers for image processing research work with latest MATLAB version and more profile memory provision.

APPENDIX

Thresholds

No	Threshold Name	Definition	Section	Present Value
1	WinX	Window Size along X-Axis	General	
2	WinY	Window Size along Y-Axis	General	
3	StepX	Window Step Size along X Axis	General	
4	StepY	Window Step Size along Y Axiz	General	
3	ZeroPad	Number of Zeros Pixel to be added to the edges of the image	General	
4	MinThreshold	The Minimum Intensity value to be used for Pixels outside the funsdus Area to create mask	PreProcessing	
5	MedfiltSize	Window Size for Median filtering	PreProcessing	
6	MeanZeroSize	Percentage of Zero to be allowed in a particular windowed data	PreProcessing	
7	ImageGroup	Number of Classes used for Segmentation	PreProcessing	
8	LengthofCandidateFovea	Length of the Object Candidate	RedSpot Processing	
9	CandidateFovea	Size of Candidate Fovea	RedSpot Processing	
10	RectArea	Size of candidate object	RedSpot Processing	
11	ObjectLength	Length of the Object Candidate	RedSpot Processing	
12	PixelArea	The number of pixel present in an object	RedSpot Processing	
13	Pixelhole	Test conducted to know if an obeject have an off pixel within it	RedSpot Processing	
14	ObjectRatio	Ratio of Minor to Major axis for a candidate spot	RedSpot Processing	
15	CompactRatio	Ratio of an ON pixel to the total area	RedSpot Processing	
16	FoveaLowerLimitSize	Size of Candidate lower limit size	RedSpot Processing	
17	NonFoveaLowerLimitSize	Minimum size for Non fovea limit size	RedSpot Processing	

List of Function used in this thesis work with a brief Description

Function Name	Description / Usage	Section Applicable
BackgroundSpotProcess_ver1.m	Detect and Diagnose DR background related diseases	Classifier Stage for Bleeding detection
BleedingProcess_ver1.m	Detect and remove bleeding points	Classifier Stage for Bleeding detection
Check4ProcessingPartialProcessing.m	Search for processed data, if not available then call all processing data	Main Processing
cnp5x5.m	Modified Crossover detection Algorithm	Classifier stage for Crossover detection
CVision.m	A GUI for DR Diagnosis	Main Processing
MyFinalImage.m	Show Final image without all the diseases	Image Output stage
SearchProcesedData.m	Check for processed Image Output, to avoid reprocessing data.	Main Processing
MyFinalMarkedImage.m	Show the Image with all the disease in different colours	Image Output stage
MyVeinProcess.m	For Crossover points detection	Classifier stage for Crossover detection
MyZeroPaddingRemoval.m	Remove added zero at the edges of image	Pre-processing stage
RemoveFovea_ver1.m	Detect Fovea like material and remove it	Classifier Stage for Bleeding detection
MyMainProcessing.m		Main Processing
MyRgb2Hsi.m	Convert an Image from RGB to HSI	Pre-processing stage
MyMean.m	Calculate the mean on data	Pre-processing stage
ZeroPadding.m	Add zeros to the edges of an Image	Pre-processing stage
MyWinAdaptiveEq.m	Perform Widowing and Adaptive Histogram Equalisation	Pre-processing stage
MyKmean.m	Segment data into two classes	Segmentation stage

MyFinalRedImage.m	Display Image with Redspot disease only	Image Output stage
MyCrossovers5x5.m	Main calling function for Modified Crossover points detection	Classifier stage for Crossover detection
MyAdaptiveEq.m	Perform adaptive Histogram Equalisation	Pre-processing stage
MakeThreshFileName.m	Create a threshold File name	Main Processing
ShowThisImageInBig.m	This shows the final image the	Image Output stage
ImSegment.m	Main function for Image segmentation	Segmentation stage
ImPreProcess.m	Main function for Image Preprocessing	Pre-processing stage
GetThresholds.m	Stored and make available thresholds used in other programs	Main Processing
DEL_BlackSpotProcess.m	Remove detected bleeding from the image	Classifier Stage for Bleeding detection

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