Segmentation of Blood Vessels in Retinal Fundus Images for Early Detection of Retinal Disorders: Issues and Challenges

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1 Introduction

Human eye forms a very important and integral part of the human anatomy and deserves relatively more protection and care. In addition to its essential functions, certain disorders in the human body are also reflected in the eye. Retina [1–3] is the key player in the structure of the eye and eye related disorders and their detection play a very crucial role in the field of ophthalmology. Anatomy of the eye consists of highly light sensitive cells termed as rods and cones. They are ultimately responsible for conversion of incoming light impulses into information which is consequently conveyed to the human brain through the neural system. Retina is a very sensitive and membranous coating located in the posterior portion of the eye and is concerned with focusing and impulse conversion mechanisms. Hence early detection of any disorders is crucial for preventive as wells as early treatment by the physician. If ignore it may result in permanent impairment of vision. A statistical survey by world health organization (WHO) puts the retinal disorder related ailments at nearly 4 million at start of 2017 [3]. Further survey also indicates that research in developing automated and highly intelligent systems for early detection of retinal disorders has drastically pulled down the numbers in recent years [4].

Retinal disorders could be classified into several categories. The first such disorder arises as a result of age related factors known as macular degeneration occurring more frequently in adults of age greater than 50 [5]. However macular disorders do not show immediate reflection in the vision quality as they progress very slowly. This is characterized by an area of unclear vision which gradually starts to spread out. However in extreme cases, they have also been found to affect

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quality of vision in a rapid manner. Some common methods of detection of macular disorders involve conventional eye drop test and consequent dilation test. Other techniques include florescence angiogram [6] where a colored dye is injected into the patient and analyzed for disorders as the dye passes through the retinal blood vessels. Another most common disorder is cataract which is widespread globally eventually causing blindness if left untreated. Cataracts are often related to ageing process while smoking, drinking are found to trigger the cataract formation process. Retina is made up of a rich network of arteries and veins which are highly useful in detection of eye related disorders as shown in Fig. 1.

In case of cataract, clear arteries, veins and optic disc indicate a clear eye, while an unclear vein classifies the cataract as mild. If both veins and arteries are unclear it is indicative of medium cataract while a severe cataract indicates severe cataract. Three different retinal conditions are depicted in Fig. 2 where a clear veins and arteries could be seen for a healthy eye while veins are unclear in the third case (Diabetic Retina).

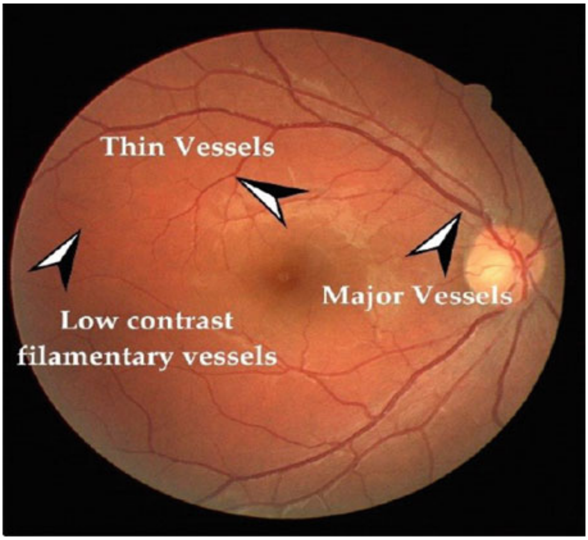

Fig. 1 Illustration of retinal nerve distribution

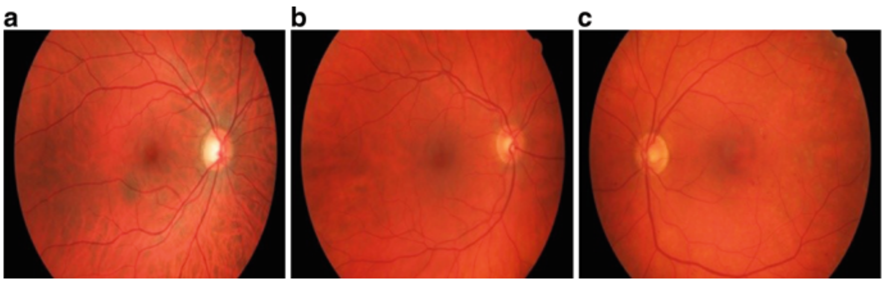

Fig. 2 (**a**) Healthy retina. (**b**) Glaucomatic retina. (**c**) Diabetic retina (HRF database)

The second case refers to Glaucomatic condition [7] where the optic nerve is progressively damaged. Glaucoma develops progressively over the years and could be treated if detected early. Based on the above points and classification of various eye related disorders, it could be found that most of retinal disorders progress slowly excluding loss of vision through physical damage. The developed systems should be capable of studying the blood vessels as they are indicators in most of the retinal disorders. The analysis should be accurate and done in the least time possible. A zero tolerance towards detection of retinal disorders is highly desirable as manual observation is prone to errors.

2 Related Works

A general retinal image detection mechanism is not a straight forward approach. It has a number of stages prior and post detection to achieve the desired objectives. The general process of retinal image detection is illustrated in Fig. 3.

As it could be seen from Fig. 3, the detection scheme involves several progressive stages namely preprocessing, enhancement through and morphological processing, extraction of features and segmentation. The extracted feature could be further utilized for classification to the target objectives.

2.1 Survey on Preprocessing Techniques

Retinal images are given as input to the automated system as fundus images and mostly prone to noise from imaging mechanism as well as jitter. The noise in these images is mostly multiplicative in nature and termed as speckle noise. Common methods of removal of speckle noise include filtering through a ask size of 3×3 by Wiener or Median filters [8]. Median filters improve the sharpness of images and rectangular patches could be selected using adaptive median filters [9, 10]. Wiener filters have a dual advantage in the sense that they can not only remove noise but

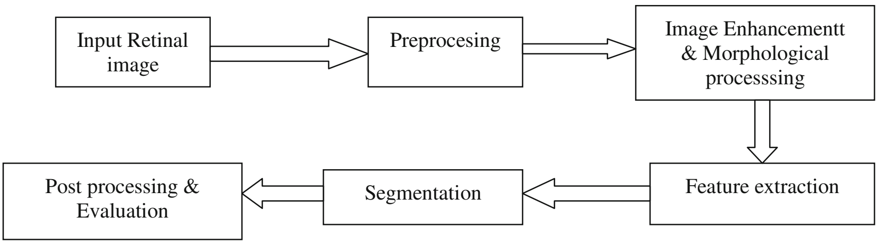

Fig. 3 Overall scheme of retinal disorder detection mechanism

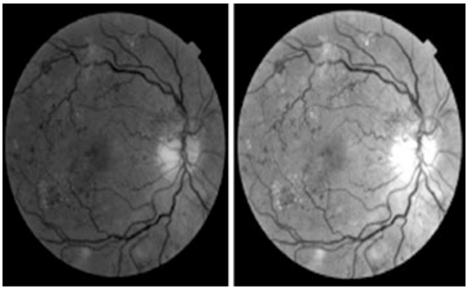

Fig. 4 Input fundus image and its preprocessed image

also retain the image content by forcing the MSE to zero. The other conventional filters such as low pass, high pass obtained through Butterworth and Chebyschev approximations could also be utilized along with homomorphic filters. An input fundus image and its preprocessed version is shown in Fig. 4.

2.2 Survey on Image Enhancement

A popular method of image enhancement is the histogram equalization [11] which redistributes the gray level intensities along the entire scale to have a uniform distribution. A modified histogram allows control of user over the enhancement parameter in modified local contrast equalization (MLCE) [12] followed by an adaptive mechanism in the form of contrast limited adaptive histogram equalization (CLAHE) [2, 8, 13] found in the literature.

2.3 Survey on Segmentation Techniques

It could be seen that the problem definition behind segmentation is due to high computational complexity in existing methods and degraded real time processing capability. Hence, system found in the literature develop new algorithm to simplify and minimize the above mentioned problem objectives. A simple form of retinal image segmentation is implemented using a two stage process namely adaptive median filtering for preprocessing and Gabor filter for feature extraction and segmentation [2, 4]. Parameter matching is employed to segment the blood vessels in the retina by comparing with the ground truth images. Accuracies of just over 95% are achieved using this method. Figure 5 depicts the input fundus image along with the next two stages of segmented image. The final image depicts the final and fine-tuned and pruned segmented image.

Threshold based methods [6, 10] have also extensively been researched in the literature where a simple separation based on a threshold value arrived at by analyzing the equalized histogram pattern is done on the retinal images. Edge based

Fig. 5 Input fundus image and segmented outputs

Table 1 Performance comparison of edge based segmentation methods

Technique	Merits	Demerits
Template matching (Prewitt) [7]	Useful for edge orientation descriptors	Estimates are not much accurate
Differential computing (Roberts) [14]	Simple in formulation and implementation	Not effective in scenarios characterized with significant levels of noise
Finite impulse response filters (Canny) [11]	Effective over a wide range of pixel variations	Not effective for all kinds of images in terms of resolution
Multivariate analysis [8]	Effective for blob detection	Causes reduction in reduction of contrast of image

methods have also been experimented in the literature a consolidated survey of edge based methods have been presented in Table 1.

Other conventional segmentation techniques include split and merge method [4] which split the given fundus image in a progressive manner until a homogeneity criterion has been achieved. Another method [14] involves subtraction of median filtered patch based images from the green channel using morphological processors like binarization, erosion, dilation, complementing and smoothing. Clusters are non-hierarchical in nature and hence do not overlap. Clusters are achieved through grouping of sub sets or classes which have some sort of similarity pattern among them. K-means clustering operates based on computing similarity based on distances with variants like Euclidean, Manhattan etc. They are found to exhibit accuracies close to 97%.

Frequency domain transforms are found to contribute significantly to segmentation with not much visual changes to the fundus images which are highly desirable especially in cases of medical images. Most well-known and effective techniques include the Wavelet transform which is composed of a network of filter banks [2, 11, 13, 15] with high pass and low pass filters. The merit lies in the fact that these filter bank structures not only segment based on the algorithm but are also quite effective in removing noise from the input fundus images.

2.4 Survey on Optimization Techniques

Several optimization algorithms have also been discussed in the literature which includes the well-known ant colony optimization algorithm. It is analogous in working principle to the natural phenomena of ants collecting their food. The behavioral pattern of ants for collection of food gatherings from one place to their destination is taken as the motivation behind the problem formulation for the optimization problem. A Kohonen self-organizing structure is found in the literature which also provides reduction in data dimension utilizing a single feed forward with each node of the input connected to every other node in the output layer. The output is generalized to two outputs namely normal and malicious packets. Other implementations include the recurrent neural network known as Elman neural network [10, 14] in which every neuron in a particular layer receives input from every other neuron in the network. They do not follow a layered arrangement and experimental observations indicate a good convergence but at the cost of increased computational cost.

Hybrid approaches have been proposed in the literature by combining Fuzzy C [11] means with artificial bee colony optimization (ABC) which is a nature inspired algorithm. ABC is used to compute the global cluster centre. The method has been tested on DRIVE and STARE databases exhibiting superior performance measured in terms of accuracy, sensitivity and specificity.

2.5 Evaluation Metrics

This section briefs a list of evaluation metrics used for retinal image segmentation. Metrics such as False Positive Rate (FPR), average Sensitivity (recall, TPR), average Specificity (1-FPR), average Accuracy, and average Precision are used for justifying the performance of the segmentation technique. The sensitivity reflects the capability of the algorithm to detect the vessels' pixels, whereas the specificity determines the ability of the algorithm to detect non-vessel pixels.

$$\text{Sensitivity} = {TP}\Big/{(TP + FN)} \tag{1}$$

$$\text{Specificity} = {TN}\Big/{(TP + FN)} \tag{2}$$

$$\text{Accuracy} = {(TP + TN)}\Big/{(TP + FN + FP + TN)} \tag{3}$$

$$\text{Precision} = {TP}\Big/{(TP + FP)} \tag{4}$$

where *TP* is True Positives, *FP* is False Positives, *FN* is False Negatives, and *TN* is True Negatives.

3 Findings of the Survey

The various inferences derived from this literature survey are as follows:

- Conventional methods of detection of retinal disorders are manual by nature and often prone to error hence necessitating the need for automated systems.
- Less emphasis is provided on feature extraction techniques based on textural features.
- Very few works are based on soft computing techniques for anatomical structure detection.
- Combination of textural based features and anatomical structure based features are very rarely used.
- Most of the works are based on only anatomical structure identification and no emphasis is given on disease classification techniques. In the very few pathology identification techniques, most of the experiments are based on bi-level classification systems which are not sufficient to prove the capability of the proposed approach.
- Artificial Intelligence techniques are rarely used for the retinal image processing applications.

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