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Research Perspective Review on Retinal Blood Vessel Detection

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Abstract. Retinal blood vessel detection is the emerging research field in digital image processing genre. It plays a vital role in medical imaging. In this paper, a review and study is made on human retinal blood vessel detection techniques in the research perspective. The most of the work focused in domain of medical industry. The identification and detection of this disease was carried out the commonly available techniques such as features extraction techniques, mathematical algorithms and artificial neural network classifiers. According to the performance and computational level, the analysis is made based on exactness of extraction of vessels.

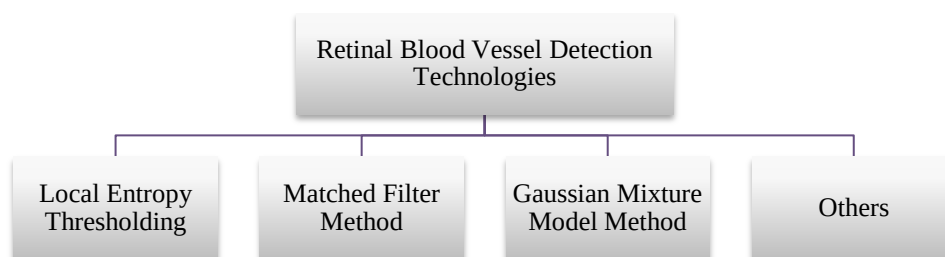
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I. Introduction

Diabetic retinopathy is major cause for visual loss and visual impaired vision worldwide. A proper detection and treatment of this disease is needed in time. In the past few years, many approaches have been used for the identification and detection of this disease using some features extraction techniques, mathematical algorithms and artificial neural network classifiers which has some drawbacks in preprocessing, extraction of appropriate features, blood vessels extraction and in the selection of the classification techniques.

The main cause of diabetic retinopathy (DR) is abnormal blood glucose level elevation, which damages vessel endothelium, thus increasing vessel permeability. The first manifestation of DR is tiny capillary dilations known as micro-aneurisms. DR propagation also causes neovascularization, hemorrhages, macular edema and in later stages of retinal detachment. Optic fundus has been widely used by the medical community for diagnosing vascular and nonvascular pathology. The inspection of the retinal vasculature may reveal hypertension, diabetes, cardiovascular disease, and stroke. Diabetic retinopathy is a major cause of blindness in adults due to changes in blood vessel structure and distribution such as new vessel growth (proliferative diabetic retinopathy) and requires laborious analysis from an ophthalmologist. The most effective treatment for many eye related diseases is the early detection through regular screenings. An automatic assessment for blood vessel anomalies of the optic fundus initially requires the segmentation of the vessels from the background. There are many previous works existing in segmenting blood vessels from retinal images. Figure 1 shows the general classification of the retinal blood vessel detection techniques.

Figure 1. The general classification of the retinal blood vessel detection techniques.



The extraction of human retina is generally carried out using Local Entropy Thresholding, Matched filtered method, Gaussian mixture method and others method such as Gabor Wavelet, Hough transformation, Neural Network method, etc.

A. Local Entropy Thresholding

In a match-filtered retinal image, the enhanced blood vessels are usually very sparse and it is compared with the uniform background. This leads to a highly peaky co-occurrence matrix with low entropy that is not appropriate for local entropy thresholding. The local entropy thresholding method aims to maximize the local entropy of foreground and background without considering the unbalanced proportion between them. Therefore, the blood vessels extracted by the original local entropy thresholding method are usually not complete and some detailed structures are missed. Therefore two modifications are introduced to improve the results of blood vessel extraction that is essential to increase the performance of algorithm. First, the co-occurrence matrix definition is

modified to increase the local entropy. The co-occurrence matrix of an image shows the intensity transitions between adjacent pixels. The original co-occurrence matrix is asymmetric by considering the horizontally right and vertically lower transitions. Here, some jittering effect is added to the co-occurrence matrix that tends to keep the similar spatial structure but with much less variations. Then by considering the sparse foreground, the optimal threshold is selected. The original threshold selection criterion aims to maximize the local entropy of foreground and background in a gray-scale image without considering the small proportion of foreground. Therefore, selecting the optimal threshold that maximizes the local entropy of the binarized image indicating the foreground/background ratio is determined. The larger the local entropy, the more will be the balanced ratio between foreground and background in the binary image [38].

A model based method was presented by K.A. Vermeera *et al* [6] for the retinal blood vessel detection obtaining a sensitivity of 92% with a specificity of 91%. The method can be optimized for the specific properties of the blood vessels in the image and it allows for detection of vessels that appear to be split due to specular reaction. Analysis of the result of the Laplace and threshold procedure resulted in an estimation of the distance between fragments (df) of not more than four pixels. The objects were therefore dilated twice. A favorable solution to the detection of blood vessels was found by using the method proposed by Edgardo Felipe-Riveron and Noel Garcia-Guimeras [8]. To extract the skeleton of the resulting vascular network, morphological thinning and pruning algorithms were used. But the presence of noise can affect the detection in some degree and the false detection of the border of the optic disk is the other drawback. Adam Hoover *et al* [5] have proposed a method for locating blood vessels in retinal images using threshold probing of a Matched Filter Response which segments roughly 75% of the vessels in a retinal fundus image with a false positive rate comparable to a human observer. The problem with this approach is that the property of connectedness is not compared in their evaluation.

A novel local adaptive thresholding algorithm for detecting retinal blood vessel was proposed by Yongping Zhang *et al.* [11] using the nonlinear orthogonal projection to capture the features of vessel networks. The experimental results indicate that there is a common suited parameter for the procedure of nonlinear projection to all images used and more than 96 percent of pixels have been correctly classified for the images from the DRIVE and the STARE databases. Some methods suffer from the problems of heavy computation and manual intervention like the one proposed by Lili Xu and Shuqian Luo [17] for blood vessel detection in retinal images based on the adaptive local thresholding that produces a binary image to extract large connected components as large vessels. The residual image fragments in the binary image including some thin vessel segments (or pixels). The proposed algorithm is tested on DRIVE database, and the average sensitivity is over 77% while the average accuracy reaches 93.2%.

Blood vessel segmentation method for high resolution retinal images was presented by J. Benadict Raja *et al* [23] using enhancement threshold which enhances the speed and accuracy of segmentation process. But the speed of segmentation is not completely satisfactory as it took 3.54 minutes for segmenting 3500x3000 size image. An automatic detection of multiple oriented blood vessels in retinal images using Gabor Filters and Entropic thresholding, which performs better with lower specificity even with the presence of lesions in the abnormal images [16]. Some of the very useful techniques used for the treatment of diabetic retinopathy patients in medical imaging department in detecting Macula in digital retinal images was proposed by Maryam Mubbashar [22] using Gabor Wavelet and Thresholding. A comparative study on retinal blood vessel detection was made by Monisha Chakraborty [29]. The algorithm comprises of four steps: second derivative Gaussian function filtering, local entropy thresholding, median filtering and length filtering. Thitiporn Chanwimaluang and Guoliang Fan [39] proposed an efficient blood vessel detection algorithm for retinal images using local entropy thresholding algorithm that retains the computational simplicity and achieves accurate segmentation results in the case of normal retinal images and images with obscure blood vessel appearance. In the case of abnormal retinal images with lesions, some lesions are also misdetected in addition to blood vessels. Manjunath V Gudur, Nanda [38] proposed an algorithm that is sensitive to lesions due to the fact that their boundaries partially match the shape of matched filter kernels. Even the smaller blood vessels can be extracted.

B. Matched filter method

A more robust approach to blood vessel detection is matched filter method [4]. This edge fitting based method used the concept of signal detection using matched filters to detect piecewise linear segments of blood vessels in retinal images. The cross section of a vessel in a retinal image was modeled by a Gaussian shaped curve. Blood vessels usually have poor local contrast. The two-dimensional matched filter kernel is designed to convolve with the original image in order to enhance the blood vessels. A prototype matched filter kernel is expressed as:

$$f(x, y) = -\exp\left(\frac{-x^2}{2\sigma^2}\right), \text{ for } |y| \leq L = 2 \quad (1)$$

where L is the length of the segment for which the vessel is assumed to have a fixed orientation. Here, the direction of the vessel is assumed to be aligned along the y-axis. Because a vessel may be oriented at any angles, the kernel needs to be rotated for all possible angles. A set of twelve 15x16 pixel kernels is applied by convolving to a fundus image and at each pixel only the maximum of their responses is retained. Given a retinal

image, which has low contrast between blood vessels and background, its MFR version, where blood vessels are significantly enhanced.

Two dimensional matched filter method [1] was used for detection of blood vessels in retinal images, which produces better results in analyzing fluoresce in angiogram images of the retina as well. With the minor modifications, this method could very well be extended to the extraction of the geographical features from satellite images and the enhancement of fingerprint images. The detection and quantification of retinopathy was done using digital algorithms based on filtering approach coupled with a priori knowledge about a retina [2]. It is an adaptive densitometric tracking technique based on local neighborhood information which can more accurately measure vessels widths under a broad range of diameters and clinical vessel geometries. But the centerline tracking algorithm may get confused and fail, because of the sample line location. Combination of the Matched Filter with a segmentation strategy by using a Cellular Automata method is used by Dalmau and Teresa Alarcon *et al.* [20]. The main problem with their method is in detecting thin vessels. Another difficulty is that the algorithm detects some lesions as vessels. Bob Zhang *et al* [18] proposed retinal vessel extraction method by matched filter with first-order derivative of Gaussian, which is a zero-mean Gaussian function, and the first-order derivative of Gaussian (FDOG). It has much lower complexity and is much easier to implement. Blood vessels in each quadrant are extracted by running a mask and the area is calculated and thereby ISNT ratio is obtained by K.Narasimhan *et al* [25]. The performance of the proposed system can be increased by using a classifier. The experimental results shows that a sensitivity of 90% is obtained from the predefined set of images.

C. Gaussian Mixture Model Method

To extract the blood vessels from the fundus retinal image, the Expectation Maximization (EM) algorithm was adapted and applied to a Gaussian mixture distribution of the pixel intensities. The EM performs the segmentation by classifying vessel's pixels in one class (foreground) and non-vessel's pixels in the other (background). The EM output is obtained by iteratively performing two steps: E-step, which computes the expected value of the likelihood function (pixel class membership function) with respect to the unknown variables, under the expected parameters of a Gaussian mixture model and M-step which maximizes the likelihood function defined in the E-step until convergence. The EM algorithm takes the value of a pixel's intensity as a random variable. Like other random variables, the pixel intensities of an image have a probability. Safia Shabbir *et al* [42] have presented a comparison and evaluation of computerized methods for blood vessel enhancement and segmentation in retinal images. First technique uses Gaussian filtering for preprocessing, LoG filtering for enhancement and adaptive thresholding for segmentation purpose. Second technique uses unsharp masking for preprocessing, Gabor wavelet for enhancement and global thresholding for segmentation. An automated detection and grading of diabetic maculopathy in digital retinal images was made by Anam Tariq *et al* [44] using Gaussian Mixture Model-based classifier with the low accuracy of 94.37 % as compared to 97.38 % of GMM. Usman Akram *et al* proposed a method for the identification and classification of micro aneurysms for early detection of diabetic retinopathy. A Gaussian mixture model based system for detection of macula in fundus images was proposed by Anam Tariq *et al* [35]. The results have shown the significance of the proposed system and are proved to be competitive when compared with other results in the literature. Usman Akram [27] proposed an algorithm for the detection of neovascularization for screening of proliferative diabetic retinopathy with 96.35%, 98.93% and 98.37% of sensitivity, specificity and PPV respectively. Segmentation of retinal blood vessels using Gaussian mixture models and expectation maximization was tried by DjibrilKaba *et al* [40] for matched filter response image using the Expectation Maximization algorithm. It has an advantage over other tracking-based methods because it applies a two-dimensional matched filter on retinal images to enhance vessel appearance and allows multiple branches models.

D. Fuzzy C-means (FCM) Clustering Algorithm

The fuzzy C-means (FCM) clustering algorithm can be used for retinal blood vessel segmentation using gray-level and moment invariants-based features [34]. Jegatha R *et al* used SVMs classifiers that provided robust and computationally efficient blood vessel segmentation method while suppressing the backgrounds. The majority of errors were due to background noise and non-uniform illumination across the retinal images and the border of the optic disc. The method consists in the application of mathematical morphology and a fuzzy clustering algorithm followed by a purification procedure. Both qualitative and quantitative experiments on normal and abnormal retinal images indicate that the proposed approach is effective and can produce identical results as the ground truth and yield a higher accuracy ratio and a lower misclassification ratio than the manual extractions [10]. Automated detection of dark and bright lesions in retinal images can be used for early detection of diabetic retinopathy [28] [30].

E. Gabor Wavelet Transform Method

2-D Gabor Wavelet and sharpening filter can be used to enhance and sharpen the vascular pattern for preprocessing and blood vessel segmentation of retinal images performing well in preprocessing, enhancing and

segmenting the retinal image and vascular pattern [12]. Computer aided diagnostic system for grading of diabetic retinopathy was presented by Anam Tariq *et al* [43]. Although the proposed system focused only on reliable detection of abnormalities, but still the system can be used for automatic screening of diabetic retinopathy. Personal identification system based on vascular pattern of human retina was proposed by Sana Qambery *et al* [33].

F. Transformation Method

A.S. Semashko *et al* [24] used Hough transform for optic disk segmentation using blood vessels location information which outperforms many other methods and has a high rate of very good segmentations.

G. Neural Network Method

Diego Marín *et al* [15] have proposed a new supervised method for blood vessel segmentation in retinal images by using gray-level and moment invariants-based features. The total time required to process a single image is less than approximately one minute and thirty seconds but this performance might still be improved. Chanjira Sinthanayothin *et al* [3] have proposed an automated localization of the optic disc, fovea, and retinal blood vessels from digital color fundus images [25]. Blood vessels were identified by means of a multilayer perceptron neural network. The sensitivity and specificity of the recognition of each retinal main component was as follows: 99.1% and 99.1% for the optic disc; 83.3% and 91.0% for blood vessels; 80.4% and 99.1% for the fovea. Artificial neural networks have been extensively investigated for segmenting retinal features such as the vasculature was presented by Edward James, Antonio Francisco [36]. As supervised methods are designed based on pre-classified data, their performance is usually better than that of unsupervised ones and can produce very good results for healthy retinal images. M. S. Sidhu *et al* [19] used Femtosecond (fs) laser microsurgery using neural network method. With that successfully captured and analyzed retinal blood vessel images from intact porcine eyes. This work has a potential application for progress in detecting and accurately monitoring retinal pathologies and in their surgical treatment.

H. Dijkstra's Shortest Path Algorithm

Rolando Estrada *et al* [21] have presented an exploratory Dijkstra forest based automatic vessel segmentation with an applications in video indirect ophthalmoscopy. This method is more likely to label a pixel as vascular if it can be directly connected to a large vascular region than if it is isolated, since the latter case is more indicative of noise rather than an actual vessel.

I. Combined Cross-point Number (CCN) Method

A.M. Aibinu *et al* [13] have proposed vascular intersection detection in retina fundus images using a new hybrid approach, which is able to detect the vascular bifurcation and intersection points in fundus images. A ROC-based analysis for this algorithm gives a very high precision and true positive rate with a very small false error rate.

J. Water Flow-Based Method

Xin U Liu, Mark S Nixon [9] proposed water flow based vessel detection in retinal images, which has been assessed on synthetic and real images showing excellent detection performance and ability to handle noise.

K. Centerlines and Morphological Bit Plane Slicing Method

A unique combination of techniques for vessel centerlines detection and morphological bit plane slicing is presented to extract the blood vessel tree from the retinal images producing 0.932 to 0.965 for accuracy, 0.66 to 0.83 for true positive rate, 0.01 to 0.06 for false positive rate and 0.73 to 0.89 for precision rate [31].

L. Two Dimensional Medialness Function Method

Elahe Moghimirad *et al* [32] presented a method for segmenting retinal blood vessel based on a weighted two-dimensional (2D) medialness function. A multi-scale method to segment retinal vessels based on a weighted two-dimensional (2D) medialness function. Supervised methods were presented by Ana Maria Mendonça and Aurélio Campilho [7] for the segmentation of blood vessels in ocular fundus images. The processing time of the algorithm is less than 2.5 min for an image of the DRIVE database and less than 3 min for a STARE image.

M. Heuristic Function

Ahmed Hamza Asad *et al* [37] have proposed an improved ant colony system for retinal blood vessel segmentation by applying a new heuristic function obtaining sensitivity from 0.6472 to 0.8188, specificity from 0.8883 to 0.9213 and accuracy from 0.8670 to 0.9122.

N. Curvelet Transform and Morphological Operators

Shirin Hajeb Mohammad Alipour *et al* [41] used digital curvelet transform (DCUT) and morphological operations. Experiments show that the system achieves respectively the specificity and sensitivity of (>98% and

>96%) for normal stage, (>98%, >95%) for Mild/Moderate Non-Proliferative DR (NPDR), and (>97% and >93%) for Sever NPDR+PDR.

O. Final Segmentation Mask Method

Ibaa Jamal et al [26] proposed a novel method with final segmentation mask prepaid by combining fine background segmentation mask and fine noise segmentation mask. The results are confirmed by visual inspection of segmented images taken from the standard diabetic retinopathy databases.

P. Noise Segmentation Mask Method

Anam Tariq and M. Usman Akram [14] used binary noise segmentation mask which includes the noisy area and it is applied on retinal image. Retinal image segmentation is done on the colored retinal images by extracting background and noise effect from the image.

II. Discussion

A study and analysis on the segmentation of blood vessel in retinal images using the different methods proposed by the researchers is made. The efficient algorithms used for fully automated blood vessel segmentation in ocular fundus images have been studied. Most of the algorithms performs very well in extracting blood vessels. Even the smaller blood vessels can be extracted. Matched filtering enhances the contrast of blood vessels against the background. Modified local entropy thresholding algorithm takes into account the spatial distribution of gray levels, performing efficiently in distinguishing between enhanced vessel segments and the background since it can preserve the structure details of an image. However, the presence of lesions in the abnormal retinal image is the major obstacle in extracting blood vessels since they are also misenhanced and misdetected as blood vessels. The algorithms are sensitive to lesions due to the fact that their boundaries partially match the shape of matched filter kernels. Improvement in the robustness of the algorithms can be done by involving color information and additional anatomical constraints. It is concluded that the method proposed by Chanjira Sinthanayothin et al [3] have identified the blood vessels in retina image by means of a multilayer perceptron neural network. The sensitivity and specificity of the recognition of each retinal main component was as follows: 99.1% and 99.1% for the optic disc; 83.3% and 91.0% for blood vessels; 80.4% and 99.1% for the fovea.

III. Conclusion

In this paper, survey has been made in the retinal blood vessel detection techniques, which is based on the positive rate, accuracy, extraction method and qualitative aspect of the detection. These kinds of works will help to step into the further enhancement in this domain, to attain the accurate, fastest and smartest devices. Research in this paper will adhere to the field of medicine sciences.

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