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Retinal Vascular Tree Extraction

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Abstract—*In this paper we propose an algorithm for the extraction of blood vasculature from eye fundus images followed with its complete segmentation from other retinal features. This paper focuses on the aim to simplify the computation involved in segmenting retinal images, leading to reduction in the time taken in diagnosing the retinal images for different vasculature conditions in order to recognize the disease as fast as possible. Our proposed algorithm provides accuracy much better than most of the algorithms proposed till date and its computational complexity is very low. The execution time taken by the tool to process 20 images altogether is 2.78 seconds. This proves that algorithm is highly efficient with accuracy measure of 96% and sensitivity measure of 81.07%.*

1. INTRODUCTION

Human health has always been a critical issue to deal with, so it requires participation of fully automated and highly efficient tools that can provide exact information of the scenario going inside human body within fraction of time units. Image processing techniques and algorithms have been developed that help to diagnose human health on a large scale. From old times, eyes play a vital role in the analysis of health, from checking up illness to diagnosing various diseases. So, studying of various diseases is done through the analysis of eye fundus images. This analysis can be done by computation of certain parameters in accordance to the structures or objects present in the image [1]. When carried out manually by the experts, it utilizes too much time due to which very few patients can be diagnosed per day, and this manual diagnosis is also prone to errors. Thus, with the advances taking place, there exists a need to improve the existing methods and automate them completely with the reduction in time taken in diagnosing.

Retinal image analysis is increasingly prominent as a nonintrusive diagnosis method in modern ophthalmology [2]. The morphological information obtained from retinal images play an important role in detection of the problem and determining the severity of diseases. This morphological information is acquired by the extraction of blood vessels and other parts from eye fundus images which can be achieved through segmentation and other image processing techniques. Blood vessels are of greater importance for the diagnosis as their features like color, size, shape, diameter, tortuosity help determining the symptoms of diseases such as diabetic retinopathy, hypertension, glaucoma, hemorrhages, vein occlusion, neovascularization etc. [2].

Many methods of segmentation have been employed till date but with the advances in technology and requirement of human life there exists a need for the development of a highly efficient technique that can provide the exact information about the disease and perform the tests accurately thus evaluating the results in fraction of seconds to ease the procedure of screening. Our work is dedicated to such a screening technique. Here an algorithm is proposed that acquires an eye fundus image and performs some operations for the extraction of retinal blood vessels, thus resulting into their segmentation. Section II gives a review of related work. Section III introduces the methodology followed by the proposed algorithm. In section IV, results obtained after the implementation of the proposed algorithm are shown, followed by the Section V that summarizes the work.

2. RELATED WORKS

Zhun Fan et. Al. [3] in the first stage performed morphological reconstruction to enhance contrast, adaptive median filter was applied on green channel image. A sum of top hat transformation was applied to enhance vessels in each direction. Then image was divided into three regions via thresholding, regions namely, preliminary vessel region, background region and undetermined region. Considering preliminary vessel region, extraction of vessel skeleton through an isotropic un-decimated wavelet transform (IUWT) was done. Global thresholding gave binary image and again image was divided into three regions namely, background region, candidate region, vessel region. On the basis of area feature for connected regions, vessel region was preserved and vessel extraction was performed. Finally preliminary vessel region was combined with vessel skeleton and vessel image was obtained. Further, in second stage, image obtained from stage 1 was processed through Hierarchical Growth Algorithm (HGA). This algorithm labelled pixels that were left undetermined in stage 1 as vessel and non-vessel. It checked the pixels one by one in an incremental manner and finally updates the labels for pixels in a hierarchy. Post-processing as the final step removes non-vessel regions estimated through defined parametric condition.

Gehad Hassan et. Al. [4] in his work proposed a system divided into two phases, preprocessing phase and classification phase. Mathematical morphology was used as the preprocessing step to reduce noise and smooth image. An opening operation is performed considering a linear structuring element followed by a top-hat transform implementing at 12 directions and summing up all responses achieved from 12 directions. This increased difference between background and vessels. Then a Gaussian filter was applied to further smooth image. In the classification phase, k-means clustering was used to minimize variance and exactly determine vessels.

Ain Nazari et. Al. [5] in his work primarily removed drawbacks in color fundus image by converting RGB color image into intensity channel of HIS color space, retaining important information from red and blue channels by average of red, blue and green channel. Histogram equalization was performed to enhance contrast then a mean filter was applied with Gaussian parameters to homogenize image for noise. A 59*59 filter was used to reproduce background image and then background image is subtracted from Gaussian image to complete homogenization. A morphological operation namely Top hat was applied on the image to brighten vessels from other components in image and remove all other not required components. This also led to generation of false vessel detection. Thus, multiscale detection was done and was merged with resultant of preprocessing phase.

Yu Quian Zhao et. Al. [6] proposed a segmentation method that uses histogram equalization technique called CLAHE and 2D Gabor Wavelet transform in the preprocessing of image to enhance the blood vessels, then for the segmentation, an anisotropic diffusion filter is applied followed by the level set method and region growing. Then the results from the level-set and region growing are added to provide the segmentation of thinner vessels as well.

Yanli Hou [7] in preprocessing stage considered inverted green channel image and background homogenization was performed on it with the help of mean filter and Gaussian kernel. Then vessel enhancement was performed through morphological Top hat transformation using line structuring element set with length of 21 pixels and each at 22.5° followed by their summation. This gives normalized image without optic disc then an improved multiscale line detection method was introduced for vessel measure. To eliminate effect of noise produced by line detector at smaller scales, the line responses of all line detectors implemented at different scales were combined. This produced a softly classified image. Finally, image was thresholded and converted to binary, pixel area was measured and reclassified for falsely detected vessels.

Nidhal Khdhair El Abbadi et. Al. [8] obtained green channel image from RGB image. In the enhancement phase, all image pixels were scanned, labels were assigned to non-zero pixels and recorded equivalent labels, then equivalence classes were resolved using Union Find Algorithm and then pixels were relabeled on the basis of classes. Maximum area was computed and boardered with white board. Background was converted to white and CLAHE was applied to equalize certain effects. Gaussian filtering was used, then to extract details from image Top hat was used. Further image intensity was adjusted and binary image was achieved. Finally, morphological operation was used to filter image and remove noisy details. Opening was done followed by opening-closing reconstruction to remove small blemishes from image. Then labelling was done to recognize blood vessels. Finally watershed transform was to obtain centerline of blood vessels. This completes segmentation of blood vessels.

Mahdi Amiri et. Al. [9] used Gabor Filter for vessel detection. Grayscale image equalized by applying CLAHE. Sharpening was done to enhance edges of vessel. Then a 30x30 median filter was used for removing background. Finally, in post-processing morphological reconstruction was applied to precise the results.

D. Siva Sundhara Raja [10] proposed a system with an accuracy of 1. In this system green channel component is extracted from fundus image and it is then enhanced using morphological dilation and erosion. Then an image with absolute difference is obtained by subtracting retinal image from processed image. Finally SVM classifier is applied to extract the required features.

Yogesh M. Rajput used 2D [11] median filtering for segmentation. In his work, green channel image was complemented and histogram equalization was performed with minimum cumulative distribution function, then morphological opening was carried out for vessel thickening followed by dilation and erosion. After it 2D median filter was used to remove noise and extract vessels.

M. Usman Akram et. Al. [12] Inverted green channel image with enhanced vessels image was obtained, followed by 2D Gabor Wavelet for thinner vessels. Gabor wavelet used here employed 2D Continuous Wavelet Transform (CWT) and Fast Fourier Transform (FFT) algorithm. Then multiple thresholds were applied one by one. A maximum value of threshold was taken, vessels having response higher than that were tracked. Thinning was done followed by filtration to produce only one pixel wide vessels. Finally, binary image was obtained by adaptive thresholding technique.

Diego Marin et. Al. [13] In the preprocessing phase, vessel's central reflex and uneven illumination was reduced using Gaussian kernel. Top hat transform was applied to enhance vessels then image pixels were classified as vessels and non-vessels based on 7-D feature vector. A multilayer feed forward neural network classifier was employed for further classification with feature vector as its input. The vessels pixels containing gaps were completed by filling in post processing and also falsely detected pixels were processed and removed.

Danu Inkaew et. Al. [14] primarily worked on finding gradient vectors. They used the concept of dependence of unit vectors upon the image features, unit vectors uses image features intensity to converge or diverge. Image features viz. linear and circular features were found in gradient orientations using discontinuity magnitude and Sobel operator at three scales followed by summation results from three scales. Finally, thresholding was applied with morphological operations to obtain segmented retinal blood vessels.

M. Akram et. Al. [15] proposed a method focused on preprocessing phase where enhancement was carried out including low contrast, improper illumination, and other objects except blood vessels were eliminated. In the processing phase, 2D Gabor Wavelet was used due to its orientation and frequency selectiveness feature. Image blurring occurred by Gabor was overcome by applying sharpening filter. Then a Canny Edge Detection was done to enhance vessels and gaps were filled by morphological dilation operation.

3. MATERIAL AND METHODOLOGY

The methodology considered for retinal blood vessel segmentation in our work is based on filtering the undesired components one by one from image, thus finally obtaining the desired retinal vasculature tree and further intensifying obtained vessels to achieve the exact vasculature condition. The algorithm preprocesses eye fundus images to estimate and normalize the undesired objects from the image that are a cause of distraction to certain tests to extract vessels. The over brightness of optic disc, contrast mismatch of macula and fovea with vessels and background texture are the main components that interrupt with retinal blood vessels segmentation. In the processing stage, such objects are removed from image with the help of Hat transform that basically processes the image based on the structuring element, this structuring element defines the component to be extracted by removing all other components or vice-versa in its second converse form. In final stage i.e. post-processing, segmented blood vessels that were left unchanged are enhanced and intensified. This is done due to the reason that after segmentation process, vessels obtained are lesser connected at ends and smaller vessels with low contrast are not clearly visible. Thresholding followed by morphological filtering technique involving the area connectivity algorithm is done to achieve final results.

The dataset used for evaluating the proposed methodology is public dataset DRIVE [16]. It contains 40 images of size [584x565] pixels.

4. IMAGE PRE-PROCESSING: ENHANCEMENT

In this phase, the retinal eye fundus image is acquired and is broken down into respective red (R), green (G) and blue (B) components. It is analyzed that green channel component shows optimum intensity, and the blood vessels are clearly visible in green channel image [17]. So, considering green channel image and the presence of various other components that are not of interest, the image is normalized on the basis of histogram equalization. For this, Contrast limited adaptive histogram equalization (CLAHE) is used. In CLAHE, smaller regions are considered and region wise image contrast is enhanced based on cumulative density function (CDF) and probability density function (PDF) [18], [19]. This results in highlighting the blood vessels in contrast with other components present in eye fundus image. This difference in contrast of blood vessels with respect to background is helpful for extracting vessels in further processing steps.

5. REMOVAL OF UNDESIRED OBJECTS

For extraction of blood vessels, it is necessary to remove all other unwanted objects present in image. In order to achieve this, we implemented hat transform.

Hat transform being the morphological operator are capable of removing unwanted structures from images and extracting details. They are of two types, namely, Top Hat Transform aka White Hat Transform and Bottom Hat Transform aka Black Hat Transform. Here Bottom Hat Transform is used. It works by subtracting image from the image that is obtained after being processed through morphological close operation. This gives an image containing objects of input image that are darker. Here image produced by CLAHE in preprocessing step takes its advantage of contrast difference and produces resultant that have blood vessels differentiated from background. The morphological close operation uses a structuring element that defines the object that is to be extracted from image. In our work we have used Bottom Hat transform with a disc shaped structuring element for the extraction and removal of optic disc, macula and fovea [20].

Then sharpening filter is used and image sharpening is done to enhance the structures contained in the image that get blurred after certain processing. It employs an un-sharp filter that subtracts an un-sharp or smoothed image from original image [21]. This produces an image exhibiting brighter objects with pixels of higher intensity.

Further global thresholding is done on the image obtained after sharpening and binary image is obtained. The image obtained from sharpening is converted into binary image using Otsu's method [22].

6. MORPHOLOGICAL FILTERING

Output of binary conversion still exhibits some discrepancies among the extracted blood vessels that are not ignorable. Sharpening also lead to enhancement of other smaller components that were not of interest. Therefore morphological reconstruction is carried out on image to overcome those discrepancies and match the results with the idealities. Under this, area opening is performed. A pixel value is defined and the objects having pixels lesser than that are removed [23].

The step-wise implementation of methodology is given below followed by the figures of each stage of implementation.

1. Image acquisition: Retinal eye fundus image was taken from Data Set mentioned in section (3).
2. Extraction of RGB Components: Red, green and blue channels were extracted from acquired true color image. It was converted to grayscale for easing the further process of segmentation. Respective red, green and blue channel images are shown in fig. 1.
3. Image enhancement: After conversion into grayscale, image enhancement was done using CLAHE over each channel image. This enhanced contrast of images thus highlighting blood vessels making their visibility darker with respect to background.
4. Hat transform: This step involved removing parts like macula, fovea, optic disk etc. from image acquired from enhancement and extraction of blood vessels is achieved.
5. Image Sharpening: This was done to improve the visibility of the blood vessels that were smoothed undergoing certain operations.
6. Grayscale to binary conversion: Image was converted into the array of 0’s and 1’s to segment the blood vessels from the background. This was done by global thresholding, giving up binary image.
7. Morphological Reconstruction: Finally, image was cleaned using area opening morphological filtering operation to finally produce the image with segmented retinal blood vessels only.

7. METHOD EVALUATION METRICS

Quality evaluation of segmentation methods is done using following parameters:

True Positive (TP) - pixels correctly detected blood vessels; False Positive (FP) - non-blood vessel pixels detected as blood vessels; True Negative (TN) - non-blood vessel pixels correctly identified as non-blood vessels; False Negative (FN) - blood vessels pixels that are not detected.

These parameters are combined by the evaluation function called accuracy, sensitivity and specificity given by

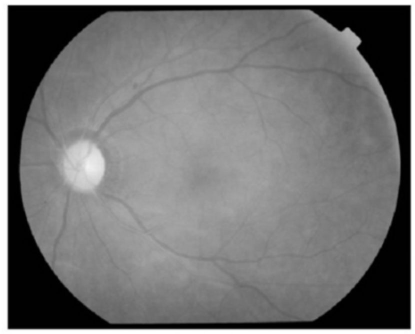
$$Accuracy(acc) = \frac{(TP + TN)}{(TP + FN + TN + FP)}$$

$True\ \ Positive\ \ Rate(TPR) = \frac{TP}{TP + FN}$, also called Sensitivity (Se), and

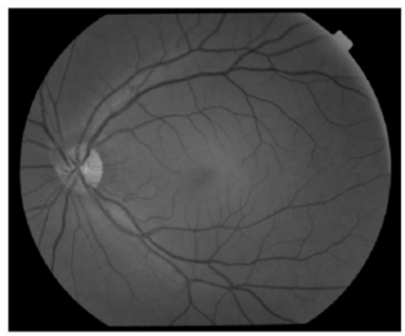
$True\ \ Negative\ \ Rate(TNR) = \frac{TN}{TN + FP}$, also called Specificity (Sp).

These metrics compares the segmentation results of the proposed method with the standard reference image, also called ground truth image that are provided by the ophthalmologists by manual segmentation of the retinal blood vessels in eye fundus images.

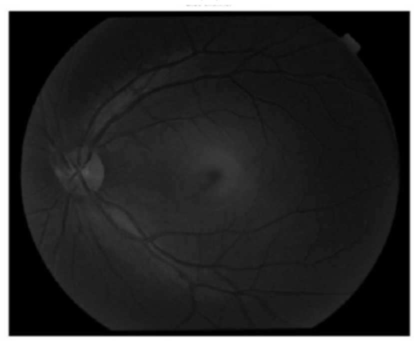
8. IMPLEMENTATION RESULTS OF PROPOSED METHODOLOGY



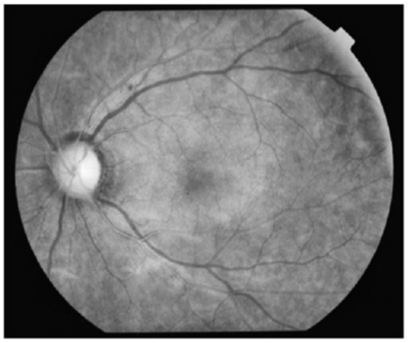
(a)



(b)

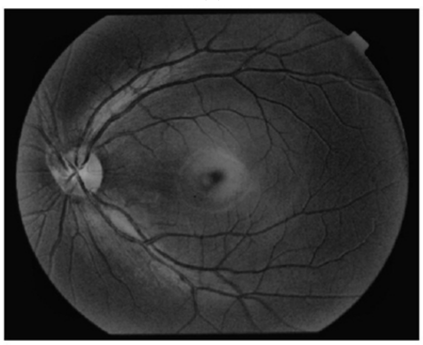


(c)

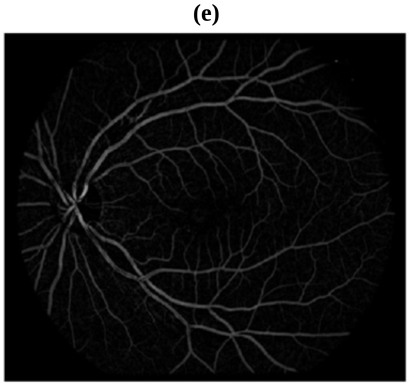


(d)

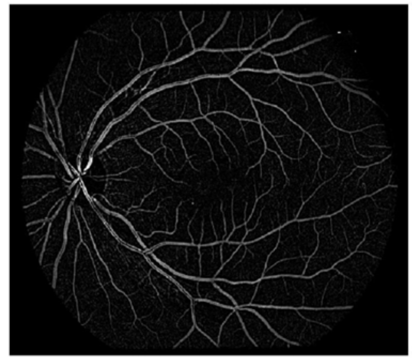
(e)



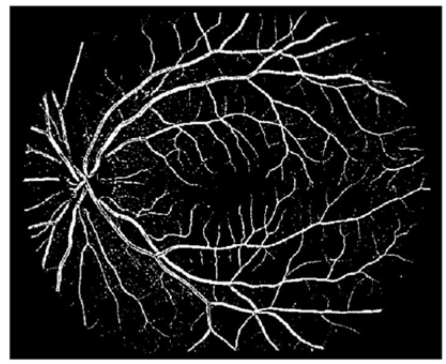
(e)



(f)



(g)



(h)

Fig. 1. Retinal blood vessel segmentation method on image. (a) Red Channel Image (b) Green Channel Image (c) Blue Channel Image (d) Image showing CLAHE operation performed on red channel image (e) CLAHE operation performed on green channel image (f) CLAHE operation performed on blue channel image (g) Hat transform implementation on image, showing extracted retinal blood vessels left after removal of optic disc, macula, fovea and other undesired objects in image (h) Enhanced image obtained by applying sharpening filter upon Hat transformed image (i) Grayscale to binary conversion of sharpened image.

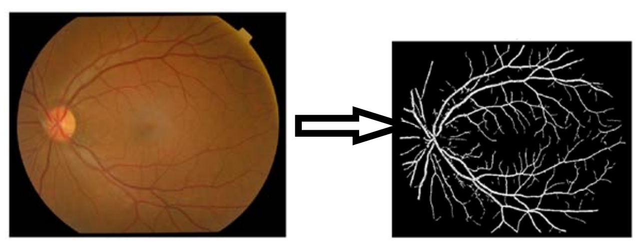


Fig. 2. (a)Original true color retinal fundus image [16]. (b) Segmented retinal vasculature tree obtained after implementation of proposed methodology

9. CONCLUSION

The method was quantitatively evaluated using Digital Retinal Images Data Set DRIVE that has been provided publicly for the researchers to evaluate their work regarding segmentation of blood vessels in retinal images. The images are of a 45 degree field of view (FOV). The FOV of each image is circular with a diameter of approximately 540 pixels [16]. The proposed work was evaluated using this dataset. Evaluation proved that the algorithm is highly efficient in performing the segmentation of huge number of digital images altogether within fraction of seconds. The accuracy achieved in segmentation of blood vessel is 96%, sensitivity of 81% and specificity of 96%. The time taken by the proposed method in complete segmentation of retinal blood vessels was 2.78 seconds for 20 images.

Algorithm for the segmentation of retinal vasculature tree was proposed. The purpose of the work was to develop a method that can efficiently work on huge databases to fasten the screening process of eye fundus images for detection of various diseases. Also the existing algorithms are very much complex that takes up too much time in processing large datasets so this would be helpful in the timely treatment of the detected disease and the accuracy of result will provide the exact area affected by the disease. The proposed method is much lesser in complexity and is very fast as compared to other methods proposed till date.

For the future work we will work on studying the screening of various diseases through analysis of retinal vasculature extracted.

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