Automated Hypertensive Retinopathy Detection from Fundus Retinal Images

Syed Nakib Hossain, Shamman Noor, Raufur Rahman Khan, Prottay Debnath, Shafi Uddin Siddique, Kazi Rezaul Karim

Department of Electrical and Electronic Engineering, Bangladesh University of Engineering and Technology, Dhaka-1205, Bangladesh

Absract—**In this paper, we propose an "Automated Hypertensive Retinopathy Detection Method" which can detect the stages of Hypertensive Retinopathy (HR) by processing a fundus retinal image. The simplicity and fast response of Morphological Image processing algorithm is exploited to pre-process and extract desired features from the retinal images. For the implementation of our algorithm, images from publicly available database DRIVE are used for feature extraction and disease detection. Contour detection and area thresholding methods are used to segment vessels in the retinal images. Using the extracted features, Arteriovenous ratio (AVR) is calculated to diagnose HR. Our proposed method of HR detection ensures recognition of four grades of the disease: grade 1, grade 2, grade 3 and grade 4. Automatic detection characteristic of our algorithm ensures flexibility as it can successfully operate on a wide range of retinal images without the need for modification. Overall, the proposed system can be very useful for diagnosing Hypertensive Retinopathy effectively and can prevent blindness.**

Keywords—Hypertensive Retinopathy, Arteriovenous Ratio, Fundus Image, Contour Detection, Disease Diagnosis, Morphological Image Processing

I. INTRODUCTION

Hypertensive retinopathy is a condition characterized by a spectrum of retinal vascular signs in people with elevated blood pressure and it leads to permanent blindness. Numerous studies have confirmed the strong association between the presence of signs of hypertensive retinopathy and elevated blood pressure [1]. Numerous changes in retinal vessels are noted with hypertension, some of which are arteriolar narrowing, caliber irregularity, alterations of the light reflex, and hiding of the arterial blood column [2]. Hypertensive retinopathy predicts coronary heart disease (CHD) in high risk men, independent of blood pressure and CHD risk factors as retinal micro vascular changes are markers of blood pressure damage [3]. In [4], it is indicated that Hypertensive Retinopathy leads to systematic morbidity and mortality. Here, indicators of mild and moderate cases of Hypertensive Retinopathy are pointed out. Mild cases are characterized by retinal arteriolar narrowing and nicking of arteries and veins and vascular diseases in some cases. Moderate case of the disease is associated with the presence of micro aneurysms, haemorrhages and soft exudates that may result in cardiovascular diseases and congestive heart failure. This is characterized by the narrowing of blood vessels, leakage of fluid from the vessels, swelling of macula and optic nerve and presence of hard and soft exudates. Hypertension is also associated with systematic target organ damage and Retinopathy is considered one of the indicators of target organ damage [5]. The classification of Hypertensive Retinopathy into different grades according to the severity of the disease is presented by Walsh *et al.* [2]. Here, Hypertensive Retinopathy is graded according to the severity of the disease. Four grades of the disease are defined: Grade 1, which is known as mild Hypertensive Retinopathy; Grade 2 is moderate Hypertensive Retinopathy; Grade 3 is a combination of Grade 1 and Grade 2 and finally Grade 4, known as accelerated Hypertensive Retinopathy. Fundus images are processed through the Image processing algorithm for feature extraction. The Arteriovenous Ratio (AVR) is used [6], [7] as a useful feature for the detection of the stages of Hypertensive Retinopathy which indicates the width of vessels in retinal image. The Arteriovenous Ratio for different severity levels of the disease is highlighted in Table I.

II. PROPOSED METHOD

The four main parts of the proposed method are Image Pre processing, Image Segmentaion, Optic Disc Detection and ROI Selection, AVR (Arteriovenous ratio) Calculation. Images are collected from the publicly available database DRIVE. The image processing tool that used in this paper is a free and non-commercial Intel Open Source Computer Vision Library (OpenCV). The flow diagram of our proposed method is illustrated in Figure 1.

A. Pre-processing:

The pre-processing starts by separating an image from the database into its green, red and blue channel. For the purpose of our method, only green channel was selected because it contains less noise which offers advantage over blue and red channel. Next, Contrast Limited Adaptive Histogram Equalization (CLAHE) was performed which limits the over amplification of noise by limiting contrast enhancement of Adaptive Histogram Equalization (AHE). It is achieved by clipping the histogram at a predefined value before computing the neighborhood Cumulative Distribution Function (CDF) of a given pixel. The difference between CLAHE and traditional histogram equalization is that CLAHE clips the histogram using a limit.

TABLE I. ARTERIOVENOUS RATIO (AVR) FOR DIFFERENT SEVERITY LEVELS OF DISEASE

Arteriovenous Ratio (AVR)	Severity of the disease
0.667-0.75	Normal People
0.5	Grade 1
0.33	Grade 2
0.25	Grade 3
greater than 0.25	Grade 4

The value at which the histogram is clipped depends on the normalization of the histogram and thereby on the size of the neighborhood region of that given pixel. Overall, by applying CLAHE on the image the dynamic range of the image is increased. After equalization, the resultant image is inverted so that the vessels now appear brighter than the background. After inversion, top-hat transformation was applied to reduce the effect of background. There exist two types of top-hat transformation: white top-hat and black top-hat transformation. The white top-hat transform is the difference between the input image and its morphological opening by a given structuring element. The black top-hat transform is the difference between the input image and its morphological closing by a given structural element. In our proposed method, white top-hat transform is applied.

B. Segmentation of Vessels:

Segmentation is the most important part of the proposed method. It refers to the labeling of a pixel as vessel or non-vessel pixel, that is, whether a pixel is situated in a region of vessel or not. Adaptive thresholding method is first used to obtain binary image as output, where all its pixel values are either one or zero.

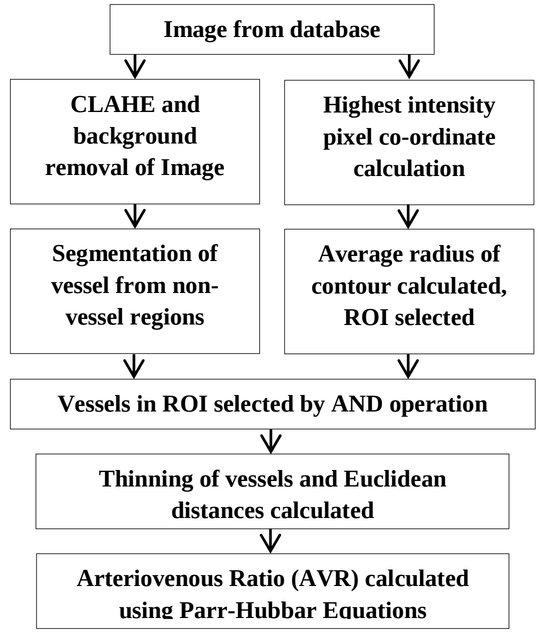


Fig. 1. Flow diagram of image processing algorithm

This way, binary images are obtained from the background removed images. This method of adaptive thresholding creates a threshold point adaptively for each image separately, thus provides automation in our process. This threshold point is then used to convert each pixel of gray-scale image into either the pixel value 1 or 0. This gives a binary image as output since all its pixels have either of the two values. After adaptive thresholding, contours of all the connected regions in the image are calculated. The connected regions having smaller area than a threshold value are considered as noise and are removed next.

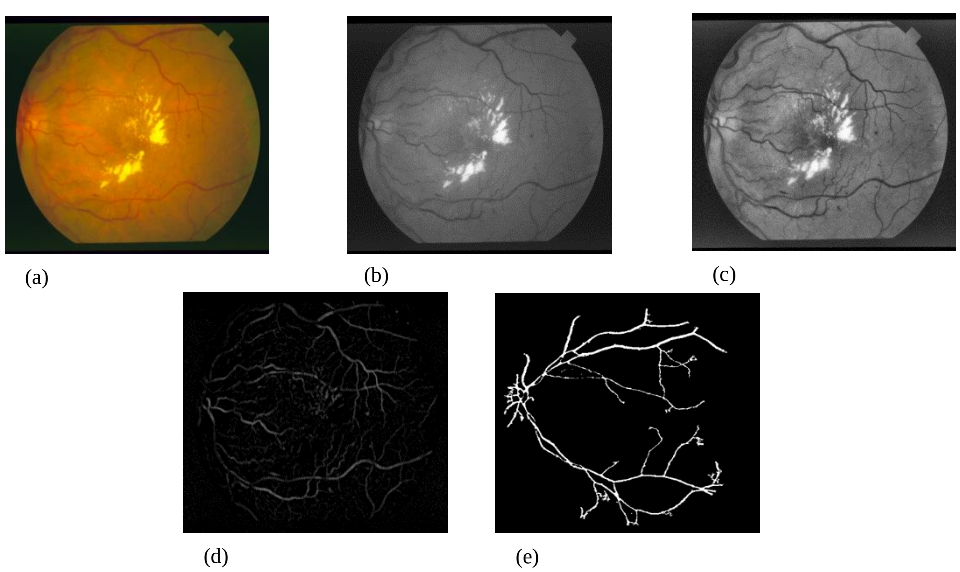


Fig. 2. Steps of segmentation process; (a) original retinal fundus image (DRIVE database), (b) green channel image, (c) contrast inhanced using adaptive histogram equalization, (d) background eliminated image, (e) segmented vessels

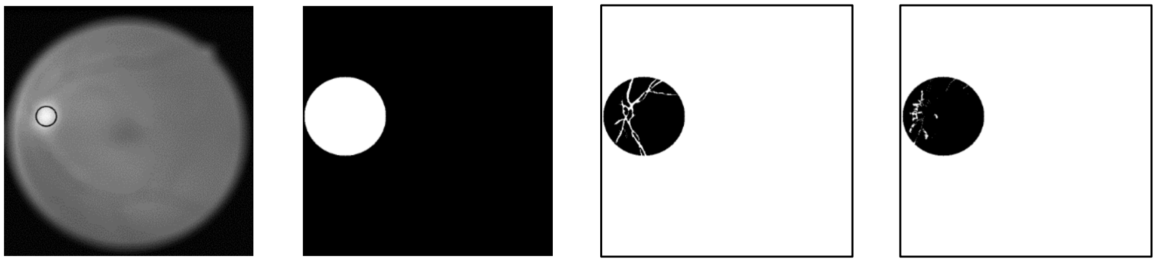


Fig. 3. Steps of ROI selection and artery and vein classification process; (a) optic disk detected (shown using a circle), (b) ROI selected four times of optical disk, (c) region of detected arteries, (d) region of detected veins

These regions are replaced by the values of background pixels to enhance the image. This entire process of adaptive thresholding and removal of noise is repeated two times to obtain a high quality image containing only the vessels. Figure 2 illustrates the morphological processes of adaptive thresholding, background removal and the segmentation process of the background removed images.

C. Optic Disc Detection and ROI Selection:

In the fundus image, the optic disc has the highest intensity. To detect the position of the pixel having the highest intensity, the conventional co-ordinate system of the image is used. The X and Y co-ordinate of the highest intensity pixel is calculated using all pixels' intensity values. This point is then used as a center to extract a circular Region of Interest (ROI). The radius of the ROI is selected by first drawing a contour around the optic disc of the retinal image. Secondly, Euclidean distances from the center point obtained before and all the points on the contour of the optic disk are calculated. Finally, the average of these distances is calculated and 4 times the average value is taken as the radius of the circular ROI. After selecting the Region of Interest, a binary image with pixel values 1 inside the ROI and 0 elsewhere is AND operated with the main image. This gives an output image with only the ROI selected.

D. Arteriovenous Ratio Calculation:

The arteries inside the ROI have higher intensity, therefore are brighter, than the veins. This property of the vessels is exploited to differentiate between the arteries and the veins next. Average intensity of the vessels is calculated and the regions containing pixels of arteries are conditioned to have higher intensity than that, and the vein regions lower intensity. Morphological thinning operation of the image yields the middle row of pixels of the vessels with their distance values associated with them. The thinning operation is performed until the vessels are one pixel in width. This is called repeated operation until stability is obtained. The thinning operation is performed using the morphological erosion operation of the image with a structural element and checking whether the vessel is single pixel wide every time inside a loop. Euclidean distance transform is then performed on the segmented image within the ROI. Here, Euclidean distances are the distances between the center pixels of a vessel and their boundary pixels. Multiplying these distance values by two gives the width of a vessel. Multiple values of vessel widths are found which are separated into two classes "Arteriole" and "Venules" based on a intensity threshold value. The classes are then sorted in an ascending order and the sorted values of widths are then used in Parr-Hubbar formulas (1), (2) and (3) to calculate Arteriovenous Ratio (AVR), where "W_b" is the median value of the widths of a class, "Arteriole" or "Venules", and "W_a" is the value in the same class exactly before the median. CRVE and CRAE are called central retinal vein equivalent and central retinal vein equivalent, respectively. Figure 3 shows the steps of selecting ROI of the segmented image and selction of artery and vein regions.

III. Result

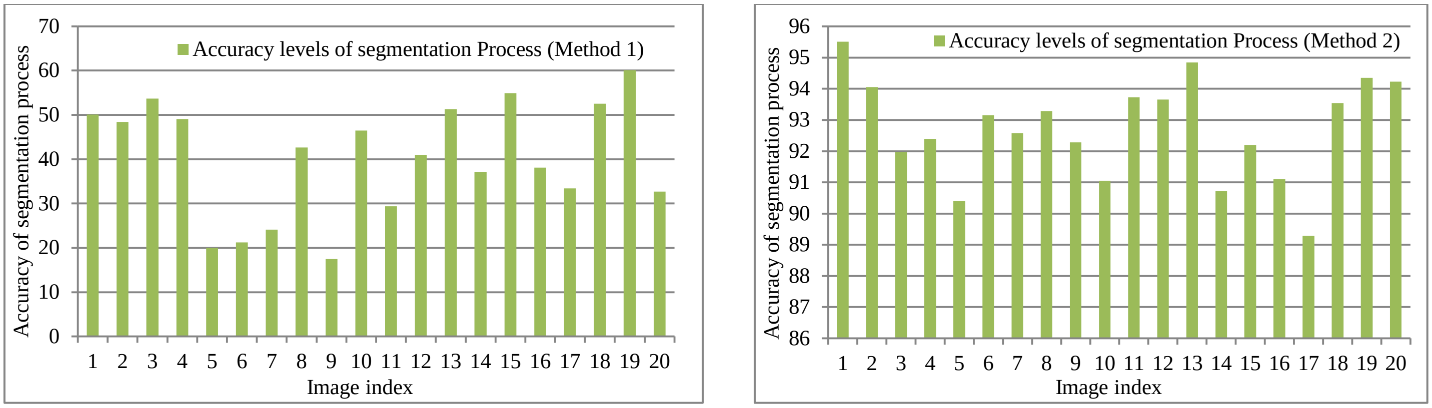
Of all the images provided in DRIVE database, 20 images contain ground truth images. These ground truth images are actually segmented images provided along the real image of retina. Segmentation of these 20 images is carried out using our proposed method. Then, a pixel to pixel comparison between the segmented image and the given ground truth image is performed. This comparison yields the accuracy level of the segmentation process. Figure 4 illustrates graphically the accuracy levels of these 40 images. On average, the accuracy level for segmentation process is 66.446% for these 20 images.

$$CRAE = (0.87{W_a}^2 + 1.01{W_b}^2 - 0.22W_aW_b - 10.73) \quad (1)$$

$$CRVE = \left(0.72{W_a}^2 + 0.91{W_b}^2 + 450.02\right) \quad (2)$$

$$AVR = \frac{CRAE}{CRVE} \quad (3)$$

The average accuracy levels are computed using two separate methods. First a pixel-to-pixel comparison method is carried out where only the white pixels of our segmented images and given ground truth images are compared. The second method involves a pixel-to-pixel comparison between the segmented images and the ground truth images where the pixels of the entire images are taken into account for comparison. These methods give average accuracy levels of 40.1745% and 92.7175%, respectively.



(a) (b)

Fig. 4. Accuracy results of segmentation process; (a) accuracy levels of first 20 images with ground truth images, (b) accuracy levels of second 20 images with ground truth images

IV. CONCLUSION

The segmentation process utilizes only morphological image processing techniques to segment vessels from the retinal images, which makes the method simple and fast. Due to its simplicity and computational speed, it can be implanted in real time applications of diagnosis of HR from retinal images. A number of limitations of the presented method should be mentioned. First, the accuracy level of segmentation can be increased by using more advanced classifiers like DNN. These classifiers can be trained to segment the images properly and more accurately. Secondly, a better method of background removing from the fundus image before segmentation should also increase the accuracy, as the noise present in the image during the segmentation process highly deteriorates performance of the process.

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