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Measurement of Arterio-Venous Ratio for Detection of Hypertensive Retinopathy through Digital Color Fundus Images

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ABSTRACT

Hypertensive retinopathy is a retinal vascular damage caused by high blood pressure which results in loss of vision. In the present work, effort has been devoted to enhance and segment the retinal vasculature which is required to calculate its anatomical characteristics such as width, length for the quantitative measurement of arterio-venous ratio (AVR). Enhancement of the retinal fundus images is done using top-hat transform and segmentation of the vessels using iterative thresholding. The performance of the proposed method is tested on 50 digital fundus images of publicly available MESSIDOR dataset. The hypertensive retinopathy can be measured quantitatively by detecting the decrement in the ratio of width of retinal artery-vein to that of the normal images. The arterio-venous ratio obtained by applying the proposed methodology was found to be 0.62-0.735 in normal cases and 0.203-0.495 in case of patients suffering from hypertensive retinopathy on MESSIDOR dataset which was not performed earlier. This measurement of arterio-venous ratio will be further helpful to identify the stages of hypertensive retinopathy.

Keywords: Hypertensive retinopathy; fundus image; arterio-venous ratio; arterio-venous nicking

1 Introduction

The abnormality of retina caused by high blood pressure is called hypertensive retinopathy. When the blood pressure is too high, the retina's blood vessel walls may thicken. This may result in narrowing of the vessels, which restricts blood to reach up to retina. Hypertensive retinopathy (HR) causes various changes in the retinal blood vessels such as leakage from blood vessels, and swelling in other parts of the retina. Figure1 (a) shows major parts of retina such as optic disc, macula, artery, vein while Figure1 (b) represents various effects of HR such as vascular wall changes, flame-shaped hemorrhages, cotton-wool spots, yellow hard exudates, and papilloedema [1,2]. Prolonged high blood pressure can cause damage to the retina's blood vessels and limit the retina's function, and can also put pressure on the optic nerve that may lead to complete vision loss. Worldwide, hypertensive retinopathy is now a leading cause of disability and mortality. Its prevalence is expected to reach 30% worldwide by 2025. Wong *et al.* [2] surveyed that hypertensive patients were 50–70% more likely to have retinal hemorrhages and micro aneurysms, 30–40% more likely to have focal arteriolar narrowing and 70–80% more likely to have arterio-venous (AV) nicking than normal individuals. Patients suffering with diabetes as well as hypertension greatly increases risk of vision loss. The automated detection of vascular changes of blood vessels is a challenging task [3]. In the present work, effort has been devoted to enhance and segment the retinal vasculature which is

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required to calculate its anatomical characteristics such as width, length for the quantitative measurement of arterio-venous ratio (AVR).

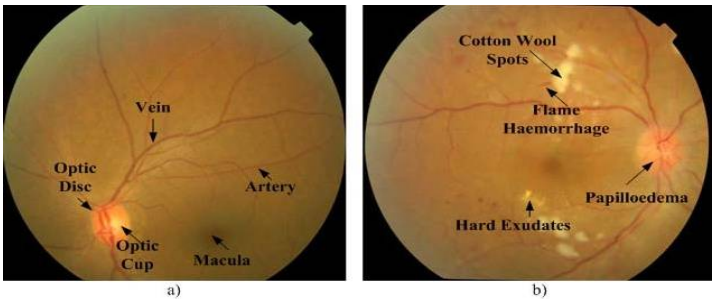

Figure 1. Hypertensive retinopathy on digital fundus image: a) normal fundus image, b) fundus image showing effects of hypertensive retinopathy.

2 Related Work

Narasimhan *et al.* [4] presented a method for blood vessel detection using median filter and top hat transform on 76 images of VICAVR database and 25 clinically acquired retinal fundus images. Inspite of using large dataset, grading has not been done in their work. Manikis *et al.* [5] work was based on hessian based vessel segmentation technique along with thresholding. It was tested on two different standard databases DRIVE, STARE. The limitation of their work was that optic disc detection technique has not been discussed properly. Agurto *et al.* [6] developed automated vessel segmentation method based on a multi-scale linear structure enhancement and the second order local entropy thresholding. Calculation of AVR is done on the six widest (major) vessels for each category on 74 clinically acquired images. The limitation of their work was that the AVR calculation has been done only on region (0.5-1) optic disc diameter (DD) which may give inappropriate results according to them. Khitran *et al.* [7] work was based on classification of vessels as arteries and veins using new feature vector. They tested their method on 58 fundus images of VICAVR and 40 images of DRIVE database. The limitation of their work was that new computation method used for AVR calculation is not discussed properly. Ortiz *et al.* [8] proposed a method to calculate the AVR by using different techniques including Gabor wavelet, gradients and morphological operations. A set of 30 images was taken to test this algorithm. Their method gave undefined classifications for low illuminance images. Ruggeri *et al.* [9] presented an algorithm to enhance the image to highlight the vessel network, which is then traced by a vessel tracking algorithm. The method was tested on 50 clinically acquired images. It appeared that some vessels were missed by the tracing procedure and therefore gave faulty AVR and thus unsatisfactory performances.

On the basis of literature review, for the best result noise removal can be done by using gaussian kernel and enhancement can be carried out using top-hat transform. This insight is helpful to design a methodology to measure AVR ratio on the images of MESSIDOR dataset which has not been done earlier.

This paper is structured as follows: Section 3 outlines the materials used and describes the proposed method. Section 4 provides the experimental results of the proposed method and discussion on these results. Section 5 summarizes the key findings of the method and scope for future research.

Table 1. Performance Comparison of Hypertensive Retinopathy Detection.

Author (Year)	Image processing Methods	Database (Number of images)	AVR	
			Normal	Abnormal
Narasimhan *et al.* (2012) [4]	Median filter, Top hat transform	VICAVR(76) Clinically acquired(25)	0.6-0.7	0.24-0.49
Manikis *et al.* (2011) [5]	CLAHE, Hessian based vessel segmentation	DRIVE(40) STARE(20)	-	0.1-0.5
Agurto *et al*. (2014) [6]	Multi-scale linear structure, enhancement	Clinically acquired(74)	0.67	0.58
Khitran *et al.* (2014) [7]	Gabor wavelet, multilayered thresholding	VICAVR(58) DRIVE(40)	-	0.1-0.5
Ortiz *et al.* (2010) [8]	Gabor wavelet, Hessian matrix	Clinically acquired(50)	>0.6	< 0.6
Ruggeri *et al.* (2007) [9]	Vessel tracking method	Clinically acquired(50)	-	<0.57

3 Materials and Methods

The retinal fundus images for the present study have been taken from open-source benchmark MESSIDOR database which is available online. MESSIDOR database were acquired by three ophthalmologic departments using a color video 3CCD camera on a Topcon TRC NW6 non-mydriatic retinograph with a 45 degree field of view. The images were captured using 8 bits per color plane at 1440×960, 2240×1488 or 2304×1536 pixels. The database contains a medical diagnosis for each image, but no manual annotations on the images, such as lesions contours or position.

The flowchart of the proposed method is presented in figure 2. Hypertensive retinopathy produces modifications in the retinal vessels; hence the present work is focused mainly on vessel enhancement and segmentation to characterize any morphological change in retina. Therefore, the main stages involved in this method are: (i) pre-processing step which mainly includes vessel enhancement process, (ii) post-processing step having vessel segmentation, binarization and optic disc detection as its main step, (iii) retinal tree labeling to perform characteristic measurements on composite image (iv) ROI detection to perform AVR calculation.

3.1 Pre-processing

The retinal fundus image consists of three channels; green, red, and blue. Amongst them, green channel is selected which has a better contrast and information than the other two channels.

Retinal blood vessels exhibit number of properties such as:

i. The blood vessels have small curvature.
ii. Vessels have lower reflectance than the background, so they appear darker.
iii. Vessel size may decrease when moving away from the optic disc, the width of a retina vessel may lie within the range of 2–10 pixels.
iv. The intensity profile may vary by a small amount from vessel to vessel.
v. The intensity profile of blood vessel has a Gaussian shape [10].

So the blood vessels are enhanced and segmented for further processing using following major steps:

3.1.1 Vessel central light reflex removal

Some blood vessels have a light streak (known as a light reflex) which runs down the central length of the blood vessel [4].The green plane of the fundus image is filtered to remove this brighter strip. So,

morphological opening is applied to the green channel using a three-pixel diameter disc as structuring element. The structuring element is selected such that it does not merge with the vessels that lie close to one another.

3.1.2 Background homogenization

The second step of preprocessing is background homogenization. A background intensity variation due to non-uniform illumination is associated with retinal fundus images. A 3x3 mean filter is applied to smooth occasional salt-and-pepper noise [11]. The image is smoothened further with a gaussian kernel with standard deviation of 0.5. A homogenized image in then obtained with reduced intensity variations in accordance to the green channel image.

3.1.3 Vessel enhancement

Vessel enhancement is the final pre-processing step to generate a new vessel enhanced image. It is performed initially by estimating the complementary image of the homogenized image [12,13]. It is further followed by morphological top-hat transformation of the complementary image. A disc structuring element of eight pixels radius was used in this step. The bright lesions i.e., optic disc, possible presence of exudates or reflection artifacts are removed while the dark features i.e., blood vessels, fovea, possible presence of micro aneurysms or hemorrhages remain in the image. The contrast between the vessels and other tissues are further improved after applying top-hat transform.

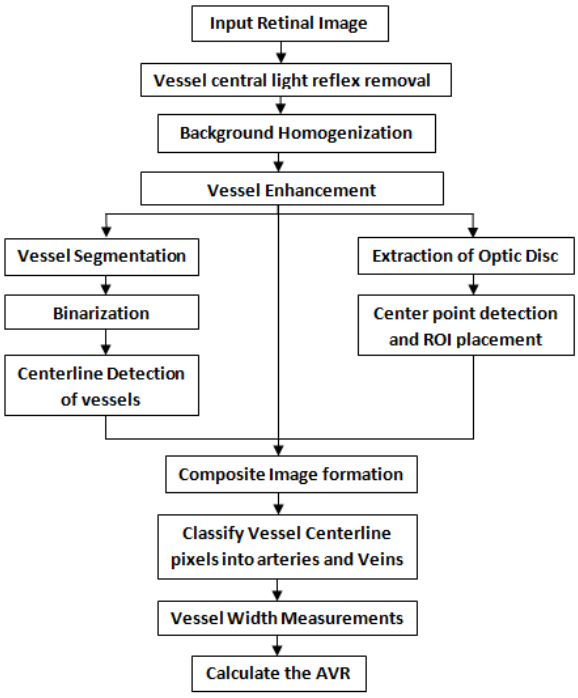

Figure 2. Flowchart of the proposed method

3.2 Post-processing

3.2.1 Vessel Segmentation

Classification of arteries and veins is an important step in HR detection. An iterative thresholding method for segmenting the blood vessel structure is applied for the binarization of the enhanced image [14,15,16]. Intensity variation and color information is used to classify the vessels as arteries and veins [17,18].

3.2.2 Optic disc detection and ROI Determination

Accurate detection of optic disc is necessary for determining the region of interest (ROI) so as to calculate the artery-vein ratio [6]. The center point of the optic disc is estimated by the automated method. The estimation is based on measurements obtained in the image and from the vessel segmentation. The target location is obtained by taking estimates in many locations in the image, ignoring those locations that are estimated to be far from the optic disc center [19]. The automated method detects the center of the optic disc and a circle with DD, is placed at this location. It was assumed that this circle corresponds to the optic disc outline in the image.

After the coordinates of the optic disc are located, two regions of interest are selected. Region A is between 0.5 and 1 DD from the optic disc center and region B is between 1 DD and 1.5 DD from the optic disc center. The two regions selected from optic disc center are shown in Figure 3(a). All analyses and evaluations performed in this work are based on measurements within region B. Region B is generally used for vessel measurements.

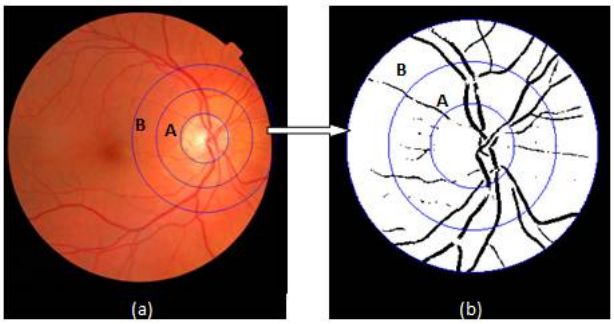

Figure 3. (a) ROI outlines marked on original image, (b) ROI in the binary image where region A is between (0.5 -1) DD and region B is between (1-1.5) DD.

3.2.3 Computation of AVR and Centerline detection

For computation of AVR, all the vessel width measurement has to be done initially. To calculate the vessel width from binary vessel mask, the center line for each vessel is obtained by morphological thinning operation. The thinning operation is performed till the vessel width equal to single pixel is obtained. This will provide center line for each vessel segment [8]. The vessel center line is combined with the filtered image and width is calculated for major six arteries and veins by measuring the perpendicular line that intersects the vessel edges [20]. Figure 4 represents the composite image obtained after the above process. The final width for each vessel segment is calculated as the median of all the widths of arteries and veins [6].

The AVR is computed by measuring Central Retinal Arterial Equivalent (CRAE) and Central Retina Venous Equivalent (CRVE). These two measurements of arterioles and venules are determined by Parr formulas

[21,22] and Hubbard [23] respectively. According to [23], the mean widths of arteries and veins segments within ROI are collected in two separate lists, namely "Arteriole" and "Venule". CRAE is computed as;

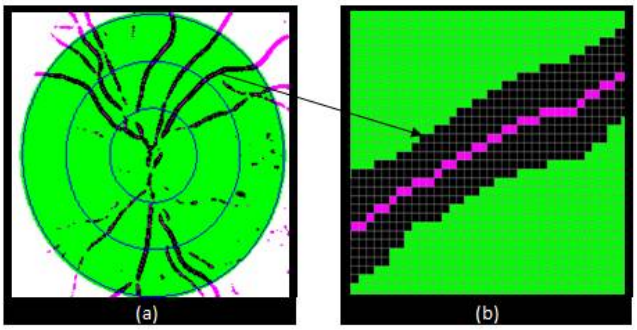

Figure 4. (a) Composite image of binarized and determined ROI image, (b) Image showing vessel width with centerline pixel.

$$CRAE = \sqrt{(0.87.X^2 + 1.01.Y^2 - 0.22.X.Y - 10.73)} \quad (1)$$

Where Y is the median value of "Arteriole" and X is the value in the same list exactly before the median Y.

$$CRVE = \sqrt{(0.72.X^2 + 0.91.Y^2 + 450.02)} \quad (2)$$

Where Y is the median of "Venule" and X is the value in the list exactly before Y. AVR is computed by dividing equation 1 and 2;

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

3.2.4 Grading of Hypertensive Retinopathy

Keith and Wegner (1939) [24] have classified hypertensive retinopathy into following four grades. The change in vessel diameters is used to calculate AVR and it is significant in determining the presence of hypertensive retinopathy and grading its severity [25,26]. Table 2 shows various stages of HR along with AVR;

Table2. Grading of HR

Degree of HR	AVR	Symptoms
Normal Retina	0.667-0.75	None
Grade 1	0.5	Mild compression of venules
Grade 2	0.33	Compression of elevation of venules
Grade 3	0.25	Right angled crossing of vessels
Grade 4	< 0.2	All above symptoms along with papilledema

4 Experimental Results and Discussion

The quantitative assessment of the proposed algorithm is done for hypertensive retinopathy detection. The algorithm was tested on 50 retinal images of MESSIDOR dataset. Images in figure 5 (a), (b) and (c) are randomly chosen retinal fundus images from MESSIDOR database that are used to demonstrate the results of proposed method.

The results of pre-processing are shown in figure 5 (d)-(i).The green channel images of the selected sample images are shown in figure 5 (d), (e) and (f) respectively. The output of homogenized image is complemented to get output image as figure 5 (g), (h) and (i) respectively. The enhancement of the processed images is then done by using top hat transform shown in figure 5 (j),(k) and (l) respectively. The contrast of the output obtained is then increased to get the enhanced image as shown in figure 5 (m), (n) and (o) respectively. The enhanced sample images are then binarized to obtain figure 6 (a),(b) and (c) respectively.

The width of arteries and veins is calculated on region B (1-1.5) DD as show in figure 3 (a), (b). The AVR is calculated after computing the width of arteries and veins as shown in figure 4 (a), (b). Table 3 displays statistical performance of the proposed method on MESSIDOR dataset. On the basis of Table 2, the retinal images can be divided into normal and abnormal images. The AVR obtained by the above mentioned methodology is 0.62-0.735 in normal cases and 0.203-0.495 in case of patients suffering from hypertensive retinopathy. Using the above algorithm 17 images out of 50 images was found to be normal images while 33 abnormal images detected the presence of hypertensive retinopathy.

In this research paper top-hat transform is used for the vessel enhancement and thresholding is used for segmentation of vessels. Optic disk detection is necessary for the correct estimation of ROI as well as for the computation of AVR.

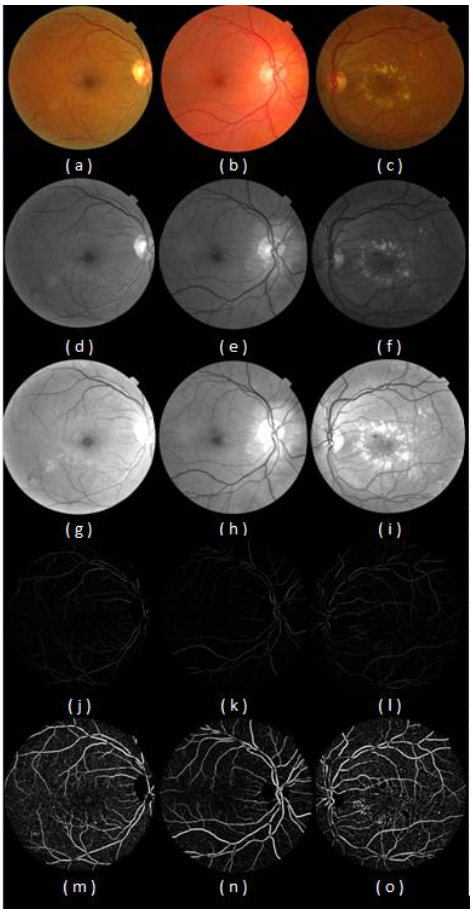

Figure5. Results of preprocessing of retinal fundus images: (a–c) original images from MESSIDOR dataset, (d–f) Green channel images, (g-i) complement of homogenized output image, (j-l) output images of top-hat transform, (m-n) enhanced images of top-hat transform outputs.

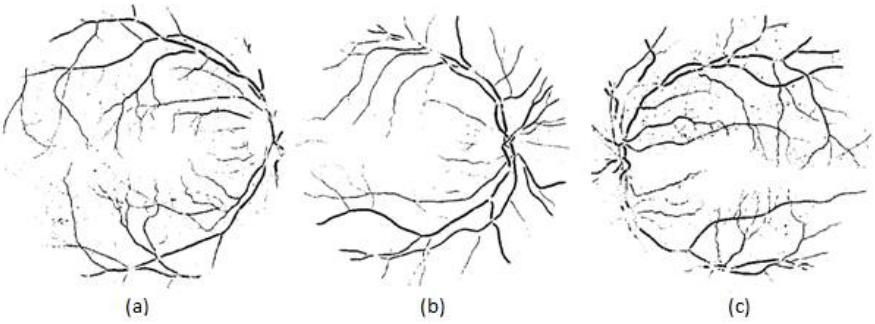

Figure 6. Binarization of enhanced image taken from sample images (a-c)

Table3. Evaluation of the proposed method by statistical performance measures.

Number of Images	AVR
Image 1	0.359
Image 2	0.7266
Image 3	0.3584
Image 4	0.3841
Image 5	0.2034
Image 6	0.3548
Image 7	0.6258
Image 8	0.6188
Image 9	455646
Image 10	0.2674
.	.
.	.
.	.
.	.
.	.
Image 44	0.3799
Image 45	0.3061
Image 46	0.2864
Image 47	0.3404
Image 48	0.5392
Image 49	0.6417
Image 50	0.495
Average	Normal -(0.62-0.735)
	Abnormal-(0.203-0.495)

5 Conclusion

Early detection of hypertensive retinopathy signs is an important step in the risk stratification of hypertensive patients for medical as well as researcher's domain. Therefore, a new and easy method is developed for the enhancement and detection of blood vessels for the purpose of detection of hypertensive retinopathy. The AVR obtained by the proposed methodology for MESSIDOR dataset is 0.62-0.735 in normal cases and 0.203-0.495 in case of patients suffering from hypertensive retinopathy

In future work, automated classification of blood vessels can be introduced. Evaluations on large set of images acquired from the subjects with much wider variations of AVR can be performed to access the reliability and clinical applicability of this algorithm.

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