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Retinal Blood Vessel Extraction using Wavelet Transform and Morphological Operations

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ABSTRACT

Retinal image plays a vital role in medical image processing for the analysis of micro vascular diseases like diabetic retinopathy and glaucoma. This research work proposes a vessel segmentation algorithm that can be used in computer aided retinal image analysis. The proposed method comprises of three main stages. In the first stage, preprocessing was done that comprises of green channel component extraction, filtering by decision based median filter and enhancement by adaptive histogram equalization. Then the morphological operations were applied for the elimination of optical disc and background before the extraction of blood vessels. Finally the binarization technique and discrete wavelet transform was applied for extraction of blood vessels and extracted blood vessel bundles were traced on the input fundus image. The quantitative analysis of the result was done by performance metrics like dice coefficient, rand index, variation of information and global consistency error. The algorithms were developed in MATLAB 2010a and tested on real time fundus image from STRIVE database comprising of healthy, diabetic retinopathy and glaucoma cases.
Keywords: Fundus image, binarization, wavelet transform, morphological operation.

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INTRODUCTION

Medical image processing plays an inevitable role in the analysis of anomalies in living beings and retinal imaging is used for the diagnosis and treatment of eye related diseases. The vision loss is an important problem in the working population of the world. Diabetic Retinopathy, Glaucoma, macular degeneration and cataracts are the most common causes. The other diseases such as atherosclerosis, hypertension, and cardiovascular problems may also change the shape of retinal blood vessel [1] [2]. The computer algorithms help physicians for the automatic detection of blood vessels, since the manual intervention is difficult. The detection of blood vessels in the retinal images are more difficult for thin vessels and the common issues are poor visibility of vascular pattern, difficult to identify the changes in blood vessels and overlapping of blood vessels. Many retinal blood vessel detection techniques are there and some of the related works are as follows.

Chandani Nayak et al. proposed Gabor wavelet approach for the segmentation of retinal blood vessels, it is efficient in vascular pattern enhancement and filtering the background noise, especially for thin blood vessels in the analysis of diabetic retinopathy [3]. Razieh Akhavan et al. formulated an iterative region growing segmentation method along with adaptive fuzzy switching median filter and improved morphological operations for the detection of blood vessels [4]. Yanli Hou applied multidirectional top hat transform with rotating structural elements for noise removal, vessel enhancement and an improved multi scale line detection algorithm was employed for retinal blood vessel segmentation [5]. Qazaleh et al. proposed a novel structural and automated method for artery/vein classification of blood vessels in retinal images. Feature extraction was performed by Gabor wavelet and classification was done by Support Vector Machine (SVM), Linear Discriminant Analysis (LDA) which produces better results than conventional clustering based approach [6].

Eysteinn Mar Sigurosson et al. formulated an unsupervised method based on improved morphological directional filtering for retinal blood vessel extraction and fuzzy set theory was used for classification [7]. S. Wilfred Franklin et al. used arithmetic mean filter and contrast adaptive histogram equalization for the preprocessing of fundus images and segmentation was performed by multilayer perceptron [8]. Adam Hoover et al. applied histogram thresholding to the matched filter response of fundus image for blood vessel extraction. Matched filter comprises of 12 kernels and it is convolved with input retinal image, the highest scoring kernel at each sub region is recorded as response [9]. K. A. Vermeera et al. developed a model based retinal blood vessel detection technique that comprises of Laplacian filter and thresholding [10].

The brief outline of the proposed work is as follows: Pre-processing is the initial stage and it comprises of green channel extraction, noise removal by decision based median filter and enhancement by adaptive histogram equalization. In the second stage, the morphological operations were applied for the removal of optical disc and background. The retinal blood vessel extraction is done in the third stage by binarization and wavelet transform. Thus the boundaries of blood vessels are traced in the input fundus image.

The paper organization is as follows: The materials and methods include data acquisition, preprocessing, removal of optical disk, removal of background noise and extraction of blood vessel. The result and discussion depicts the result of proposed algorithm for normal, diabetic retinopathy and glaucoma fundus images and finally conclusion is drawn.

MATERIALS AND METHODS

Data acquisition

The high resolution fundus strive image database is used in this paper. The STRIVE database comprises of 15 images of healthy patients, 15 images of patients with diabetic retinopathy & 15 images of glaucomatous patients. The algorithm was tested on all the images and the results of typical images are depicted here.

Preprocessing

Before the segmentation of blood vessels, preprocessing operations are done to enhance the input retinal images. The input retinal fundus images are color images in RGB model. The green component shows good contrast for blood vessels while the red and blue component shows low contrast and is noisy. The image resizing was done initially and then green channel component was extracted, since it is good for the extraction of blood vessels. The Decision Based Median Filter (DBMS) was used for the removal of noise. The non-noisy pixels are not disturbed unlike the conventional median filter. The filtered green channel was complemented and then subjected to Adaptive Histogram Equalization (AHE). In adaptive histogram equalization instead of performing the operation on the entire image, small regions (tiles) are considered and the contrast is enhanced. The bilinear interpolation is employed to combine the contrast enhanced neighborhood tiles. Fig. 1 shows the preprocessing of retinal fundus image.

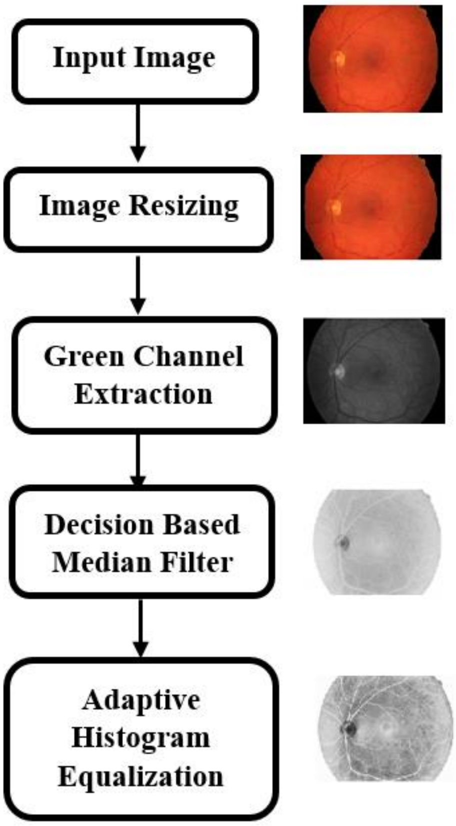


Fig. 1 Preprocessing stage

Removal of optical disc

The optical disc in retinal fundus images was removed before the extraction of blood vessels. The morphological opening operation was performed after adaptive histogram equalization. The morphological open image was subtracted from the adaptive histogram equalization output for the removal of optical disk. Fig. 2 shows the removal of optical disk by using morphological operation.

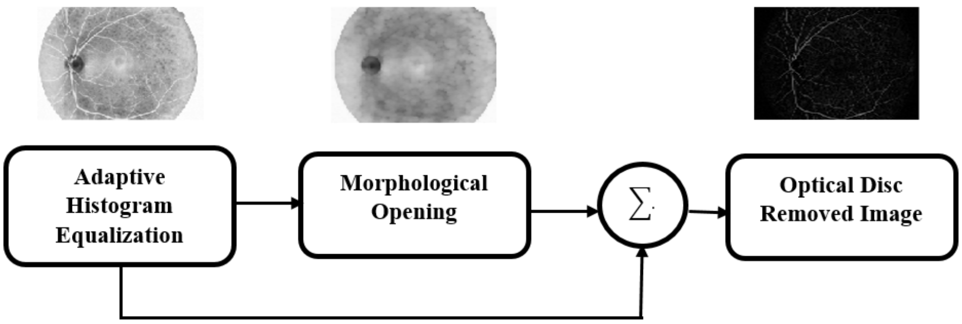


Fig. 2 Removal of optical disk

Removal of background

After the removal of optical disk, the median filter was applied for the removal of noise generated in the previous stage. The morphological open operation was then performed on the median filter output and it is subtracted from the median filter output for the removal of background. Fig. 3 shows the removal of background by using morphological opening operation.

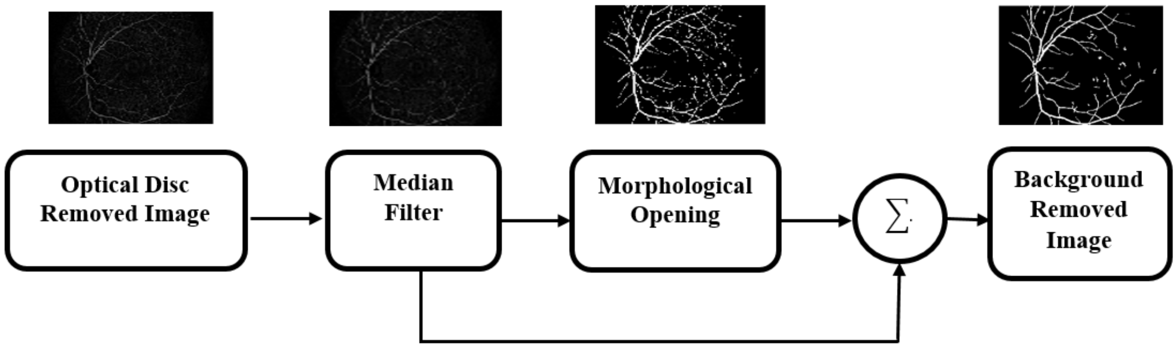


Fig. 3 Removal of background

Extraction of retinal blood vessels

The background removed image was subjected to binarization and morphological open operation prior to the application of Discrete Wavelet Transform (DWT). The 2D DWT is applied to the retinal image which splits the image into sub bands. The image is decomposed into four sub images such as LL, HL, LH and HH. LL is the approximate component and it is the low frequency band which is taken into account for further processing. The sub images LH, HL and HH are sensitive to vertical, horizontal and diagonal frequencies. The LL sub image component consists of most of the energy and the least energy in the HH component. The LH and the HL component contain the edge information. The sym4 wavelet is used, it belongs to symmetrical wavelets family and it has maximum number of vanishing moments for a given compact support. After the extraction of blood vessels, the boundaries are traced on the input images.

RESULTS AND DISCUSSION

The algorithms were analyzed using MATLAB 2010a. The retinal fundus images obtained from STRIVE database were used for the analysis of algorithms. The results of nine retinal fundus images including 3 images of healthy eyes, 3 images of Diabetic Retinopathy patients, 3 images of Glaucoma patients are depicted here. Fig. 4 depicts the blood vessel segmentation results on fundus images of healthy eyes and the details are as follows.

- The first row represents the input fundus images of healthy eyes.
- The green channel component extraction was done on input images and is depicted in the second row.
- The preprocessing results after applying decision based median filter and adaptive histogram equalization are depicted in third row.
- The optical disc removed images are depicted in fourth row. The morphological opening operation was done in this stage with non-flat structuring element 'ball' of radius 8 and height 8. The process is depicted in Fig. 2 and the results are depicted in fourth row.
- The background was eliminated and the blood vessel extraction was done by 2D discrete wavelet transform and the boundaries of the blood vessels were traced. The background was eliminated and the blood vessel extraction was done by 2D discrete wavelet transform and the boundaries of the blood vessels were traced on the input image. The process is depicted in Fig. 3. In the removal of background, morphological open operation was done by flat structuring element 'disk' of radius 15. The gray thresholded binary image was morphologically opened prior to the application of wavelet transform. The results are depicted in fifth row.

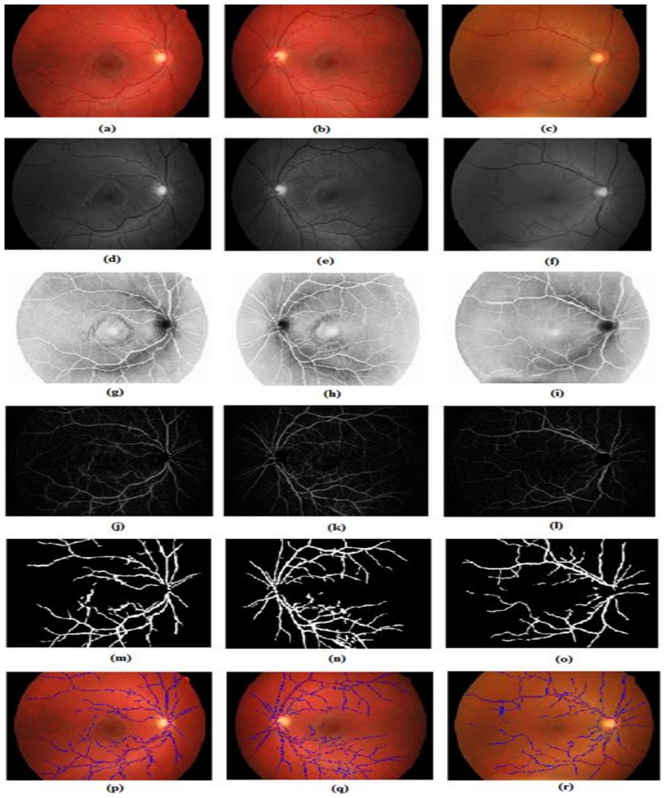


Fig. 4 Blood vessel extraction of retinal images of healthy eyes (T1, T2 and T3)

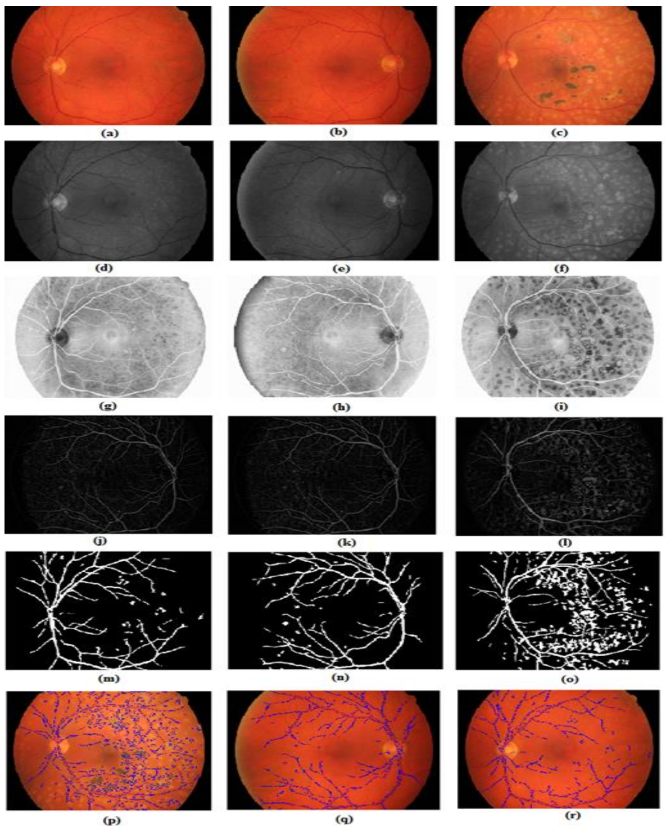


Fig. 5 Blood vessel extraction of retinal images with diabetic retinopathy (T4, T5 and T6)

Fig. 5 depicts the blood vessel extraction results of diabetic retinopathy fundus images. Fig. 6 depicts the blood vessel extraction results of glaucoma fundus images. The results of proposed method are used to identify the major parts of blood vessels. Result of the proposed algorithm was compared with Kirsch template edge detection algorithm. The effectiveness of segmentation result was evaluated by performance metrics like Dice Coefficient (DC), Rand Index (RI), Global Consistency Error (GCE) and Variation of Information (VI).

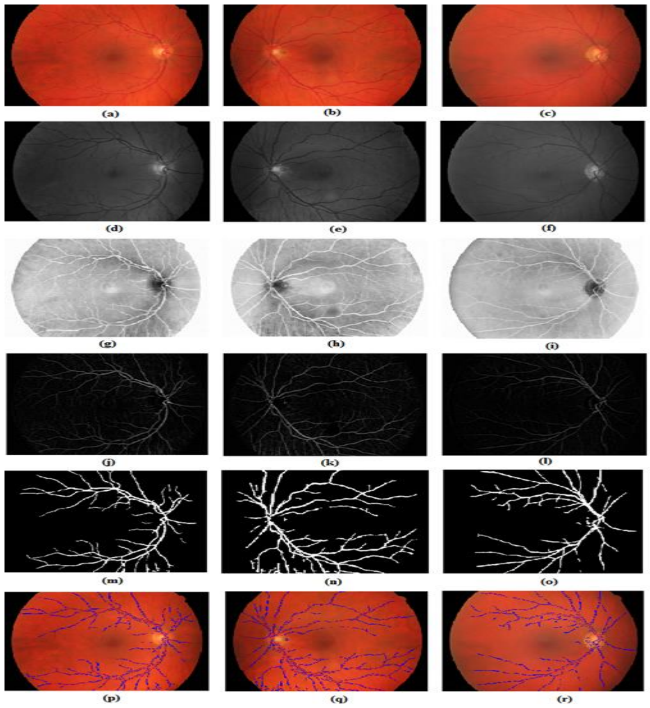


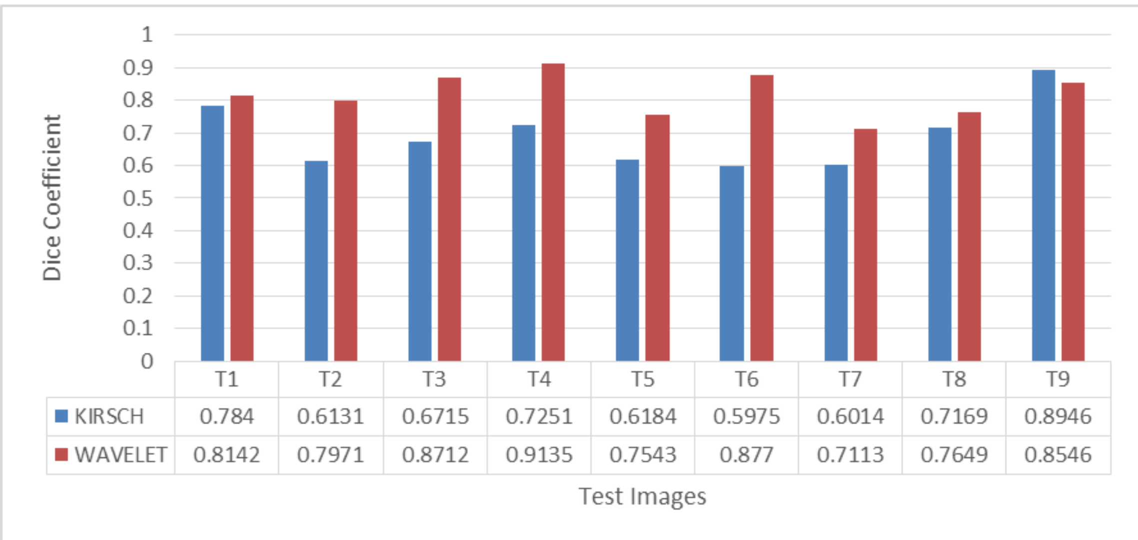
Fig. 6 Blood vessel extraction of retinal images with glaucoma (T7, T8 and T9)

The degree of spatial overlap between two binary images is represented by dice coefficient (Segmented image (S) & Ground truth image (G)).

$$DC = \frac{2\,|TP|}{2|TP| + |FN| + |FP|}$$

The value ranges from 0 to 1, 0 represents no overlap and 1 represents perfect matching. The Dice Coefficient plot of test images (T1 to T9) for Kirsch and Wavelet segmentation approach is depicted in Table 1.

Table 1. Dice Coefficient plot of Kirsch and Wavelet approach

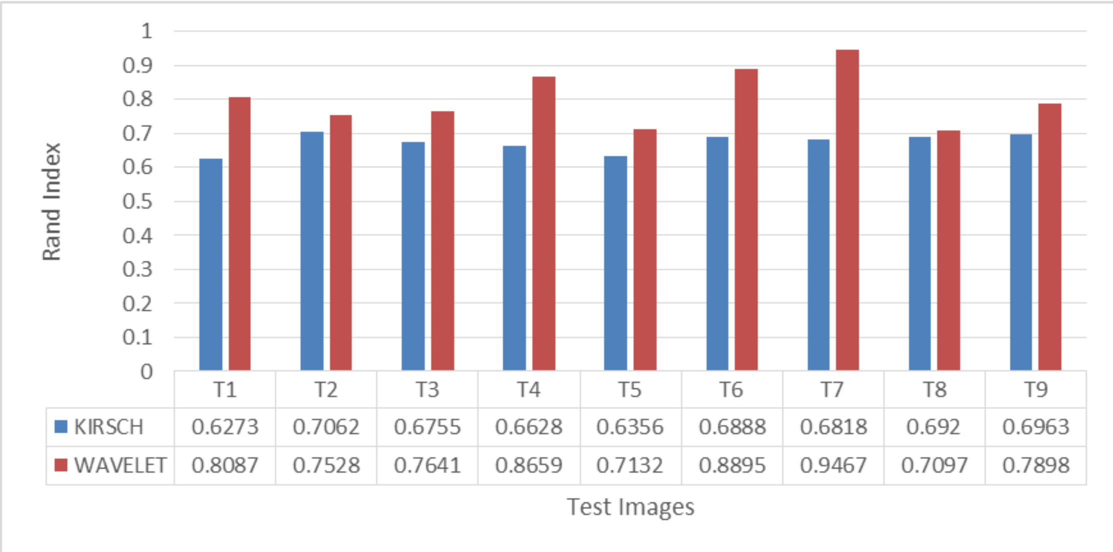


The DC value of proposed wavelet segmentation algorithm is better than Kirsch template edge detection algorithm. The consistency of pixels in the segmented and ground truth image is investigated by rand index.

$$RI = \frac{|TP| + |TN|}{|TP| + |FN| + |TN| + |FP|}$$

The range of RI is from 0 to 1, 0 represents the variation between S and G and 1 indicates the likeness between S and G. The Rand Index plot of test images (T1 to T9) for Kirsch and Wavelet segmentation approach is depicted in Table 2.

Table 2. Rand Index plot of Kirsch and Wavelet approach



The RI value of proposed wavelet based segmentation algorithm is better than Kirsch template edge detection algorithm that indicates the efficiency of wavelet approach.

For effective segmentation, the value of Global Consistency Error is zero. When there is an inconsistency between segmentation algorithm output and ground truth image, the value gets increased.

$$GCE(S,G) = \frac{1}{N}\min\left\{\sum_i \mathrm{LRE}\ (S,G,x_i)\ \sum_i \mathrm{LRE}\ (G,S,x_i)\right\}$$

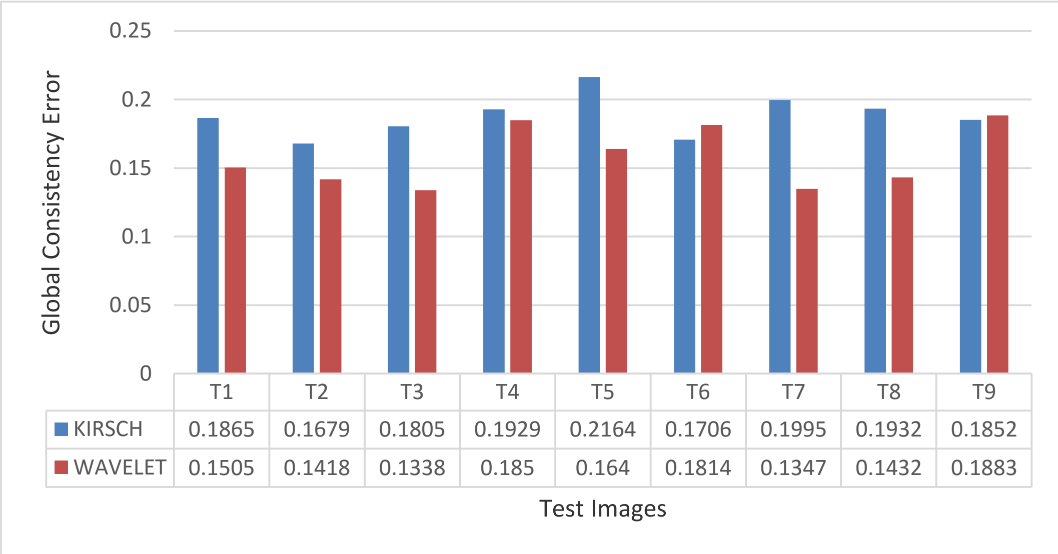
$$LRE(S,G,x_i) = \frac{\left| {C\ (S,\ xi)}/{C\ (G,\ xi)} \right|}{|C\,(S,\ xi)|}$$

Similarly,

$$LRE(G,S,x_i) = \frac{\left| {C\ (G,\ xi)}/{C\ (S,\ xi)} \right|}{|C\ (G,\ xi)|}$$

In the above expression, LRE represents the local refinement error. The Global Consistency Error plot of test images (T1 to T9) for Kirsch and Wavelet segmentation approach is depicted in Table 3.

Table 3. Global Consistency Error plot of Kirsch and Wavelet approach

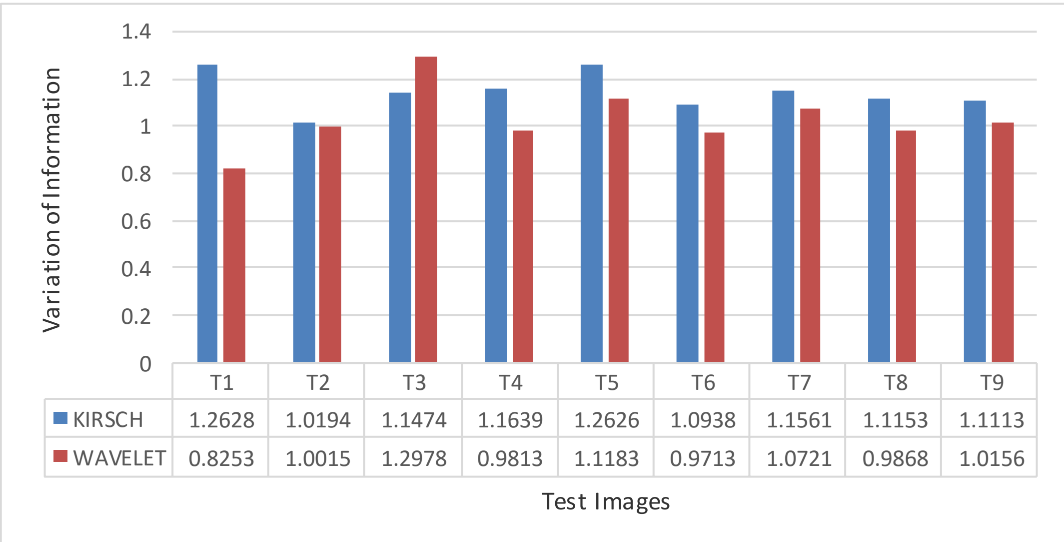


The Variation of Information (VI) is a distance measure that is determined using entropy and mutual information.

$$VI(S,G) = H(S) + H(G) + I(S,G)$$

It is a degree of randomness and for better segmentation, the value should be low. H(S) and H (G) are the entropy values of the segmented and ground truth image and I(S, G) is the mutual information between S and G. The Variation of Information (VI) plot of test images (T1 to T9) for Kirsch and Wavelet segmentation approach is depicted in Table 4.

Table 4. Variation of Information plot of Kirsch and Wavelet approach



The GCE and VI metric for the proposed wavelet based segmentation are lower than the Kirsch template edge detection algorithm that also indicates the proficiency of wavelet approach.

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CONCLUSION

This paper presents 2D discrete wavelet transform based algorithm for the extraction of retinal blood vessels. The preprocessing technique comprises of decision based median filter and adaptive histogram equalization technique. The optical disk and background was removed by morphological operations. The blood vessels were segmented by using 2D discrete wavelet transform and it traces the boundaries on the input image. The proposed algorithm gives satisfactory results in the extraction of blood vessels for healthy, diabetic retinopathy and glaucoma retinal fundus images from the STRIVE database.

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