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Retinal Blood Vessels Extraction Based on Curvelet Transform and by Combining Bothat and Tophat Morphology

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ABSTRACT

Retinal image contains vital information about the health of the sensory part of the visual system. Extracting these features is the first and most important step to analysis of retinal images for various applications of medical or human recognition. The proposed method consists of preprocessing, contrast enhancement and blood vessels extraction stages. In preprocessing, since the green channel from the coloured retinal images has the highest contrast between the subbands so the green component is selected. To uniform the brightness of image adaptive histogram equalization is used since it provides an image with a uniformed, darker background and brighter grey level of the blood vessels. Furthermore Curvelet transforms is used to enhance the contrast of an image by highlighting its edges in various scales and directions. Eventually the combination of Bothat and Tophat morphololological function followed by local thresholding is provided to classify the blood vessels. Hence the retinal blood vessels are separated from the background image.

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1. INTRODUCTION

One of the most important internal components of eye is called retina, which covers all posterior compartment. Any damage in retina leads to severe diseases. Disorders in retina resulted from special diseases are diagnosed by special images which are obtained by using optic imaging called Fundus image. The Fundus images are used for diagnosis by trained clinicians to check for any abnormalities or any change in the retina. They are captured by using special devices called ophthalmoscopes. Each pixel in the fundus image consists of three values namely Red, Green and Blue, each value being quantized to 256 levels. The blood vessels are the important parts of the retinal images consisting of arteries and arterioles. Checking the obtained changes in retinal images in an especial period can help the physician to diagnose the disease. Applications of retinal images are diagnosing the progress of some cardiovascular diseases, diagnosing the region with no blood vessels (Macula), using such images in biometric applications and in helping automatic laser surgery on eye, etc.

On the other hand, extracting the retinal blood vessels is done in some cases by physician manually, which is difficult and time consuming and is accompanied by high mistakes due to much dependence on the physicians skill level. So the exact extraction of the blood vessels from the retinal images necessitates using algorithm and instruments which reduce the dependency on the function and eliminate the error factors. While capturing the image because of the variability of light reflection coefficient in different parts of the retinal layer also due to the defects in imaging systems there occurs nonuniform illumination in the retinal image, pixels related to the blood vessels cannot be classified carefully.This improper contrast is due to different vessels have different contrast; arteries have higher contrast than veins. In addition to this, presence of noise, fovea and optical disk, width of the vessels, effects of lesions and pathological changes should also be considered. So, for extraction of blood vessels with high accuracy, we need of an effective algorithm.

In the proposed algorithm, the focus will be on the extraction of blood vessels constitutes of digital colored images of retina as its input which is then converted to green channel image with best contrast. Since the preprocessing phase plays an important role in final extraction results. One of the advantages of this phase is by applying the adaptive histogram equalization and Curvelet transform on the image to reduce the noise and improve the contrast. Therefore the inadequacy of previous methods is resolved. Since the blood vessels are distributed in different directions, applying morphological operation causes the blood vessels with high accuracy to be separated from the background and finally the connected components with defined threshold, frills in the image are removed and extracted blood vessels are obtained.

2. LITERATURE REVIEW

Recently many automated detection techniques are constantly devised and implemented to help ophthalmologists detect blood vessels by applying image processing and pattern recognition techniques.

In 2012, M. Kalaivani, M. S. Jeyalakshmi and Aparna.V [6] used Adaptive Histogram Equalization for initial enhancement, followed by this the curvelet transforms to the equalized image and the curvelet coefficients are obtained. The vessel extraction is done based on thresholding technique and the Kirsch's templates. It involves spatial filtering of the image using the templates in eight different orientations. The masking of redundant regions in the obtained output image is carried out using boundary techniques.

In other related work, Marwan D. Saleh and C. Eswaran [5] proposed the algorithm has employed techniques, such as background removal, contrast enhancement, h-maxima transformation, thresholding, etc. After converting the RGB image to gray-scale, both morphological top-hat and bottom-hat transforms have been exploited to perform the contrast enhancement. Other techniques such as h-maxima transform and multilevel thresholding have been exploited to decrease the intensity levels as much as possible to facilitate the threshold selection for binarization in 2012.

Iqbal, M.I et al [14] in 2007 used Color Space Conversion, Edge Zero Padding, Median Filtering and Adaptive Histogram Equalization as pre-processing techniques and they used segmentation to group the image into regions with same property or characteristics. Methods of image segmentation include simple thresholding, K-means Algorithm and Fuzzy C-means. Since it takes more time to load the data.

An efficient retinal analysis method based on curvelet transform and multi structure elements was proposed by Miri et al [9] in 2011, he described that green channel of the original colored image was selected. Obtain the fundus region mask using Otsu algorithm followed by morphological closing and multiply its result image with FDCT via wrapping, then modify the curvelet coefficients and obtained the enhanced image. Then subtracts the estimated background from the enhanced image. Thereby modified top-hat transforms using the multistructure elements morphology were applied and by providing opening function the image were reconstructed. In order to eliminate the remained false edges, apply length filtering along with CCA [2] locally but the image resulted from TopHat function can include all negligible changes in the grey levels existing in the image (such as noise).

Priya R et al [8] in 2011 used preprocessing techniques like Gray scale Conversion, Adaptive Histogram Equalization, Matched Filter Response and proposed a method for feature extraction based on Area of on pixels, Mean and Standard Deviation. Also in 2012, Jaspreet Kaur and Dr. H.P.Sinha [3] presented a Filter based approach with morphological filters is used to segment the vessels. The morphological filter is tuned to match that part of vessel to be extracted in a green channel image. To classify the pixels into vessels and non vessels local thresholding based on gray level co-occurrence matrix as it contained information on the distribution of gray level frequency and edge information have been presented.

In 2012, Paintamilselvi et.al [4] carried out blood vessels extraction in five steps. First the RGB image was converted into gray scale. Secondly morphological opening and closing operation is used to reduce small noise. In the third step to obtain the vessel structure a unique technique called top hat transformation was used. In the fourth step, the resultant image was obtained after binarisation and thresholding. Finally connected component analysis was used to obtain an image which was free from noise.

The rest of the paper is organized as follows: In Section 3 proposed methods is described while section 3.1.1 & 3.1.2 examines green channel selection and image enhancement using adaptive histogram equalization, In Section 3.1.3. describes Contrast enhancement using FDCT and section 3.2 presents the method for extraction of vessels from colored retinal image. In section 4 the results of the algorithm over an extensive dataset are presented and conclusions are reviewed in section 5.

3. PROPOSED METHOD

The proposed system in this work consists of following steps preprocessing and blood vessels extraction. The block diagram of retinal blood vessels extraction is shown in Figure 1.

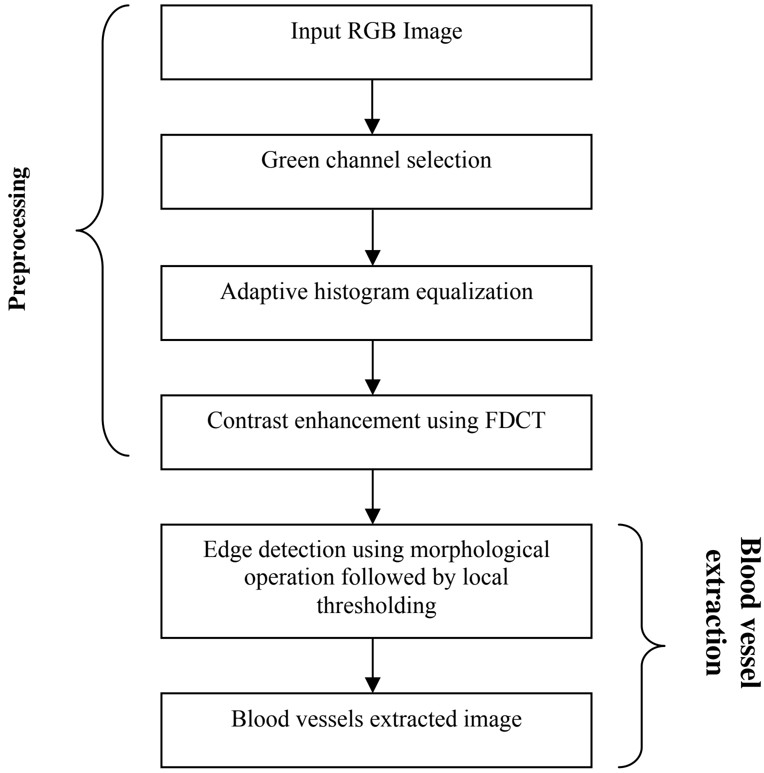

Figure 1. Block diagram of retinal blood vessels extraction technique

3.1. Preprocessing

3.1.1. Green Channel Selection

If the three channels of a RGB coloured retinal image are observed, the red channel shows a poorly contrasted retinal vasculature on top of the choroidal vasculature. The Green channel shows well contrasted arteries and veins with a clear dark fovea in the centre. The blue channel shows a noisier image of the vasculature. So that green channel has the best contrast by experience is shown in Figure 2. Hence it is selected for further work.

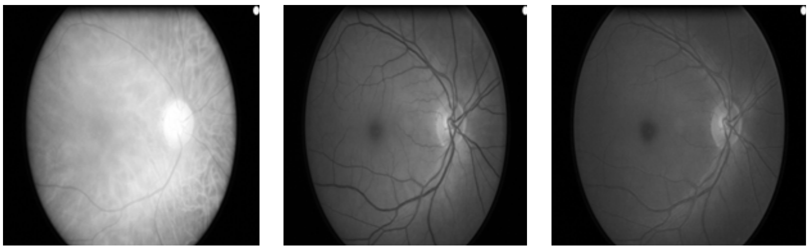

Figure 2. (a) Red channel, (b) green channel and (c) blue channel

3.1.2. Adaptive Histogram Equalization

We initially worked on the colour retinal image. To reduce the effect of different lightning conditions and to uniform illumination Adaptive histogram Equalization is used. It is an enhancement technique capable of increasing the local Contrast also it improves the brightness of an image. It differs from ordinary histogram equalization in the respective that adaptive method computes several histograms each corresponding to distinct section of the image and uses them to redistribute the lightness values of image. So that contrast of the image was adjusted to the limit 0 and 1 hence the blood vessels are highlighted.

3.1.3. Contrast Enhancement using Fast Discrete Curvelet Transform

Curvelet transform is developed to overcome the limitation of wavelet and Gabor transforms [10]. Although, wavelets are widely used in feature extraction but it fails to handle randomly oriented edges of the object and the singularities of the object. Gabor filters overcome the limitation of wavelet transform and deal with the oriented edges, but it loses the spectral information of the image. Curvelet transform is used to overcome these problems of the wavelet and Gabor filters. It can obtain the complete spectral information of the image and handle with the different orientations of the image edges.

The idea of curvelet is to represent a curve as a superposition of functions of various lengths and widths obeying the scaling law width ≈ length^2. This can be done by first decomposing the image into subbands i.e. separating the object into a series of disjoint scales. Then, each scale is analyzed by a local ridgelet transform. The newly constructed and improved version of the curvelet transform is known as Fast Discrete Curvelet Transform (FDCT). The new constructed version is faster, simpler and less redundant than the original curvelet transform, which based on Ridgelet. As mentioned, according to Cand'es *et al.* [15] two implementations of FDCT are proposed:

1. Unequally spaced Fast Fourier Transform (USFFT)
2. Wrapping Function

Both implementations of FDCT differ mainly in choosing the spatial grid that used to translate curvelet at each scale and angle. Both digital transformations return a table of digital curvelet coefficients indexed by scale, orientation and location parameters. Here, we use the wrapping method to implement the Fast Discrete Curvelet Transform (FDCT) on the retinal image which is a two dimensional signal. The wrapping implementation is simpler, faster and has less computational complexity than existing approaches. Wrapping based curvelet transform is a multi-scale pyramid which consists of different orientations and positions at a low frequency level. Basically, multiresolution discrete curvelet transform in the spectral domain utilizes the advantages of fast Fourier Transform (FFT). During FFT, both the image and the curvelet at a given scale and orientation are transformed into the Fourier domain. At the end of this computation process, we obtain a set of curvelet coefficients by applying inverse FFT to the spectral product. This set contains curvelet coefficients in ascending order of the scales and orientations [11].

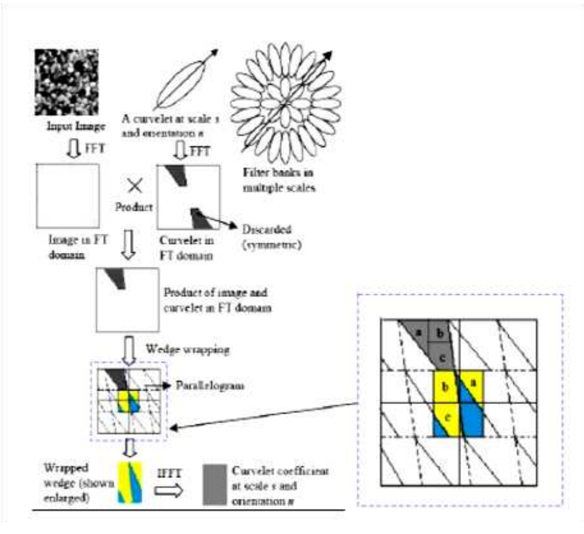

Figure 3. Steps in FDCT via wrapping method

In order to obtain the curvelet coefficients for an image the below steps are performed sequentially.

1) Apply the 2D FFT and obtain Fourier samples

$$\hat{f}\ [n1,n2],\ -n/2<n1,\ n2<n/2 \tag{1}$$

2) For each scale j and angle l, form the product

$$\tilde{U}_{j,l[n1,n2]} \; \hat{f}_{[n1,n2]} \tag{2}$$

Where, j, l [n1, n2] is the discrete localizing window.

3) Wrap this product around the origin and obtained

$$\hat{f}_{[n1,\,n2]} = W(\tilde{U}_{j,l} \; \hat{f})[n1,n2] \tag{3}$$

Where, the range for n1 is now 0 < n1 < L1,j and 0 < n2 < L2 are constant.

4) Apply the inverse 2D FFT to each *f(j,l)*, hence collecting the discrete coefficients C^D (j, l, k).

Since the Curvelet transform is well adapted to represent the images containing edges, it is a good candidate for edge enhancement. Furthermore the contrast of an image is enhanced using modified curvelet coefficients. Subsequently our proposed method to analyze the retinal image consists of the following steps:

i) Applying FDCT via wrapping method, we obtain a set of scales S_j and directional bands C_i coefficients.
ii) For each directional band, C{1}{1} the minimum threshold value were determined and replace all the coefficients with these values.
iii) Reconstruct the enhanced image using these modified coefficients.

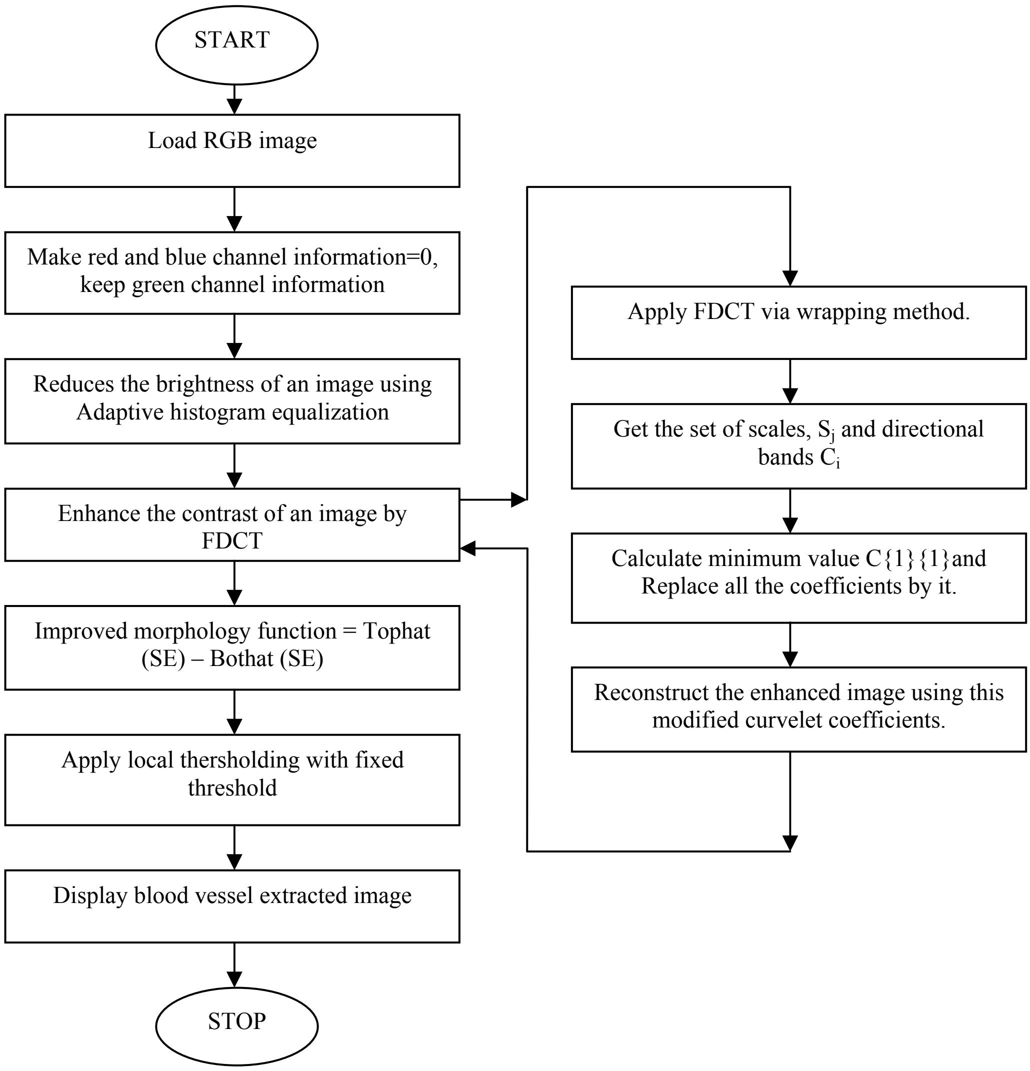

Figure 4. Flow Chart to classify Blood Vessels from retinal image

3.2. Extraction of Blood Vessels

Morphology is a broad set of image processing operations that process images based on shapes. Morphological operations apply a structuring element to an input image, creating an output image of the same size [7]. In a morphological operation, the value of each pixel in the output image is based on a comparison of the corresponding pixel in the input image with its neighbors. Many morphology functions are applied in feature extraction (e.g., opening), but the problem of this function is that the pixels in the resulted image can include all negligible changes in the grey levels existing in the image.

In our proposed algorithm, improved morphology function is used and it is defined as,

$$Improved\ function = imsubtract\ \{(I_0 - (I_0 \circ SE) - (I_0 \bullet SE) - I_0)\} \quad (4)$$

Where, I_0 is the image to be processed, ◦–opening operator,•–closing operator, SE is the disk shaped structuring element. A structuring element is a matrix consisting of only 0's and 1's that can have any arbitrary shape and size. The pixels with values of 1 define the neighborhood. The center pixel of the structuring element, called the origin, identifies the pixel being processed.

The Tophat transform is used for extracting small or narrow, bright or dark features in an image. It is represented as,

$$h = I_0 - (I_0 \circ SE) \quad (5)$$

The Bothat transform, also called closing residue, is used to extract valleys such as dark lines and dark spots. It is a process which is done by the subtraction of the original image from the closing result. Therefore, the blood vessels of the retina, actually considered as dark lines are extracted by applying the bothat transform. The bottom-hat transform is expressed as the following equation,

$$h = (I_0 \bullet SE) - I_0 \quad (6)$$

In our proposed work, morphological operation is performed by highlighting its background to a line size of 7. Ten rotated structuring elements are applied with a radial resolution of 15 . The structuring element length should be chosen such that it must be smaller than the lowest pixels present in the set. Then the highlighted background is subtracted using Tophat and Bothat transformation so the blood vessels are shown much clearly when compared to the original image. As a result there occur some frills in the final edge image due to intrinsic noise present in the retinal image. It is completely removed and converted in to binary image with local thresholding technique. The final image is displayed with extracted blood vessels are shown in black and the background as in white

4. EXPERIMENTAL RESULTS

The automatic extraction of blood vessels from retinal image was evaluated on the publicly available DRIVE and STARE databases. The experiments were implemented using the MATLAB version 7.5 software initially CurveLab toolbox was installed in Matlab. Some of the values are different for different images, as they were estimated from different orientations and background settings.

The proposed methodology describes the various techniques used for contrast enhancement and edge detection in RGB retinal image. The Figure 5 shows the input coloured retinal image. Since the RGB image has higher dimension it was resized to less than half of the original size. In preprocessing, green channel in Figure 6 shows the best background contrast than other two channels; so it was selected for further process. Since the nonuniformity of illumination generates the frills in the final edge image, so it is necessary to uniform the image illumination. This enhancement is done by using adaptive histogram equalization; it makes the vessels appear brighter than the background is shown in Figure 7. Afterward by using multiscale and the multidirectional Curvelet transform edges of an image are enhanced thereby increasing the contrast. At the outset of FDCT via wrapping, a set of scales S_j and directional bands C_i coefficients are obtained. For each directional band, C{1}{1} the minimum threshold value is determined and replace all the coefficients with these modified coefficient values after that image were reconstructed using IFDCT is shown in Figure 8.

By introducing improved morphological function with structuring elements the blood vessels are extracted. It is performed by highlighting its background to a line size of 7. Ten rotated structuring elements are applied with a radial resolution of 15 . The highlighted background is subtracted with Tophat and Bothat transformation, so that blood vessels alone are shown much clear than background pixels. The image is then converted to a binary image with Local thresholding of fixed size. Hence the resultant image where the extracted blood vessels are in black and the background in white are shown in Figure 9.

To facilitate the performance of retinal vessel extraction algorithms, we have selected the PSNR and RMSE as performance measures. Those measures are estimated as follows.

Figure 5. Input RGB image

Figure 6. Green channel representation

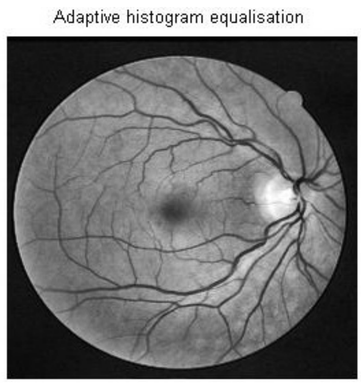

Figure 7. Adaptive histogram equalized image

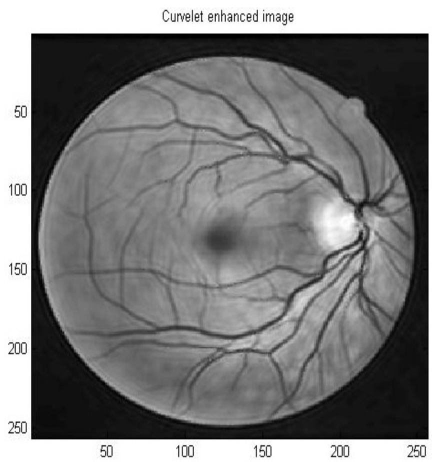

Figure 8. Curvelet enhanced image

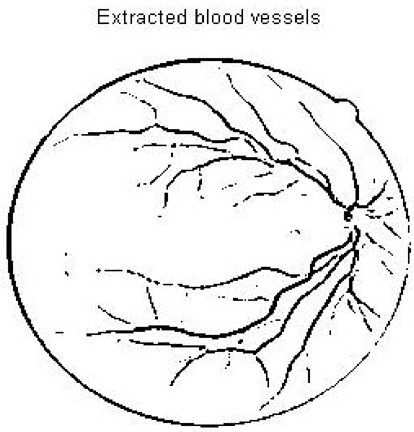

Figure 9. Segmented blood vessels

Peak Signal to Noise Ratio (PSNR): PSNR evaluates the intensity changes of an image between the original and the processed image.

$$\text{PSNR} = 20 \log_{10} (255/\text{MSE})^2 \quad (7)$$

Mean Squared Error (MSE): MSE(Mean Squared Error) is computed via,

$$\text{MSE} = \frac{1}{mn} \sum_{i=1}^{m} \sum_{j=1}^{n} ||I_0(i,j)-I_p(i,j)|| \quad (8)$$

$$\text{RMSE} = \sqrt{MSE} \quad (9)$$

Where, MSE are mean squared error of image, I_o is the original image and I_e is the enhanced image.

Table I . Performance Analysis

Module	PSNR (dB)	RMSE
Preprocessing	30.236	28.419
Enhancement Using FDCT	31.56	22.89
Extraction of blood Vessels using morphological operation	34.48	22.67

5. CONCLUSION

Here we present a novel method to develop a quick algorithm for classifying the blood vessels in retinal images. It has considered the criteria for assessing the methods used for enhancing the contrast of the images and extracting the blood vessels. Since the Edge enhancement plays an important role in final extraction results, applying histogram equalization on retinal image will have a noticeable effect on both having the retinal images with uniform illumination as well as improving the accuracy of the final edge image. Considering the aforesaid attributes of the Curvelet transform, it was seen that, this developed instrument has served successful in enhancing the contrast of the images. In the method of combination of tophat and bothat morphology function with structuring elements, the structure elements act with more power in recognizing the edges. Of course, there were some frills in the edge image due to the changes in illumination of the background. These frills were removed effectively by local thresholding with defined value. Considering that the algorithm can extract blood vessels from the retinal images with high accuracy in nearly good time, it can be used as the fast and reliable method. Actually automated analysis of fundus images requires segmentation of image into regions such as optic disk, fovea, vessels, and background retina. The technique described here can perform part of this extraction process i.e. blood vessels extraction. In future, improved preprocessing techniques should be used on the proposed algorithms. Such techniques could contribute to further improvements on the algorithms, resulting in more robust and more precise detection that eventually can be accepted for the clinical purposes.

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