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An Effective Method for Blood Vessel Detection in Sclera

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***Abstract*— This paper proposes a new method for vessel detection in sclera by incorporating the concept of frangi filter and wavelet transform. Sclera blood vessel detection is an important step in human identification. Sclera is the white and opaque outer protective covering of an eye. Sclera area detection is used to identify the relevant portions of the sclera from the eye region for further processing and identification. Sclera area is detected based on Otsu's thresholding method. Blood vessel structure in the sclera area portion is detected based upon frangi filter and wavelet transform. In frangi filter the eigen value analysis of the hessian matrix is performed. Then wavelet decomposition of the filtered image is used to obtain the vessel structure in the sclera.**

***Index Terms*— Otsu thresholding, frangi filter, discrete wavelet transform**

I. INTRODUCTION

The sclera is the white part of the eye. It is the tough, opaque tissue that serves as the eye's protective outer coat. It forms the supporting wall of the eye ball. The sclera is made up of four layers of tissue-episclera, stroma, lamina fusca and endothelium. The white appearance is because of the scattering of all wavelengths of light by dense irregular bundles of collagen in sclera. In children, a bluish hue is observed because of the extremely thin sclera which allows the visibility of underlying choroid. In older age the sclera may appear slightly yellowish because of the deposition of fat.The episclera is the thin densely vascularized layer of connective tissue overlying the sclera.

The blood vessel structure in sclera is unique to each person and stable. This blood vessel structure in the sclera can be used as a biometric for human identification. Figure 1 shows the structure of an eye where the blood vessel structure in the sclera portion is in the left side.

Blood vessel structure of sclera can also be used for diagnosis of eye diseases. Eye redness is due to swollen or dilated blood vessels. It causes the surface of the eye to look red or bloodshot. Redness on the white of the eye is one of the symptoms of scleritis and episcleritis diseases. To analyze about the blood vessels, vessel structure is to be detected

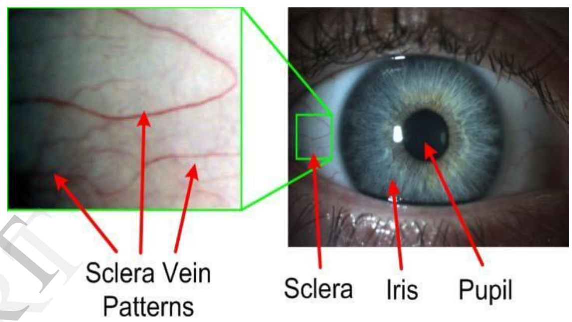


Fig 1: The structure of an eye

In the related works, conjunctival vasculature detection is being used as a preprocessing step in human identification. In [3] Derakhshani *et. al* proposed Contrast limited adaptive histogram equalization (CLAHE) method is used to enhance the green color plane of the RGB image because the green layer of the RGB image has a better contrast between the blood vessels and the background. A multi-scale region growing approach is used to identify the sclera veins from the image background. In [5] Crihalmeanu *et. al* proposed a CLAHE method to enhance the vessel and selective line enhancement filter to detect the vein.

Here a new method is introduced which combines frangi filter and wavelet transform for vessel detection. In the frangi filter eigen value analysis of the hessian matrix is used to detect the vessel structure. Wavelet transform is the time frequency representation of the signals.

This paper is organized as follows. In section II, proposed method for blood vessel detection is discussed. Section III introduces sclera area detection. Section IV describes vessel detection.

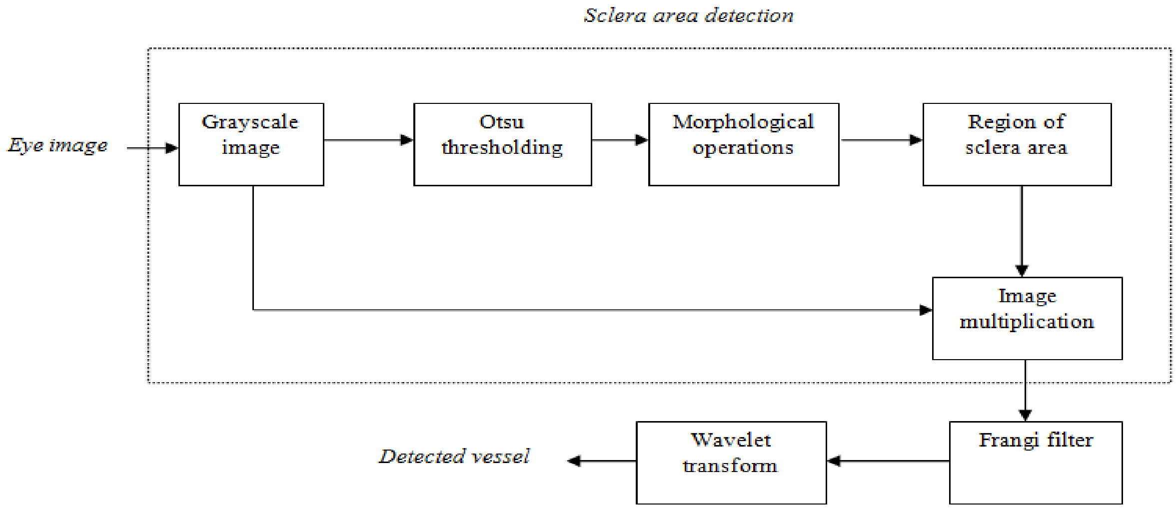


Fig 2: Block diagram of proposed method

II. PROPOSED METHOD

The proposed method is a combination of frangi filter and wavelet transform to detect the vessel structure. Fig 2 shows the block diagram of the proposed method to detect the vessel structure in the sclera area.

In this method, first eye image is subjected to sclera area detection. Sclera area detection is developed that can accurately detect the sclera region from the eye image. The proposed method detects the sclera area based on Otsu's thresholding method. The thresholded sclera area is subjected to morphological operation to remove the noise. Region of sclera area is then multiplied with the grey scale eye image to obtain the sclera area. This is to identify and extract the relevant portions of the sclera from the original image of the eye region for further processing. Detected sclera area is then subjected to vessel detection technique. In the vessel detection method frangi filter is applied to detected sclera area and the filtered image thus obtained is transformed using wavelet.

III. SCLERA AREA DETECTION

Sclera area detection is used to identify and extract the relevant portion of the sclera from the original image of the eye region for further processing. It includes grayscale image conversion, Otsu thresholding, morphological operation and image multiplication.

In this technique, eye image in the form of a color image is converted in to grayscale image. A grayscale image is one in which the colors are shades of gray. The reason for differentiating such images from color image is that less information needs to be provided for each pixel. Otsu thresholding method is appled to grayscale image.

Otsu's method [6] is a Linear Discriminant Analysis-based thresholding method. It assumes that there are two classes In an image, foreground (object) and background, which can be separated into two classes by intensity. Otsu's method automatically searches for the optimum threshold that can maximize the between-class distance. Figure 3 shows the sclera area detection from the eye image.

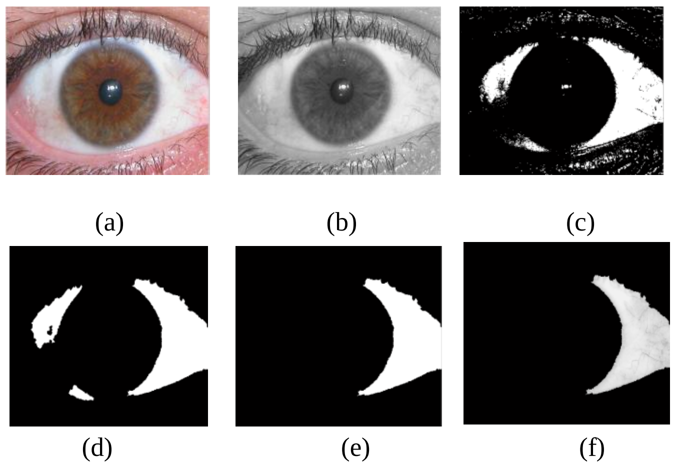


Fig 3: Sclera area detection (a) Eye image (b) Grayscale image (c) Thresholded image (d) morphological operated image (e) region of sclera area (f) sclera detected area

Otsu's method is applied to the grey scale image to obtain potential sclera areas. The algorithm for Otsu's thresholding method is as follows:

- Compute the normalized histogram of the input image. Denote the components of the histogram by p_i ,i=0, 1, …, L-1.
- Compute the cumulative sums P_1 (k), for k = 0,1, …,… L-1.
- Compute the cumulative means, m(k), for k = 0,1, …, L-1.
- Compute the global intensity mean.
- Compute the between-class variance, for k = 0,1, ….. L-1.
- Obtain the Otsu‘s threshold, k*.

IV. VESSEL DETECTION

The vessel is being detected from the sclera region by means of frangi filter and wavelet transform. Frangi filtering process searches for geometrical structures regarded as tubular. Discrete wavelet transform is applied to the frangi filtered image to generate the filter coefficients. Low frequency coefficient of the transformed image contains the vessel structures clearly.

A. Frangi Filter

A common approach to analyze the local behavior of an image L, is to consider its Taylor expansion in the neighborhood of a point x_o .

$$L(x_o + \delta x_{o,s}) = L(x_o, s) + \delta x_o^T \nabla_{o,s} + \delta x_o^T \mathcal{H}_{o,s} \delta x_o$$
(1)

This expansion approximates the structure of the image up to second order. $\nabla_{o,s}$ and $\mathcal{H}_{o,s}$ are the gradient vector and Hessian matrix of the image computed in at scale s. Differentiation is defined as a convolution with derivatives of Gaussians:

$$\frac{\partial L(x,s)}{\partial x} = s^{\gamma} L(x) + \frac{\partial G(x,s)}{\partial x} \quad (2)$$

Where the D-dimensional Gaussian is defined as:

$$G(x,s) = \frac{1}{\sqrt{2\pi s^2}^{D}} e^{-\frac{\|x\|^2}{2s^2}} \quad (3)$$

The parameter γ was introduced by Lindeberg to define a family of normalized derivatives. This normalization is particularly important for a fair comparison of the response of differential operators at multiple scales. When no scale is preferred γ should be set to unity. Analyzing the second order information (Hessian) has an intuitive justification in the context of vessel detection. The third term in Eq (1) gives the second order directional derivative.

$$\delta x_o^T \mathcal{H}_{o,s} \delta x_o = \left(\frac{\partial}{\partial \delta x_o}\right)\left(\frac{\partial}{\partial \delta x_o}\right) L(x_o, s) \quad (4)$$

The idea behind eigen value analysis of the Hessian is to extract the principal directions in which the local second order structure of the image can be decomposed.

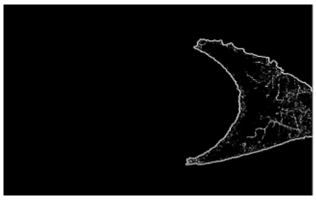


Fig 4: Frangi filtered image

The partial derivative is defined as pixel intensity differences in the neighborhood of the pixel. The hessian matrix describes the 2nd order local image intensity variations around the selected pixel. For the obtained Hessian matrix, the eigen value and eigen vector are calculated. Fig 4 shows the frangi filtered image. Frangi introduced two measures to describe structure in images:

Second order structureness is defined as:

$$S = \|\mathcal{H}\|_F = \sqrt{\sum_{j \le D} \lambda_j^{2}}$$
(5)

Blobness measure is defined as:

$$R_B = \frac{\lambda_1}{\lambda_2}$$
(6)

The vesselness measure is the likelihood that a pixel belongs to a blood vessel, which is maximum for a line structure

$$v(s) = \begin{cases} 0 & if \lambda_2 > 0 \\ \exp\left(\frac{-R_B{}^2}{2\beta^2}\right)\left(1 - \exp\left(\frac{-s^2}{2c^2}\right)\right. \end{cases}$$
(7)

where β and c are thresholds which control the sensitivity of the line filter to the measures R_B and S.

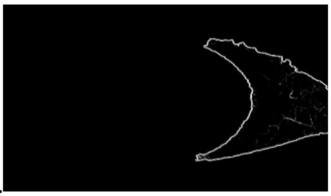
B. *Wavelet Transform*

Discrete wavelet transform is applied to the frangi filtered image in order to generate the filter coefficients.The transform of a signal is just another form of representing the signal.

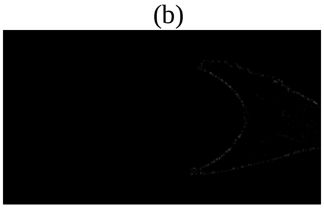
A wave is an oscillating function of time or space and is periodic. Wavelets are localized waves, have their energy concentrated in time or space and are suited to analysis of transient signals. Fourier Transform and STFT use waves to analyze signals, the Wavelet Transform uses wavelets of finite energy. The signal to be analyzed is multiplied with a wavelet function just as it is multiplied with a window function in STFT, and then the transform is computed for each segment generated.

However unlike STFT, in Wavelet Transform the width of the wavelet function changes with each spectral component. The Wavelet Transform at high frequencies gives good time resolution and poor frequency resolution while at low frequencies the Wavelet Transform gives good frequency resolution and poor time resolution.

The Wavelet Series is just a sampled version of CWT and its computation may consume significant amount of time and resources, depending on the resolution required.




(a) (b)

(c) (d)

Fig 5: Wavelet transform coefficient (a)approximation(b)horizontal(c)vertical (d) diagonal

The Discrete Wavelet Transform (DWT) is based on sub-band coding is found to yield a fast computation of Wavelet Transform. It is easy to implement and reduces the computation time and resources required. In CWT, the signals are analyzed using a set of basis functions which relate to each other by simple scaling and translation. In the case of DWT, a time-scale representation of the digital signal is obtained using digital filtering techniques. The signal to be analyzed is passed through filters with different cutoff frequencies at different scales. Figure 5 shows the wavelet transform coefficients.

Filters are one of the most widely used signal processing functions.The resolution of the signal, which is a measure of the amount of detail information in the signal is determined by the filtering operations and the scale is determined by upsampling and down sampling (sub sampling) operations Subsampling a signal corresponds to reducing the sampling rate or removing some of the samples of the signal.Subsampling by a factor n reduces the number of samples in the signal n times.Upsampling a signal corresponds to increasing the sampling rate of a signal by adding new samples to the signal. For example, upsampling by two refers to adding a new sample, usually a zero or an interpolated value between every two samples of the signal. Upsampling a signal by a factor of n increases the number of samples in the signal by a factor of n.

After applying 1st level wavelet decomposition in to the frangi filtered image, four coefficients are generated. One is low frequency component or approximation coefficient and other three coefficients are high frequency coefficients or detailed coefficients. Vessel structure is more visible in the approximation coefficient. Figure 6 shows the detected vessel structure.

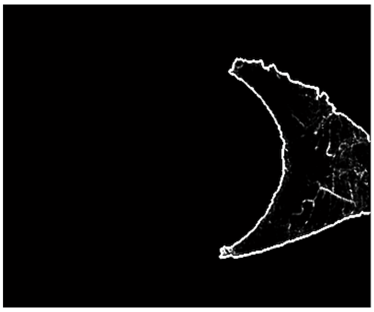


Fig 6: Detected vessel structure

V. CONCLUSION

Vessel detection has an important role in the human identification and diagnosing diseases. The blood vessel structure of sclera is unique to each person, so it can be used as a biometric for identification. Here sclera area is detected by means of Otsu thresholding method. Vessel structure is detected using frangi filter and wavelet transform.

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