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A Comparison between Contrast Limited Adaptive Histogram Equalization and Gabor Filter Sclera Blood Vessel Enhancement Techniques

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Abstract— The importance of the human sclera lies in the uniqueness of the blood vessel structure which can be easily obtained non-intrusively in visible wavelengths. The unique and persistent characteristic of the sclera vessel patterns makes it a suitable candidate for human identification (ID). The proper segmentation of the sclera region and obtaining the sclera vessel patterns are the main problems that this biometric has to deal with. Images of sclera vessel patterns are often defocused or blurry and, most importantly, the vessel structure in the sclera is multilayered and has complex nonlinear deformations. This paper compares two sclera vessel enhancement methods. The first method uses a contrast limited adaptive histogram equalization with region growing technique. The other technique uses a directional Gabor filter bank to enhance the sclera veins. Experimental results showed that the Gabor filter-enhancement method yields faster and better results as compared to the histogram equalization and region growing method.

Index Terms—Gabor filter, histogram, region-growing, sclera vessel pattern.

I. INTRODUCTION

The human eye has always been a suitable biometric due to the unique characteristics of the iris, which is the circular diaphragm that controls the diameter and size of the pupil and thus the amount of light reaching the retina. The reliability of the iris biometric lies in the fact that its structure is unique and stable with time when captured in the near-infra red (NIR) spectrum. Another recent characteristic of the eye that exhibits biometric properties is the human sclera. The sclera, also known as the white of the eye, is the opaque, fibrous, protective, outer layer of the eye containing collagen and elastic fiber. In humans the whole sclera is white, contrasting with the colored iris. In children, it is thinner and shows some of the underlying pigment, appearing slightly blue. For adults, fatty deposits on the sclera can make it appear slightly yellow. The sclera is made up of four layers of tissue: the episclera, stroma, lamina fusca, and endothelium. Its outer surface, called episclera, contains the blood vessels nourishing the sclera. The blood vessel patterns of the sclera are the most significant in the sense that they are unique for each person and are persistent with age. One of the main advantages of using the sclera blood vessels as a biometric is that the structure of the blood vessels can be clearly obtained non-intrusively within visible wavelength illumination. Fig. 1 shows an image of an eye under visible wavelength illumination with identification of the sclera vein patterns [1].

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A crucial part of a sclera biometric system is to obtain a clear picture of the sclera blood vessel patterns [2].

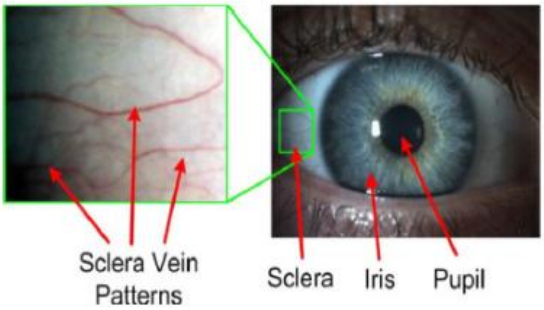

Fig. 1. The structure of the eye and sclera region

The anterior part of the sclera is covered by the conjuctival membrane - a thin membrane containing secretory epithelium that helps lubricate the eyes for eyelid closure. Most of the previous research works involve identification of users using the conjuctival vasculature. However, the conjunctiva is the top-most transparent layer of the sclera and images of the sclera region capture more than just this top-most layer. Generally, it is hard to make out the conjunctival vascular with the naked eye from a distance. This paper focuses on two sclera vein enhancement methods.

The remainder of this paper is organized as follows. Section II discusses the terminology of the field. Section III states the research challenges. In Section IV two sclera vein enhancement schemes are explained. Section V gives a brief comparison between the two sclera vein enhancement methods. The paper is concluded in Section VI.

II. TERMINOLOGY

a). Image segmentation- refers to the procedure that partitions the image into regions of interest according to pixel intensity values, based on either discontinuities (abrupt changes in intensity values such as edges) or similarities (such as grouping pixels based on predefined criteria).

b). Image enhancement- refers to the improvement of the quality of digital without knowledge about the source of degradation. Contrast stretching is a linear transformation that increases the dynamic range of an image [3]. Another image enhancement method is the histogram equalization technique.

c). Image binarization- converts an image of up to 256 gray levels to a black and white image. Normally a threshold value is chosen, and all pixels with values above this threshold are classified as white and all other pixels as black. In many cases, finding one threshold compatible to the entire image is very difficult, and in many cases even impossible. Therefore, adaptive image binarization is needed where an optimal threshold is chosen for each image area.

III. CHALLENGES

The eye region has been extensively used for positive human identification by using, most notably, the iris and, less so, the retina [4-8]. However, little work has been done that uses the sclera region for identification. The main challenge faced by most researchers is the sclera vessel pattern extraction techniques used previously have not been accurate enough and has affected the identification results to a great extent. Accurately segmenting the sclera area and obtaining the blood vessel patterns from the eye image is very important for further processing in a biometric system.

Some of the technical challenges faced during the segmentation and enhancement process are listed below:

i) The eye is a moving organ, and the sclera blood vessel patterns move and become deformed as the eye moves (including the movement of the eye and eyelids, and dilation/contraction of pupil).

ii) The sclera is reflective, so the sclera patterns may be blurry or saturated.

iii) The sclera vasculature is composed of many layers, and hence there is complicated non-linear deformation of the patterns as the eye and/or the surrounding tissues move (such as the eyelids) [9, 10].

IV. SCLERA BLOOD VESSEL ENHANCEMENT TECHNIQUES

Vein enhancement has been implemented and studied for human identification, such as finger vein recognition, palm vein recognition, retina vein recognition, and sub lingual vein recognition. The following are the existing sclera vein enhancement methods.

A. Contrast-limited Adaptive Histogram Equalization

In [11], Derakhshani et. al. first proposed using conjunctival vascular patterns for user identification. The conjuctiva is the thin top layer of the sclera region, and the conjuctival vasculature is the system of veins and arteries in this layer. Image enhancement was accomplished in two steps.

In the first step they applied a contrast-limited adaptive histogram equalization (CLAHE) scheme to the region of interest in order to enhance the color image. The green component of the RGB image was used as it leads to a better contrast between the blood vessels and the background. Then a selective line enhancement scheme was used to enhance the blood vessels of the green component. This scheme identifies lines and curves while suppressing objects of other shapes. The algorithm is based on the second derivatives, using the Hessian matrix, of the intensity image.

$$H = \begin{bmatrix} I_{xx} & I_{xy} \\ I_{yx} & I_{yy} \end{bmatrix}$$

The image is first convolved with a Gaussian function as derivatives are sensitive to noise. The standard deviation of the Gaussian function represents the scale of the lines, its implicitly and the distance around of the blood vessels being detected. For every pixel in the image, two eigen values of the Hessian matrix are computed:

$$\lambda_1 = K + \sqrt{K^2 - Q^2},$$

$$\lambda_2 = K + \sqrt{K^2 - Q^2}$$

Where $K = \frac{I_{xx}+I_{yy}}{2}$, $Q=\sqrt{I_{xx}I_{yy} - I_{xy}I_{yx}}$

Each pixel of the enhanced image is obtained as,

$$I_{line(\lambda_1,\lambda_2)} = \begin{cases} |\lambda_1| - |\lambda_2|, if\ \lambda_1 < 0 \\ 0, if\ \lambda_1 \geq 0 \end{cases}$$

A multi-scale, iterative Gaussian enhancement filter with varying σ is needed since the veins are of different thickness over the image. First the range of vessel calibers are empirically determined and defined $(\sigma_1, \sigma_2 ,,,,,,,,, \sigma_n)$ accordingly. Then the original image is smoothed with a 2D Gaussian. The Hessian matrix and its two eigen values are then computed for every pixel in the smoothed image. Then the line-enhanced image is computed for every pixel. The intensity is normalized by multiplying the output by σ_i^2. The final value of a pixel in the enhanced image is obtained as the maximum of the outputs corresponding to all the σ_i's.

To trace the sclera veins a "region growing" method is used to classify a pixel as foreground (i.e., blood vessel, V) or background (B) [12]. This obtains a binarized representation of conjunctival vascular trees. Otsu's threshold is used to binarize the image so that the pixels can be grouped into two classes [13]. It then uses the information provided by the local intensity values and image gradient magnitudes to determine the final labels. The result of this region growing algorithm is a binary image of the underlying vasculature. This same enhancement method was further used in their preceding research works [14], [15].

B. Gabor filter enhancement

In [16], Thomas incorporates a Gabor filter-based vein enhancement method. The segmented sclera area is highly reflective. As a result, the sclera vascular patterns are often blurry and/or have very low contrast. To mitigate the illumination effect to achieve an illumination-invariant process, it is important to enhance the vascular patterns. Because the vascular patterns could have multiple orientations, a bank of directional Gabor filters is used for vascular pattern enhancement.

$$G(x, y, v, s) = e^{-\pi\left(\frac{(x-x_0)^2+(y-y_0)^2}{s^2}\right)} \times e^{-2\pi i(\cos v(x-x_0)+\sin v(y-y_0))}$$

where (x_0, y_0) is the center frequency of the filter, s is the variance of the Gaussian, and is the angle of the sinusoidal modulation. The even filter is preferred for feature extraction of the vessels, since the even filter is symmetric and its response was determined to identify the locations of vessels adequately. The resulting images after the application of the Gabor filters are summed up to obtain the vessel boosted image. An adaptive threshold is then applied to obtain the blood vessel patterns. The image is first filtered with Gabor filters with different orientations and scales. After Gabor enhancement but before thresholding the vessel structure is clearly visible. An adaptive threshold, based on the distribution of filtered pixel values, is used to determine a threshold to binarize the Gabor filtered image after thresholding. Then, small simply connected regions in the binary mask image are removed using more morphological operations.

V. PERFORMANCE ANALYSIS

For the performance analysis the two methods were implemented with 50 images in MATLAB version 7.10. The Otsu's threshold method was used for the segmentation process. The resulting images show the sclera vessel patterns obtained using both the methods.

The computational time for both the blood vessel enhancement methods was also calculated. The sclera blood vessel patterns for an image under visible wavelength obtained using CLAHE technique is shown in Figure 2.

2a) **2b)**

Fig. 2. a) Original image of the sclera. b) Sclera vessel patterns after CLAHE and region growing.

The Gabor filter method results in the sclera vessel patterns as shown in Fig. 3. The vessel patterns obtained are as a result of all the layers of the sclera vasculature since the directional bank of Gabor filters were used which makes this enhancement method orientation invariant.

Fig. 3. Sclera vessel patterns using Gabor filter enhancement.

In Fig. 4 the computational time of both the enhancement methods is calculated. When using the contrast limited adaptive histogram equalization technique with the region growing method the patterns are obtained with an average the time complexity is 3.3471s.

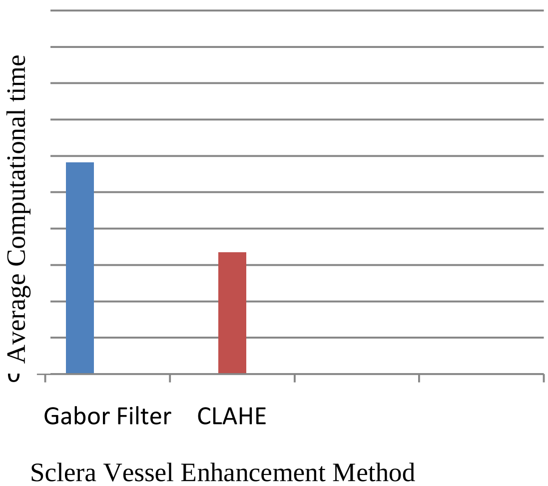

Fig. 4. Comparison of sclera blood vessel enhancement techniques

The Gabor filter enhancement method takes an average of 5.8235s thus making this enhancement approach 49% faster than the CLAHE technique. The results are graphically represented in Fig. 4.

VI.CONCLUSION

A comparison of two approaches to sclera vessel pattern enhancement was performed. The contrast limited adaptive histogram equalization technique used a region growing method to detect the areas that contained blood vessels. However this method only considered the conjunctiva vasculature. The Gabor filter enhancement method overcame this drawback by using the Gabor directional bank which obtained enhanced sclera vessel patterns from multiple layers. The comparison results show that the Gabor filter method obtains the enhanced sclera blood vessel patterns in lesser time than the CLAHE technique. Although the use of the Gabor filter makes this enhancement technique orientation invariant it is computationally expensive. The image resolution and speed of the enhancement process can be improved by using wavelet approaches.

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