

An Effective Retinal Vessel and Landmark Detection Algorithm in RGB images

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ABSTRACT

We present an effective algorithm for automatic tracing of retinal vessel structure and vascular landmark extraction of bifurcations and ending points. In this paper we deal with vascular patterns from RGB images for personal identification. Vessel tracing algorithms are of interest in a variety of biometric and medical application such as personal identification, biometrics, and ophthalmic disorders like vessel change detection. However eye surface vasculature tracing in RGB images has many problems which are subject to improper illumination, glare, fade-out, shadow and artifacts arising from reflection, refraction, and dispersion. The proposed algorithm on vascular tracing employs multi-stage processing of ten-layers as followings: Image Acquisition, Image Enhancement by gray scale retinal image enhancement, reducing background artifact and illuminations and removing interlacing minute characteristics of vessels, Vascular Structure Extraction by connecting broken vessels, extracting vascular structure using eight directional information, and extracting retinal vascular structure, and Vascular Landmark Extraction by extracting bifurcations and ending points. The results of automatic retinal vessel extraction using five different thresholds applied 34 eye images are presented. The results of vasculature tracing algorithm shows that the suggested algorithm can obtain not only robust and accurate vessel tracing but also vascular landmarks according to thresholds.

Keywords: Retinal Vessel detection, Landmark detection, RGB image.

1. INTRODUCTION

Retinal Vessel detection technique is an important and interesting area in a variety of biometric and medical applications such as: personal identification, biometrics, and ophthalmic disorders like vessel change detection [1-3], [14-18]. Notably, the recent advances of information technology and the increasing requirement for security have led to a rapid development of intelligent personal identification systems based on biometrics. Biometrics employs physiological or behavioral characteristics to accurately identify each subject. Commonly used biometric features include face, fingerprints, voice, facial thermograms, iris, retina, gait, palm-prints, hand geometry, etc [2][3]. Of all these biometric features, fingerprint verification has received the most attention, and has been successfully used in law enforcement applications. Face recognition and speaker recognition have also been widely studied over the last 25 years, whereas iris recognition and vasculature recognition are a newly emergent approach to personal identification. It is reported that human eye recognition including iris or sclera is one of the most reliable biometrics analyzed to this point [2].

Human eye is consists of pupil (generally appearing black in

an image), iris (annular part), and the white sclera. It has extraordinary structures and provides many interlacing minute characteristics such as freckles, coronas, stripes in iris, and arterial and venous blood vessels of different girth, depth, and intensity in sclera. Human eye includes these visible characteristics including iris, retinal vessel that are unique to each subject. Compared with other biometric features such as face, voice, etc, the eye recognition is more stable and reliable for identification. Furthermore since human eye is an externally visible organ, eye-based personal identification systems can non-invasive to their users, which is of great importance for practical applications. Eye-based recognition for personal identification has desirable properties such as uniqueness, stability, non-invasiveness, and permanence. Sclera vessel structure especially, can be one of the most reliable biometrics due to intentionally unchanged characteristics while wearing contact lens can protect iris recognition.

While most works of vessel tracings dealt with high-resolution fundus image, our research deals with vessel patterns from digital camera shown in Fig. 1. Unlike Retinal Fundus images many challenges exist for tracing conjunctival vascular patterns from digital images. First, the scleral backgrounds of images are contaminated with unpredictable shadows, glares, fade-out, and artifacts arising from reflection, refraction, and dispersion. Second, the conjunctival vessels are of different girth, depth, and intensity. Third, some vessels seem to

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intermittently submerge into, or emerge out of the lower conjunctival vessel layers. Fourth, the vasculature seems to have fractal-like structure and thus lacks predictable patterns for heuristic-based tracing that is used for retinal scans. Nevertheless, vasculature-tracing algorithm must be considered to be reliable process in the face of non-ideal imaging conditions and image variability.

Eye surface vasculature tracing algorithm employs four-stage main processing as followings: Image Acquisition, Image Enhancement by gray scale retinal image enhancement, reducing background artifact and illuminations and removing interlacing minute characteristics of vessels, Vascular Structure Extraction by connecting broken vessels, extracting vasculature structure using eight directional information, and extracting retinal vascular structure. Vascular Landmark Extraction by extracting bifurcations and ending points. The proposed algorithm can obtain not only robust and accurate retinal vessel tracing but also vascular landmarks according to thresholds. This paper represents algorithm that is not only adaptive enough to be useful and reliable but is also effective enough to handle thresholds of interests.

2. BACKGROUND

Eye-based recognition for personal identification has desirable properties such as uniqueness, stability, noninvasiveness, and permanence. Iris-based recognition especially, is expanded rapidly. However, research on retinal vessel structure for personal identification has not revealed its full potential. The sclera vessel has very unique features for each person, so it will be one of the most reliable biometrics.

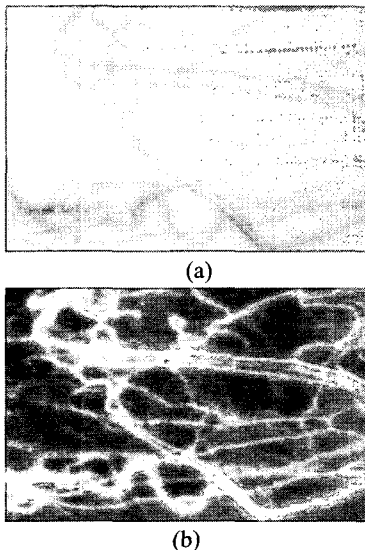


Fig. 1. (a) the example of a color retinal vessel image. (b) the example of inversed gray retinal vessel image

Reliable vessel extraction is a prerequisite for subsequent retinal image analysis and processing because vessels are the predominant and most stable structures appearing in image. Many published algorithm for optic disc detection [4], image

registration [5], change detection [6], pathology detection and quantification, tracking in video sequences, and computer-aided screening systems, depend on vessel extraction [3-6]. The techniques published in the research of retinal vessel extraction may be roughly categorized into methods based on matched filters, adaptive thresholds, intensity edges, region growing, statistical inference, mathematical morphology, and Hessian measures. This wide range of techniques closely corresponds to the suite of methods that have been applied throughout the medical image analysis literature [3][14-18].

Our algorithm has several different approaches. Our algorithm deals with commercial camera image to extract retinal vasculature structure. It produces robust and accurate handling of retinal vascular structure and vascular landmarks and provides effective handling of discontinuous blood vessels by relying on local intensity and edge orientation information.

3. VASCULATURE TRACING ALGORITHM

Here we describe an effective algorithm for robust tracing of the conjunctival vasculature from digital images. Our vasculature tracing algorithm employs four-stage main processing of ten-layers as following.

3.1 Image Acquisition

Image acquisition includes three step processes as follows: a color close-up image of the eye is acquired using a digital camera. The image is manually segmented and the conjunctival target area is extracted. A gray-level image is produced by extracting the green layer of the original RGB image. As for color retinal image, the blue band appears to be weak and does not contain much information compared with green channel of image. The vessel appears in red, however the red band usually contains too much disturbance, or is simply saturated since most of the features emit a signal in the red band. On the other hand, the green component of color image gives the blood vessels on a highly contrasted background (dark blood vessels on a bright background). Hence, the green channel of image is employed in the retinal vasculature detection.

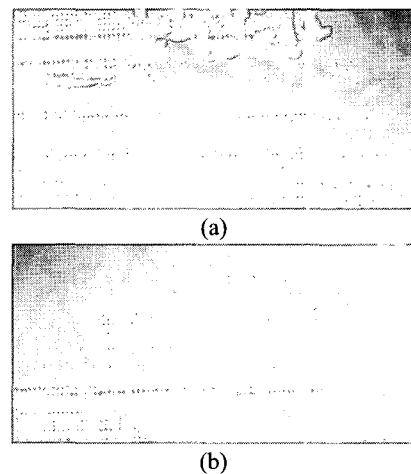


Fig.2 (a) a color digital image including strong reflection from middle upper part to left boundary and dark noise in right upper boundary. (b) a color digital image including dark shadows particularly caused from eye ball curvature in left upper boundary and reflection in right upper side.

3.2 Image Enhancement for Vessel Detection

Usually eye surface is covered with fluid from tear ducts which generate artifacts arising from reflection, refraction, dispersion. Some examples of the segmented blood vessel image are illustrated in Fig. 2. The image of Fig. 2(a) shows a strong reflection from middle upper part to the left boundary and dark noise is in right upper boundary. The scleral backgrounds of images are contaminated with unpredictable shadows, glares, fade-out due to illuminations and eye surface curvatures. The example of this case is illustrated in Fig. 2(b) which has included dark shadows particularly caused from eye ball curvature in left upper boundary and reflection in right upper side. For removing background reflection and artifacts, image enhancement is performed by three-step processes as following.

3.2.1 Gray scale retinal image enhancement

Fig. 2 shows examples of retinal images, which have different conditions and different shapes and vessel sizes. Notice that the strong responses in the center or boundary of image, which are obviously not vessel, are unfortunately much stronger than the responses on the other side of the image, which are vessel. In this case, applying a single global threshold does not provide adequate classification. Therefore, before segmenting blood vessels, we use adaptive histogram equalization to enhance the contrast of the vasculature images. The strength of this method provides the adaptive contrast enhancement according to the intensity of region-based attributes. This process is for achieving more apparent vessel structures by adjusting the overall background intensity of vessel images [11][12].

3.2.2 Reducing background artifacts and illumination noises

This process minimizes background interlacing minute vessel information and background artifacts, and allows retinal vessel structure to be detected reliably by measuring local symmetry. The measure is invariant to the magnitude of the local contrast and so background features that we might consider to be of little significance can be strong symmetry. Also being a low-level measure that only considers local intensity values there is no distinction between foreground and background. Using this effect of phase symmetry operation we lessened background artifacts, shadows and illumination and background very weak interlacing minute vessels and found the invariant quantities of image i.e., retinal vessel edges[6][7].

Symmetry of an object under a certain transform is given by

$$\begin{aligned} Sym(x) &= \frac{\sum_n [A_n(x) [|\cos(\phi_n(x))| - |\sin(\phi_n(x))|] - T]}{\sum_n A_n(x) + \epsilon} \\ &= \frac{\sum_n [[|e_n(x)| - |o_n(x)|] - T]}{\sum_n A_n(x) + \epsilon} \end{aligned} \quad (1)$$

where $A_n(x)$ is amplitude of the transform, and the phase is given by $\phi_n \cdot e_n$ and o_n can be thought of as real and imaginary part of the complex valued frequency component. The term ϵ is a small constant to prevent division by zero where the signal is uniform and no filter response is obtained. The factor T is for noise compensation and represents the maximum response that can be generated by noise alone [6][7].

3.2.3 Removing interlacing minute characteristics of vessels

This is for erasing background interlacing faded vessels from previous process such as overlapped weak blood vessels of lower layer which appears as noises when using threshold method. Object pixels of retinal vessels are selected by hysteresis threshold. The histogram is divided into three parts of object vessels, clear connected overlapped part of retinal vessels and eliminated background. We consider the former two objects as extracted vessel structure and the latter background as removable object [3][10].

3.3 Vessel structure extraction

3.3.1 Connecting broken edges of retinal vessel

This step is for connecting main vessels by joining broken edges within close proximities arising from the previous step. This process is implemented using 2D Gaussian smoothing filter. This process is implemented using the following 2D Gaussian smoothing filter.

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{((x-x_0)^2 + (y-y_0)^2)}{2\sigma^2}} \quad (2)$$

Where σ is the width or standard deviation of the filter, and (x_0, y_0) is the centre or mean of the filter.

3.3.2 Extracting vascular structure using eight-directional information.

Retinal vessel structure has extraordinary structures and provides many interlacing minute characteristics. There are close parallel arterial and venous blood vessels of different girth, depth, and intensity in sclera. Some of them are represented main vessels. There is risk to lose some of main vessels information by removing the weak intensity lower layer vessel of the previous processing. So this is performed vessel structure extraction using eight-directional information. This process is implemented using three-Gaussian filters as the followings.

$$G(\sigma, x) = e^{-\frac{x^2}{2\sigma^2}} \quad (3)$$

$$S(x, y) = (G(c_e, x) - G(c_i, x)) \cdot G(c_{en}, y) \quad (4)$$

$$S_\theta(x, y) = S(x \cos \theta - y \sin \theta, x \sin \theta + y \cos \theta), \quad (5)$$

$$\theta = \frac{\pi}{8} d \text{ [rad]}, \quad d = 0, 1, 2, \dots, 7$$

Where c is the width or standard deviation of the filter, and c_e , c_i are the excitatory and inhibitory width or standard deviation of the filter. c_{en} is the sensitivity of the preferred orientation of the filter. θ is a preferred orientation or optimal orientation of the filter.

3.3.2 Extracting vasculature skeleton image of vessel structure

It is usually desirable to reduce the images to thin representations located along the approximated middle of the original curve or line. Thinning is the process of reducing a shape to its core components while retaining the essential features of the original object. The thinned image is also called the skeleton, and is commonly used in conjunction with edge detectors. The most important thing is that the thinned representations is typically easier to process in later stages producing savings in both time and storage complexity [8][9]. The goal of this process is to detect vasculature structures that preserve the connectivity and that curves or lines should be unchanged.

3.4 Vascular Landmarks Extraction

For computational convenience and simplification we deal with bifurcation and ending point as vascular landmarks. Generally the continuous blood vessel without vascular landmarks has two connections of its eight connected neighbors. However the blood vessel with vascular landmarks has different connections according to vessel structures. Bifurcations as vascular landmarks are classified by two kinds of tree branch structure according to the number of connection of its eight connected neighbors: cross perpendicular structure and Y-type structure. The former has four connections of its eight connected neighbors, while the latter has three connections of its eight connected neighbors. Y-type structure bifurcation is divided to perpendicular (convex) Y-type structure that has two perpendicular angles and general Y-type structure. Ending point as vascular landmarks is defined by one connection of its eight connected neighbors.

4. EXPERIMENT RESULTS OF RETINAL VESSEL EXTRACTION

To show the effectiveness of the algorithm, we present the results of each process and show the tracing results of the vasculature changes according to five different thresholds from

34 eye images and then we described the results of vascular landmark extraction. We implemented the processes using mainly MATLAB 7 and its image processing toolbox on a mainstream 3 GHz Pentium IV desktop PC. The size of extracted images is 200*400 pixels.

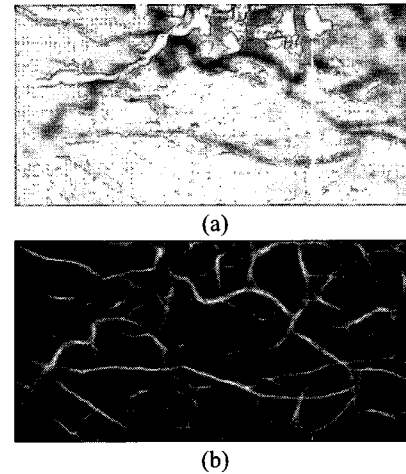
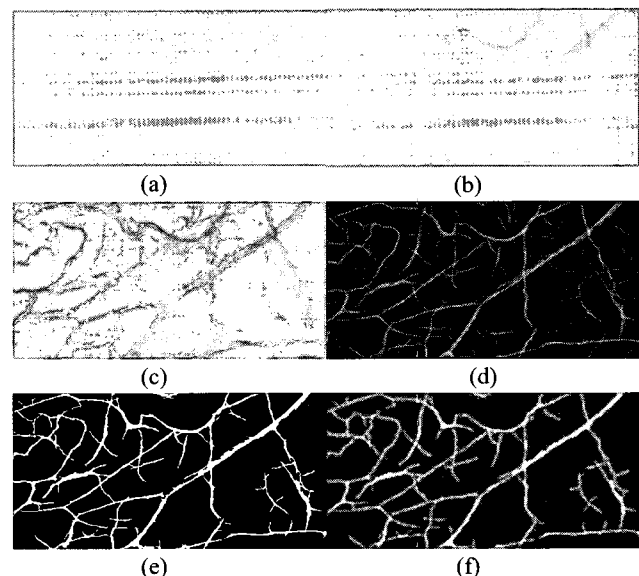


Fig. 3. the example images of reducing background artifacts (a) the gray image of (a) in Fig. 2. (b) the result image after reducing background shadows and artifacts from (a).

The experiment results of each process of our algorithm are illustrated in Fig. 4. It is shown that the proposed algorithm can obtain not only robust and accurate vessel structure but also vascular landmarks according to thresholds.

We present example images after reducing background shadows and artifacts shown in Fig. 3. The original images of Fig. 2 have included background dark shadows or bright artifacts. Yet the images of Fig. 3 have lessened background bright artifacts, dark shadows and noises. The result image is represented strong reflection from middle upper part to left boundary and dark noise and dark shadows in right upper boundary in Fig. 3(a). We obtain the enhanced results regardless of background partial illumination changes using symmetry characteristics illustrated in Fig. 3(b).



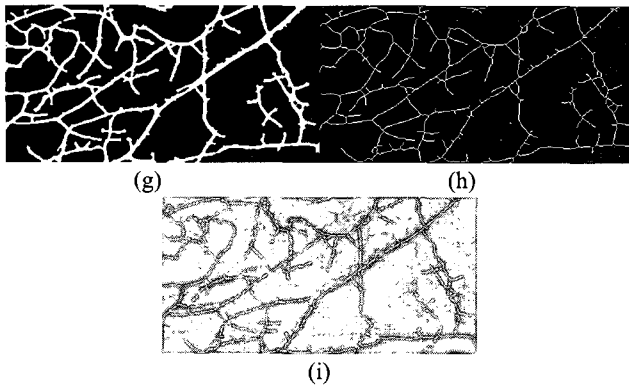


Fig. 4. the results of retinal vessels and vascular landmarks extraction. (a) original image. (b) green channel image. (c) the results of gray image enhancement (d) the result image after reducing background artifacts. (e) the results after removing background (f) the result image after connecting broken edges. (g) the result of extracting vessel structure using 8-directional information (h) the result of extracting vasculature skeleton. (i) the result after extracting bifurcations and ending points which represent red pixels and green pixels.

In order to verify the effectiveness of the proposed algorithm and to compare the extracted retinal vessels according to thresholds we represent the thinned results in Fig. 5. The results of the extracted retinal vessels are increased by decreasing to the lower threshold of intensity. The experiment results of Fig. 4, Fig. 5 and Fig.6 are shown that our algorithm can detect vasculature structures that preserve the connectivity and that curves or lines should be unchanged and the results also located along the original vasculature structure. The extracted bifurcations and ending points of retinal vessel are depicted in Fig. 4(i).

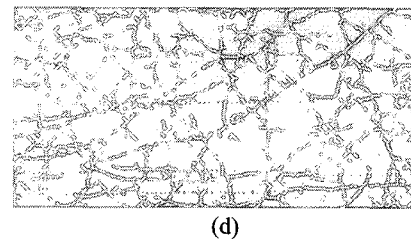
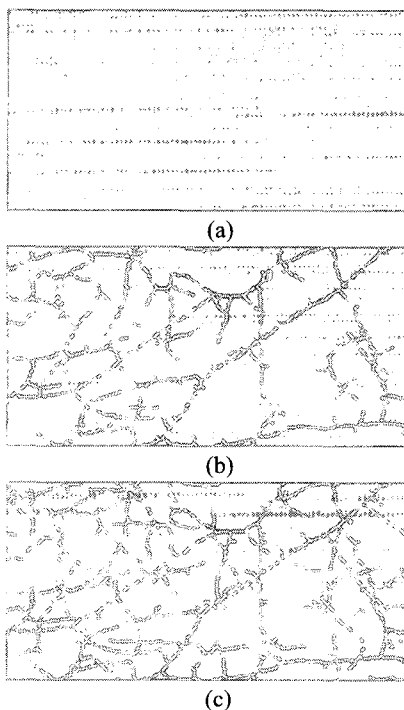


Fig. 5. the results of retinal vessel extraction using five different thresholds. (a) the original retinal vessel image. (b) the extracted results of about 84.31% retinal vessels using the lower threshold of intensity about 15.69%. (c) the extracted results of about 92.15% retinal vessels using the lower threshold of intensity about 7.84%. (d) the extracted results of about 98.03% retinal vessels using the lower threshold of intensity about 1.96%.

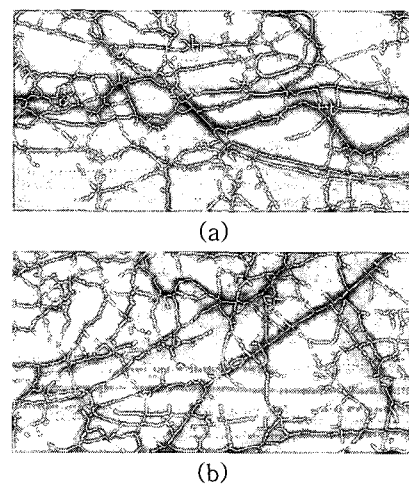


Fig. 6. the results of vasculature landmark extraction. (a) The result of vasculature landmark extraction from original image of Fig. 2(a). (b) the result of vasculature landmark extraction from original image of Fig. 5(a), where red pixels are bifurcations and green pixels are ending points.

5. CONCLUSIONS AND FUTURE WORK

We present an effective algorithm for automatic tracing of vasculature structures and vascular landmark extraction of bifurcations and ending points from 34 human eye images according to five different thresholds for personal identification.

Our algorithm was able to extract retinal vascular patterns and vascular landmarks for identification with satisfactory results. Depending upon the level of details required, the parameters of the suggested sequential operations can be set to reveal different levels of detail and vascular complexities. Our algorithm can be used for real time or near real time applications as the complete process, implemented with MATLAB 7, takes only a few seconds on Pentium IV desktop PC. This method can be used in conjunction with a lot of applications that can benefit from the characterization of conjunctival vasculature. For future work, we intend to enhance our procedure by improving the procedures in order to avoid false pattern matching for personal identification. We are also planning to apply this method to a large number of different

sample images.

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