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Towards finger-vein image restoration and enhancement for finger-vein recognition ☆

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ABSTRACT

Biometric recognition based on human finger-vein patterns is an emerging technique and has been receiving increasing attention. Due to light attenuation in biological tissue, the collected finger-vein images are often seriously degraded. This makes finger-vein feature representation unreliable, and inevitably impairs the accuracy of finger-vein recognition. Exploring suitable ways of finger-vein image restoration and enhancement is indispensable for finger-vein based personal identification. In this paper, we first analyze the intrinsic factors causing the degradation of finger-vein images, and propose a simple but effective scattering removal method to improve the visibility of finger-vein images. Moreover, to handle venous region enhancement problem effectively, a directional filtering method based on a family of Gabor filters is proposed. Finally, a Phase-Only-Correlation strategy is used to measure the similarity of the enhanced finger-vein images. Experiments performed on a large finger-vein image database show that the proposed method is effective and reliable in finger-vein image restoration and enhancement.

1. Introduction

Finger-vein recognition as an accurate and fraud-proof biometric technique has drawn increasing attention from biometrics community in recent years [30,38,60,8,78,76,59,23,32,75,71,70,64,36,55,46,18,65,66,63,62,72,33,34,49,53,69,68,67,74,31]. Compared with conventional biometric traits, e.g., face, iris, fingerprint, plamprint, finger-vein is high live and forgery-proof by itself, high acceptable by users, and very convenient to use. This distinctly differentiates finger-vein from the classical traits and promotes its utilization in many security applications.

In embryology, the formation of vascular tissues is subject to a combined action of both deterministic and random processes in embryogenesis [21,43]. The inherent stochastic mechanism of vascular development is a key factor that directly causes the randomness of finger-vein networks, which therefore makes the finger-vein pattern highly unique and stable as a biometric pattern.

In anatomy, the finger-veins used for biometrics are superficial veins that present between the two layers of superficial fascia without accompanied arteries [57]. Owing to the opaqueness of skin layer, the superficial veins embedded in subcutaneous tissue cannot be visualized clearly by visible light. Hence, for vein imaging, the near infrared (NIR) light (700–900 nm) is often adopted in real applications since the NIR light can be absorbed by the hemoglobin in blood [79]. Especially, the finger-vein images can be captured in a contactless and non-invasive way using a NIR transillumination imaging device

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since the NIR light can penetrate through the human fingers, which is of great importance for user friendliness in practical application.

Unfortunately, it is impossible to capture finger-vein images with high visibility in practice. The biological tissue is highly heterogeneous and behaves as a multiple scattering medium in NIR imaging [1], which inevitably results in the deterioration of image resolution. Therefore, the finger-vein images are always degraded seriously because of multiple scattering interaction in biological tissue [54].

The degradation of finger-vein images brings a big challenge for finger-vein recognition since finger-vein network features cannot be exploited reliably when the separability is poor between the venous and non-venous regions. Over the past years, many efforts have been devoted for finger-vein image enhancement. Histogram equalization based algorithms were used to enhance the contrast of finger-vein images [60,78]. Wang et al. [59] combined the fuzzy and the retinex theory together to enhance the near-infrared vein images. Pi et al. [46] used edge-preserving filter and elliptic high-pass filter together to denoise and enhance some small blurred finger veins. Gao *et al.* [18] combined the traditional high frequency emphasis filtering algorithm and the histogram equalization to sharpen the image contrast. Oh and Hwang [44] proposed a homomorphic filter incorporating morphological subband decomposition to enhance the dark blood vessels. Lee et al. [34] and Rosdi et al. [49] used Gaussian-based high-pass filters to enhance the contrast of finger-vein images. Considering the variations of vein-coursing directions, Yang et al. [70,64,65] used different oriented filtering strategies to highlight the finger-vein texture. Although these methods can enhance finger-vein images to some extent, their performances were considerably undesirable in terms of visibility improvement since none of these methods treats the key issue of light scattering in finger-vein image degradation.

Strong scattering occurring in biological tissue during imaging is the main reason causing contrast deterioration in finger-vein images [7,2]. Considering light transport in skin tissue, Lee and Park used an depth-dependent point spread function (D-PSF) to address the blurring issue in finger-vein imaging [32,33]. This method is encouraging in finger-vein visibility improvement, however, D-PSF was derived for handling degraded issues in transcutaneous fluorescent imaging manner but not in transillumination manner [52]. Thus, the performance of D-PSF on light scattering suppression is still unsatisfying for finger-vein images since, in transillumination, light attenuation (absorption and scattering) arises not only from the skin but also from other tissues of the finger, such as bone, muscles, and blood vessels [6,61]. Moreover, estimating biological parameters properly is also a difficult task for D-PSF based image debluring in practice. To deal with scattering issue, a scattering removal method based on a biological optical model was proposed in our previous works [62,69]. However, our previous method did not take into account the effects of background illumination, and only provided a rough method of scattering estimation. Hence, traditional scattering removal methods still cannot handle the finger-vein restoration problems effectively and reliably.

In this paper, instead of developing an elegant method of finger-vein feature analysis, we focus on two fundamental problems: multiple scattering removal and venous region enhancement, which is directly related to the usability and stability of finger-vein trait in human identification. The main contributions of this paper are the following:

1. A new biological optical model is proposed to reasonably describe the process of finger-vein image degradation.
2. A new scattering removal method is proposed to effectively improve the visibility of finger-vein images.
3. A new Gabor based filtering method is proposed to enhance venous regions as well as suppress fake veins and noises.

The remainder of this paper is organized as follows. In Section 2, we briefly introduce a homemade finger-vein imaging system. The proposed biological optical model is presented in Section 3. Section 4 details the proposed method in finger-vein image restoration. In Section 5, a Gabor-based method is proposed for venous region enhancement. Experimental results are reported in Section 7. Section 8 summarizes this paper.

2. Finger-vein image acquisition

To obtain finger-vein images, we have designed a homemade finger-vein imaging system, which can automatically capture a finger-vein image, as shown in Fig. 1(b). An open window (70×25 mm^2) centered in the width of imaging plane is set for finger-vein imaging. The luminaire is a NIR light-emitting diode (LED) array at a wavelength of 760 nm, and in NIR transillumination, a CCD sensor is placed underneath a finger, as shown in Fig. 1(a).

To localize the ROIs from finger-vein images, a simple but effective method proposed in our previous work [66,68] is used here, as shown in Fig. 1(c). From Fig. 1(c), we can see that veins cast dark "shadows" on the imaging plane while the surrounding tissue (e.g., fat) presents a bright background. These shadows called "angiogram" in medical imaging actually create the finger-vein imageries in NIR transillumination.

Some finger-vein ROIs of one subject at different instants are listed in Fig. 1(d). We can notice from Fig. 1(d) that the sample ROIs have little intra-class variation, which obviously is beneficial for accurate finger-vein recognition.

3. Weighted biological optical model

According to diaphanography in modern medicine, finger-vein imaging is a kind of optical transillumination modality [14]. In this manner, the NIR lights penetrating through a human finger can be refracted, absorbed and scattered by the