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Experimental demonstrations of noise-robustness of compression-based joint wavelet transform correlator in retinal recognition

Komin Kaewphaluk[a], Joewono Widjaja[b,*]

[a] Department of Physics, Academic Division, Chulachomklao Royal Military Academy, Nakhon Nayok 26001, Thailand
[b] School of Physics, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand

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ABSTRACT

Noise robustness of joint wavelet transform correlator with joint photographic experts group (JPEG) image compressions in low-contrast retinal recognition is experimentally demonstrated. The noise robustness is achieved by localizing particular spectra of joint power spectrum via a wavelet filter and an image compression of retinal targets. Besides being robust to noise, experimental results verify that image compression effects on the proposed retinal recognition are minimized.

1. Introduction

In the past few years, vital role of human retina in health medicine and safety has increased rapidly. Systemic diseases related to diabetes, hypertension, aging or other ocular abnormalities can be diagnosed via blood vessels in retinal fundus images [1,2]. In biometric-based security systems, retinal images can be used to prevent counterfeiting of identity [3–6]. This can be easily understood because in normal situation it is impossible to access retina which is located at the back of the eyes and its vessels are uniquely distributed. However, due to its narrow vessel width [7] and occurrence of inter-reflection and shading artefact of light incident in the eye [8], retinal images are characterized by having poor contrast.

On the other hand, the retinal identification and diagnosis by using correlation-based pattern recognition has been reported. Individual identification by using retinal image target is accomplished by calculating its correlation with templates acquired from users [9,10]. In its application to diagnosis of ocular abnormalities, these templates are a set of retinal fundus images recorded over a certain period of time [11–13].

In order to facilitate developments of tele-ophthalmology, compression-based joint transform correlator (CBJTC) has been proposed and experimentally verified [14,15]. The reason for this interest is that automatic ocular diagnosis needs to be implemented by employing small file size of retinal fundus images [16,17]. An important feature of the CBJTC is that both retinal reference and target images are compressed into joint photographic experts group (JPEG) formats. Besides satisfying the small size requirement, our studies reveal that the JPEG's noise suppressive nature [18] can improve the recognition of retinal images corrupted by noise of digital sensors [19,20].

* Corresponding author.
E-mail address: widjaja@sut.ac.th (J. Widjaja).

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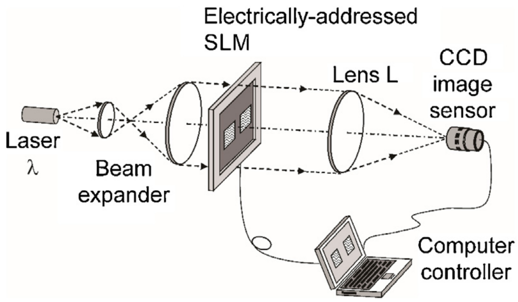

Fig. 1. A schematic diagram of the CBJWTC for demonstrating noise robustness in the retinal recognition.

Although results of our previous studies confirm the improvement of the poor-contrast retinal recognition, its performance is inferior to that of the conventional JTC which does not have high discrimination ability [21–23]. This may be caused by incomplete noise removal of the image compression. Recently, an optical implementation of noisy low-contrast retinal recognition by using compression-based joint wavelet transform correlator (CBJWTC) has been reported [24]. In the CBJWTC, the noise is suppressed in two steps. The first step employs the JPEG compression, while the second one filters out the residual noise by applying wavelet filters to a joint power spectrum (JPS). The whole process is equivalent to a cross-correlation of two wavelet-enhanced JPEG-compressed retinal images [25]. It is found that the CBJWTC is robust to noise and the image compression effects on the proposed retinal recognition are minimized, provided the wavelet filter can enhance low-frequency contents of the JPS. This work verifies further feasibility of the CBJWTC through experiments.

2. Theory

2.1. JPEG algorithm

In the JPEG algorithm, redundant information of digital images is permanently discarded to reduce file size via four processes [26]. The first process is to perform discrete cosine transform (DCT) of each image segment consisting of 8×8 pixels. The second one is to quantize 63 ac components of the DCT output by using a quantization table. The quantization values are set by a quality factor (QF). As a result, the dc component is preserved, while the ac ones are approximated. The third one is to round the resultant coefficients to integers. The ac components decrease to zeros for small QF, yielding lossy compression. Finally, further compressions are done by run-length encoding and Huffman enconding.

2.2. The CBJWTC of retinal images

Fig. 1 illustrates a schematic diagram of the CBJWTC for demonstrating the noise robustness in the retinal recognition. A spatial light modulator EASLM located in the front focal plane of a lens L with a focal length f. This electrically-controlled modulator is illuminated by coherent plane wave with a wavelength λ. The wavelet filters dilated with different factors and the JPEG-compressed retinal references $r_c(x_0,y_0)$ are prepared in a computer controller. The joint input image $g(x_0,y_0)$ consisting of the target $t_c(x_0,y_0)$ corrupted by the additive Gaussian noise $n_c(x_0,y_0)$ and the reference are displayed onto the EASLM with a spatial separation d [27]

$$g(x_0,y_0) = t_c(x_0+d,y_0) + n_c(x_0+d,y_0) + r_c(x_0-d,y_0). \qquad (1)$$

Its optically generated spectrum $G(\xi,\eta)$ is acquired by using a CCD image sensor placed in the back focal plane of a lens L. Next, the captured JPS is digitally modulated by a square modulus of the wavelet filter $|H_a(\xi,\eta)|^2$ which behaves like band pass filter

$$\begin{aligned} O(a,\xi,\eta) &= |H_a(\xi,\eta)|^2 |G(\xi,\eta)|^2 \\ &= |H_a(\xi,\eta)|^2 \Big\{ |T_c(\xi,\eta)|^2 + |N_c(\xi,\eta)|^2 + |R_c(\xi,\eta)|^2 \\ &+ T_c(\xi,\eta)N_c^*(\xi,\eta) + T_c^*(\xi,\eta)N_c(\xi,\eta) \\ &+ T_c(\xi,\eta)R_c^*(\xi,\eta)\exp(j4\pi d\xi) + T_c^*(\xi,\eta)R_c(\xi,\eta)\exp(-j4\pi d\xi) \\ &+ N_c(\xi,\eta)R_c^*(\xi,\eta)\exp(j4\pi d\xi) + N_c^*(\xi,\eta)R_c(\xi,\eta)\exp(-j4\pi d\xi) \Big\}, \end{aligned} \qquad (2)$$