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Experimental verifications of noise suppression in retinal recognition by using compression-based joint transform correlator

Joewono Widjaja*, Komin Kaewphaluk

Institute of Science, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand

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ABSTRACT

Noise suppression in retinal recognition by using a compression-based joint transform correlator (CBJTC) is experimentally studied. The experimental results show that the noise suppression can be done by compressing targets into a joint-photographic expert group (JPEG) format with appropriate image compression quality. In the case of the weak noise suppression, the improved recognition performance is as high as that of the classical JTC.

1. Introduction

The retina plays an important role in vision, because it senses light focused from the lens and sends visual information converted from the light to the brain through the optic nerve. The retina receives nutrient supply from blood vessels which are branched out from the optic nerve. Occurrence of local ocular or systemic disease such as diabetes, hypertension, high cholesterol etc. can be detected from appearance of these vessels [1]. In order to monitor development of ocular diseases, it is important to do initial screening by comparing retinal images recorded at different time period [2–4]. On the other hand, retinal pattern is indeed the most reliable and stable for identity authentication in biometrics-based security system [5,6]. This is because it is impossible to counterfeit retinal images without cooperation from subjects. In security applications, retinal recognition is implemented by comparing this unique vessel feature against set of templates in database. Therefore, implementation of retinal recognition is important for both security and ophthalmology.

In our previous work, we have studied theoretically feasibility of retinal recognition by using compression-based joint transform correlator (CBJTC) where both target and reference images are digitally compressed [7]. The results show that the compression of noise-corrupted retinal targets into a joint-photographic expert group (JPEG) improves recognition of the CBJTC. This is because the JPEG algorithm discards high spatial-frequency components of images to be compressed in order to reduce file size. Since noise contains mainly high frequency components, the compression simultaneously reduces the file size and suppresses noise.

In the present work, optical implementation of the noisy retinal recognition by using the CBJTC is experimentally verified. To our best knowledge, the experimental demonstration of the JTC by using compressed target and reference retinal images has never been reported. The other reasons for this interest are that firstly, the JPEG compression of retinal images has been proposed to facilitate development of tele-opthalmology for remote area, because retinal images are normally captured by fundus cameras with resolution of several tens of mega pixels [8,9]. Secondly, correlation-pattern recognition-based diagnosis has been proposed as one of automatic assessment methods of ocular diseases [3,10,11]. Since JTC is one of the promising optical architectures for real-time pattern recognition [12–18], it can be employed to implement ocular diagnosis. Thirdly, performance of the CBJTC for recognition of target images having low spatial-frequency components such as retinal images is as high as that of the conventional JTC [19–21]. Finally, the CBJTC is suitable for recognition of high-resolution target images, because it solves slow transfer time of an electrically-addressed spatial light modulator (EASLM) in displaying a large image file size.

In this work, the same set of compressed target and reference images used in our previous work is employed as test scenes. The retinal recognition performance of our proposed method is quantified by using a ratio of the correlation peak intensity to the standard deviation of the correlation output or peak-to-correlation-deviation (PCD). Section 2 introduces the JPEG algorithm for digital image compression and the theoretical background of the CBJTC. Experimental results are discussed in Section 3. Finally, Section 4 summaries this work.

* Corresponding author.
E-mail addresses: widjaja@sut.ac.th, joe_widjaja@yahoo.com (J. Widjaja).

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2. Theoretical background

2.1. JPEG compression

JPEG compression is one of digital compression standards designed for still images [22]. In order to compress still images, the JPEG algorithm divides picture elements of the input image into 8×8 pixel blocks and calculates its spatial frequency by using the 2-D discrete cosine transform (DCT). The DCT generates 8×8 spatial frequencies consisting of 1 dc and 63 ac frequency coefficients. Since in general the pixel values of the image vary slowly, the value of the dc coefficient is larger than that of the ac coefficients. A quantization of these coefficients is then made in conjunction with a quantization table scaled by a factor which is derived from a quality factor (QF). The QF is provided by compression software and can be specified by users in such a way that the smaller the QF, the smaller the ac components or the lower the quality of the compressed images. Therefore, the quantization preserves closely the low-frequency coefficients and approximates the high-frequency ones. After the quantization, the results are rounded to integers, yielding ac components which almost become zeroes. This causes irretrievable loss of information. To obtain higher compression, the dc coefficient is then processed by storing the difference between dc coefficients of consecutive blocks. As for the ac coefficients which consist of zeros values, further compression is achieved by using the run length encoding and the Huffman coding.

2.2. The CBJTC

A schematic diagram of an optical setup for performing experimental verifications is shown in Fig. 1. The compressed target image $t_c(x,y)$ captured a CCD image sensor and the compressed reference image $r_c(x,y)$ stored in a computer system are displayed side-by-side with a spatial separation of $2x_0$ onto an EASLM. They can be mathematically written as [7]

$$f(x,y) = r_C(x-x_0,y) + t_C(x+x_0,y) + n_C(x+x_0,y), \tag{1}$$

where $n(x,y)$ is the additive white Gaussian noise of the input target which may be caused by an image sensor. After a Fourier transformation by a lens L1, a joint power spectrum (JPS) captured by the CCD sensor is given by

$$\begin{aligned} U(u,v) = & |R_C(u,v)|^2 + |T_C(u,v)|^2 + |N_C(u,v)|^2 \\ & + T_C^*(u,v)N_C(u,v) + T_C(u,v)N_C^*(u,v) \\ & + R_C(u,v)T_C^*(u,v)\exp(-j2ux_0) + T_C(u,v)R_C^*(u,v)\exp(j2ux_0) \\ & + R_C(u,v)N_C^*(u,v)\exp(-j2ux_0) + N_C(u,v)R_C^*(u,v)\exp(j2ux_0), \end{aligned} \tag{2}$$

where (u,v) are the coordinates at the Fourier plane of the lens. $R_c(u,v)$, $T_c(u,v)$ and $N_c(u,v)$ are the Fourier transforms of the reference, the target, and the noise, respectively. By displaying the captured JPS onto the EASLM, the second Fourier transformation produces the correlation output at the back focal plane of the lens L1. The correlation signals corresponding to the sixth, the seventh and the eighth terms of Eq. (2) can be expressed as

$$I(x,y) = r_C(x,y) * t_C(x,y) * \delta(x \pm 2x_0) + r_C(x,y) * n_C(x,y) * \delta(x \pm 2x_0), \tag{3}$$

where $*$ denotes the correlation operation. In Eq. (3), the first term corresponds to the desired correlation of the compressed target with the reference, while the second one is the unwanted correlation of the compressed reference with the compressed noise. Eq. (3) indicates that besides the image quality of the compressed images, the recognition performance depends on the noise. This is because the two correlation terms appear at the same position of $\pm 2x_0$. Therefore, the image compression and the noise affect the correlation performance of the CBJTC.

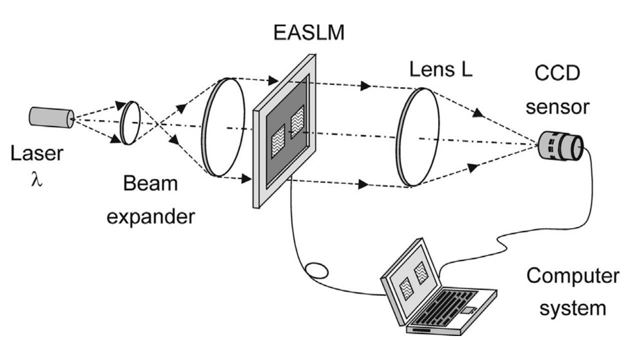

Fig. 1. A schematic diagram of an optical setup for performing experimental verifications of the noisy retinal recognition by using the CBJTC.

3. Experimental verifications

In order to perform experimental verifications, retinal images were captured by using a non-mydriatic auto fundus camera (Nidek AFC-210) with resolution of 3744×3744 pixels. A green-channel of the captured image was then converted into an 8-bit gray scale image in order to have better contrast. An area of 124×186 pixels around an optic disc shown in Fig. 2(a) was selected and used as the original test scene with file size of 23.5 KB. This test scene was replicated as the target and reference images. The Gaussian noise generated by using the IMNOISE command of MATLAB 6.0 was added to the target images. The target and the reference images were compressed into the JPEG format by using the ACDsee software (The 2000 ACD systems, Ltd.) with different QF whose value can be varied from 100 to 0. Higher value of the QF produces bigger file size and better image quality of the compressed image. Fig. 2(b) and (c) shows the noisy retinal images with variance $\sigma^2 = 0.01$ and 1 employed as targets in the experimental verifications, respectively. In comparison with the original image shown in Fig. 2(a), it is clear that the noise with variance $\sigma^2 = 1$ corrupts significantly the retinal information.

In the experiments, the retinal target and the reference images were combined as the joint input image $f(x,y)$ with the horizontal separation $2x_0 = 248$ pixels. The joint input image was displayed on an EASLM (Jenoptik SLM-M/460) having resolution of 832×624 pixels with the pixel size of $27 \times 23\ \mu m^2$ and the pixel pitch of $32 \times 32\ \mu m^2$. The EASLM was perpendicularly illuminated by a collimated coherent light generated from a He–Ne laser source operating at a wavelength of 632.8 nm. An eight-bit CCD sensor (Pulnix TM-2016-8) having a pixel resolution of 1920×1080, pixel size and pitch of $7.4 \times 7.4\ \mu m^2$, was used to capture the generated JPS and the correlation output intensity at the back focal plane of the lens L1. In order to prevent overlapping of the adjacent correlation outputs caused by a pixilated structure of the EASLM, the lens with the focal length $f = 300$ mm was used [19]. The recognition performance was quantitatively assessed by computing the PCD of the correlation intensity distribution given by [23]

$$\mathrm{PCD} = \frac{I(i,j)_{max}}{\left\{(1/M \times N)\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}[I(i,j) - E\{I(i,j)\}]^2\right\}^{1/2}}, \tag{4}$$

where $I(i,j)_{max}$ is the maximum intensity of the correlation output, while $E\{I(i,j)\}$ is the mean of the correlation intensity. In order to have better insight on the noise suppression, the PCD was normalized by that of the autocorrelation of the noise-free retina image obtained by the classical JTC.