Effects of JPEG Compression on Joint Transform Correlator

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Abstract: A real-time joint transform correlator by using JPEG-compressed reference images is proposed as practical solution to storage problem and improvement of processing time of automatic target recognition system [1]. Effects of compression on recognition performance of join transform correlator are quantitatively investigated under situations where the target is suffered from noise and has contrast difference with respect to the reference. Two images with different spatial-frequency contents and contrast were used as the test scenes. The simulation results show that, the recognition performance of joint transform correlator by using the compressed reference images with high spatial-frequency components is more sensitive to noise and contrast difference than the low spatial-frequency image.

Keywords: optical pattern recognition, joint transform correlator, correlation performance, JPEG image compression.

1. INTRODUCTION

Real-time joint transform correlator (JTC) [2] has been widely applied to many real-time automatic target recognition systems such as face recognition [3], fingerprint identifications [4], and particle sizing and tracking [5]. In real-time JTC, a target image captured by a charge-couple device (CCD) camera and a reference image stored in a computer system are displayed side-by-side onto an electrically addressed spatial light modulator (EASLM) placed in a front focal plane of a Fourier transforming lens. By illuminating perpendicularly the EASLM with the coherent plane wave, the joint Fourier spectra of the input images are generated at the back focal plane of the lens. By capturing the Fourier spectra onto a CCD sensor, the joint power spectra (JPS) is generated. This JPS is then re-Fourier transformed either optically or digitally in order to obtain the correlation output. By quantifying the correlation output, the degree of similarity between the target and the reference images can be measured. However, since both images are needed to be displayed onto the EASLM, the JTC suffers from time delay caused by a serial nature of signal communication between the computer and the EASLM. In practice, we may also have to store a large number of references in the JTC-based recognition system which requires considerable storage capability.

In order to solve storage problem and improve time response of the real-time JTC, the reference images can be digitally compressed. However, compressing the image leads to loss of information content of the reference. This will result in the degradation of the recognition performance of the JTC. In this study, we investigate quantitatively the effects of JPEG compression of the reference images on the correlation performance of the JTC, by using two types of images with low and high spatial-frequency contents.

2. REAL-TIME JTC

An optical setup for implementing the real-time JTC with compressed reference images is depicted in Fig.1. The input target $t(x,y)$ and the compressed reference $r_c(x,y)$ images are displayed side-by-side onto the EASLM. By positioning the reference and the target images at x_0, and $-x_0$ in the x direction, respectively, the joint input image can be mathematically described as

$$f(x,y) = r_c(x-x_0,y) + t(x+x_0,y)\,. \qquad (1)$$

When the target is corrupted by an additive white Gaussian noise $n(x,y)$ and has a contrast difference with respect to the compressed reference image, the joint input image can be rewritten as

$$f(x,y) = r_c(x-x_0,y) + c_T t(x+x_0,y) + n(x+x_0,y)\,, \qquad (2)$$

where c_T is the amplitude ratio of the target to the reference images whose value is greater than 1 when the contrast of the reference image is lower than that of the target. After a Fourier transformation by the lens L_1, the JPS is recorded by the CCD camera and re-displayed onto the EASLM. By applying the Fourier transformation of the recorded JPS, the correlation output can be obtained as

$$\begin{aligned} C(x,y) = {} & r_c(x,y)\otimes r_c^*(-x,-y) + c_T[t(x,y)\otimes t^*(-x,-y)] \\ & + n(x,y)\otimes n^*(-x,-y) \\ & + c_T[t^*(-x,-y)\otimes n(x,y) + t(x,y)\otimes n^*(-x,-y)] \\ & + c_T[r_c(x,y)\otimes t^*(-x,-y)\otimes \delta(x-2x_0)] \\ & + c_T[t(x,y)\otimes r_c^*(-x,-y)\otimes \delta(x+2x_0)] \\ & + r_c(x,y)\otimes n^*(-x,-y)\otimes \delta(x-2x_0) \\ & + n(x,y)\otimes r_c^*(-x,-y)\otimes \delta(x+2x_0), \end{aligned} \qquad (3)$$

where $\otimes$ denotes correlation. The last four terms of Eq. (3) are of particular interest. They correspond to the desired correlation between the target and the compressed reference images which is scaled by the factor c_T and appears at the same position $\pm 2x_0$ as the unwanted correlation of the noise and the compressed reference. This indicates that besides the image quality of the compressed reference $r_c(x,y)$ the correlation output depends on both the contrast and the noise.

3. COMPRESSED REFERENCE IMAGES

In order to study the effects of compression of the reference image on the correlation performance of the JTC, the fingerprint and human face images with different contrast as shown in Figs. 2(a), (b), (c), and (d) were first prepared. The fingerprint image is characterized by having more high spatial-frequency components than the human face image does. It can be seen from Figs. 2(c) and (d) that the intensity variation of the low-contrast reference image is smaller than that of the high-contrast reference image. Each reference image was 23 Kbytes and consisted of 124×186 pixels with gray scale levels.

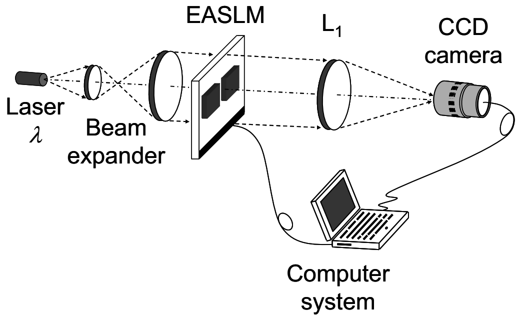

Fig. 1 Optical setup for implementing real-time JTC with compressed reference images.

The JPEG-compressed reference images were generated by using ACDsee software (The 2000 ACD systems, Ltd.) whose compression quality is determined by a parameter called the quality factor (QF). The higher the QF, the better the image quality of decompressed image. Here the compression performance is measured by the compression ratio (CR) defined as the ratio of the size of the original to the compressed images. According to the JPEG algorithm, the compression is achieved by the following steps [6]:

- Group the image pixel values into 8×8 blocks
- Transform each 8×8 block into the frequency domain by using a discrete cosine transform (DCT)
- Divide each of the 64 DCT frequency coefficients by a quantization coefficient and round the result to integers. The quantization coefficient for the high spatial-frequency components is higher than that for the lower one. This process causes irretrievable information lost because most of the high spatial-frequency coefficients become zeroes.
- Encode each 64 quantized coefficient by using the combination of the run length encoding (RLE) and the Huffman coding. This process reduces further data size without degradation of the image quality.

(a) (b) (c) (d)

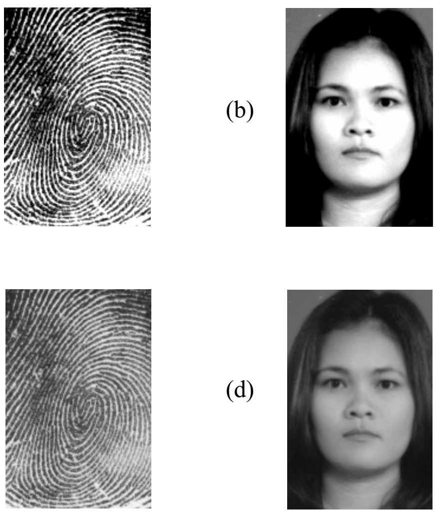

Fig. 2 Original images: (a) high-contrast fingerprint, (b) high-contrast human face, (c) low-contrast fingerprint, and (d) low-contrast human face.

Figure 3 shows the variation of the CR as a function of the QF for different reference images. It is clear that the CR reduces as the QF increases. Regardless of the spatial-frequency contents, the CR of the low-contrast image is higher than that of the high-contrast image, because the low-contrast image contains less high spatial-frequency components than the high contrast image. The quantization process applied to the low-contrast image gives high redundancy of zeroes which can be efficiently encoded by the RLE and Huffman coding. This reason is also valid for the case of the high-contrast human face which has higher CR than the fingerprint does.

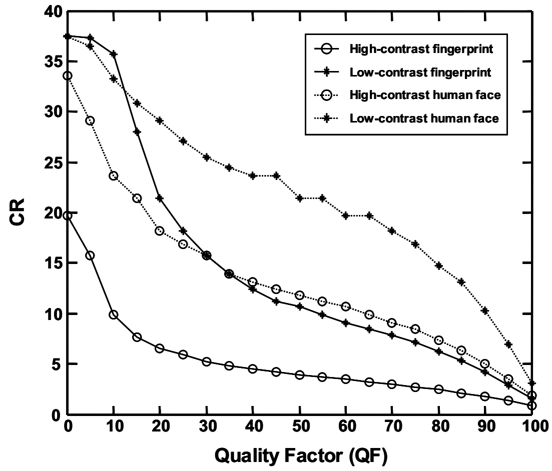

Fig. 3 The CR as function of the QF.

4. RESULTS AND DISCUSSIONS

In the simulation, the target and the compressed reference images were first combined to form the joint input image of 832×624 pixels with a separation of $2x_0 = 248$ pixels. All computation were done by using Matlab 6.1 (The math works, Inc.). The correlation quality of the JTC output was quantified by measuring a ratio of the correlation peak intensity to the standard deviation of the correlation intensity (PCD) [7] defined as

$$PCD = \frac{I(x,y)_{\max}}{\left\{ \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} \left[I(x,y) - E\{I(x,y)\} \right]^2 \right\}^{1/2}}, \qquad (4)$$

where $I(x,y)_{\max}$ is the maximum intensity of the correlation output, while $E\{I(x,y)\}$ is the mean of the correlation intensity. A large PCD means that the correlation function has a sharp peak and thus, the degree of similarity between target and reference is high. In order to compare the recognition performance at difference compression levels, each PCD is normalized by its autocorrelation value.

4.1 Compressed high-contrast fingerprint as the reference image

The variation of the PCDs as a function of the QF of the compressed high-contrast fingerprint for different target scenes is shown in Fig. 4. The PCDs increase gradually as the QF increases, because as the QF becomes larger less information is discarded from the compressed reference. Therefore, the degree of similarity between the target and the compressed reference images is getting higher. When the target is noise-corrupted low-contrast fingerprint with variance $\sigma^2 = 1$, the PCD drops drastically. This can be explained by considering the correlation output described by Eq. (3), where the correlation term $r_C(x, y) \otimes t^*(-x,-y)$ is reduced by the factor c_T which is less than 1. Therefore, under the presence of the same noise level, the PDC is low.

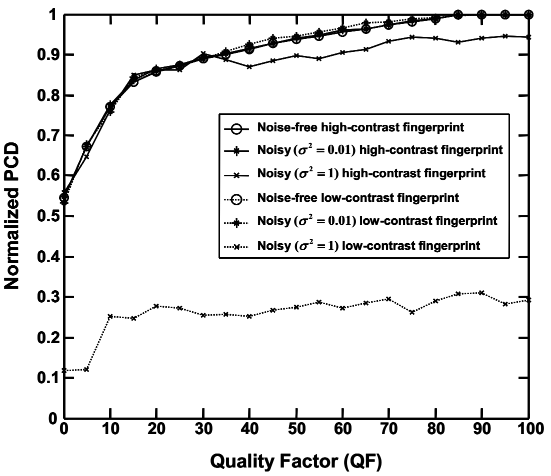

Fig. 4 Correlation performance of the JTC as a function of the QF of the compressed high-contrast fingerprint reference.

4.2 Compressed low-contrast fingerprint as the reference image

Figure 5 shows the variation of the normalized PCDs as a function of the QF of the compressed low-contrast fingerprint for different target scenes. It is clear that the PCDs increase rapidly as the QF increases. This indicates that by using compressed low-contrast fingerprint as the reference, the correlation performance of the JTC is significantly degraded especially for very low QF. This is mainly caused by the effect of compression on the low-contrast fingerprint image which causes more loss of the high-spatial frequency components than that of the high-contrast fingerprint reference.

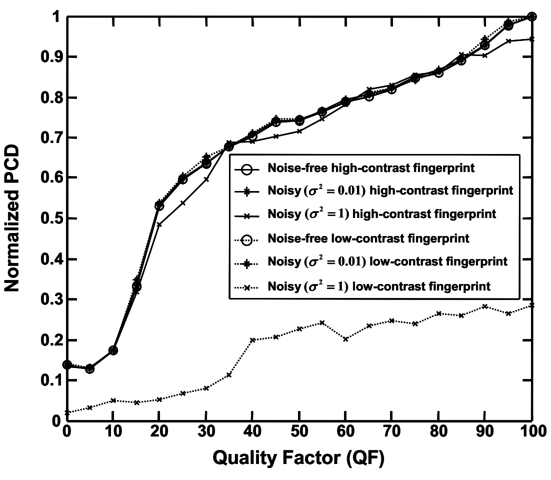

Fig. 5 Correlation performance of the JTC as a function of the QF of the compressed low-contrast fingerprint reference.

When the target is the noise-corrupted low-contrast fingerprint with variance $\sigma^2 = 1$, the PCD becomes less than 0.3In this case although the contrast ratio c_T is unity, the noise term $r_C(x, y) \otimes n^*(-x,-y)$ may be stronger than the desired correlation term $r_C(x, y) \otimes t^*(-x,-y)$. As a consequence, the correlation output is strongly disturbed by the noise. However at the same noise level, the PCD of the noise-corrupted high-contrast fingerprint target is higher, because the correlation term $r_C(x, y) \otimes t^*(-x,-y)$ is increased by the factor c_T which is greater than unity.

4.3 Compressed high-contrast human face as the reference image

The variation of the normalized PCDs as a function of the QF of the compressed high-contrast human face reference for different target scenes is illustrated in Fig. 6. It can be seen that for all given targets, the PCDs are almost maximum for all compression levels. This is caused by the characteristic of the human face image which contains less high spatial-frequency information. The impulse response of the JTC by using human face as the reference is broader than the fingerprint target. The impulse response further broadens when the human face reference is compressed. As a result the degradation caused by the noise and the contrast different do not affect significantly the standard deviation of the correlation output. The results imply that the correlation performance of the JTC by using the compressed high-contrast human face is not only independent upon the compression, but also insensitive to noise and contrast difference.

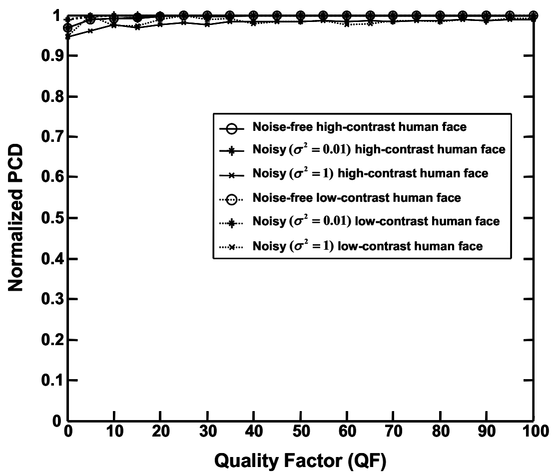

Fig. 6 Correlation performance of the JTC as a function of the QF of the compressed high-contrast human face reference.

4.4 Compressed low-contrast human face as the reference image

Figure 7 shows the variation of the normalized PCDs as a function of the QF of low-contrast human face as the reference for different target scenes. The PCDs are greater than 0.9 for all situations except for the QF is less than 20, because more information is discarded from the compressed reference image. In addition, when the input target is the low-contrast human face, the degradation of the correlation performance caused by the noise is less than the case of low-contrast fingerprint reference. This is caused by the fact that the correlation term $r_C(x,y)\otimes t^*(-x,-y)$ is broad and its peak is high. Therefore the contribution of the noise term $r_C(x,y)\otimes n^*(-x,-y)$ does not affect significantly the correlation output. It is worth mentioning that although the file size is small, the correlation performance of the JTC by using compressed low-contrast human face as the reference is good.

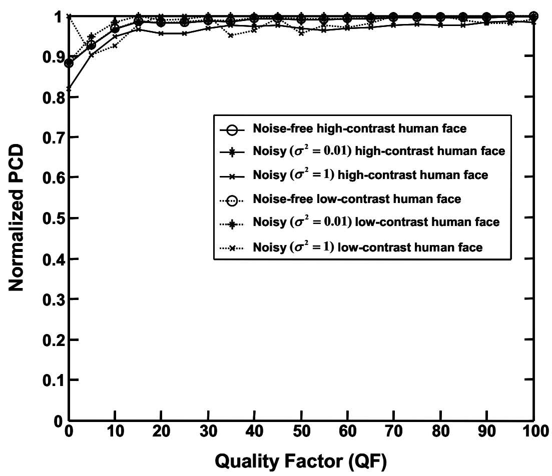

Fig. 7 Correlation performance of the JTC as a function of the QF of the compressed low-contrast human face reference.

5. CONCLUSIONS

We have studied quantitatively the effects of the lossy-JPEG compression on the recognition performance of the JTC by using the normalized PCD. Our study took into account the presence of noise in the input and the contrast difference between the target and the reference that may rise due to unbalance illuminations. The simulation results show that the effects of compression of the high-contrast human face reference on the correlation performance of the JTC is not significant for all given target scenes.

In addition, although the correlation performance of the JTC by using the compressed low-contrast human face decreases at the low QF, the degradation due to the noise presence and the contrast difference is small. In contrast, besides being sensitive to noise, the correlation performance of the JTC by using the compressed fingerprint as the reference depends on the compression where the degradation for the low-contrast fingerprint reference is more severe than the high-contrast fingerprint.

6. ACKNOWLEGMENTS

This work was supported by the SUT Research Grant 2547.

7. REFERENCES

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