Enhanced Face Preprocessing and Feature Extraction Methods Robust to Illumination Variation

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Abstract. This paper presents an enhanced facial preprocessing and feature extraction technique for an illumination-roust face recognition system. Overall, the proposed face recognition system consists of a novel preprocessing descriptor, a differential two-dimensional principal component analysis technique, and a fusion module as sequential steps. In particular, the proposed system additionally introduces an enhanced center-symmetric local binary pattern as preprocessing descriptor to achieve performance improvement. To verify the proposed system, performance evaluation was carried out using various binary pattern descriptors and recognition algorithms on the extended Yale B database. As a result, the proposed system showed the best recognition accuracy of 99.03% compared to other approaches, and we confirmed that the proposed approach is effective for consumer applications.

Keywords: Face recognition, Preprocessing, illumination variation.

1 Introduction

Numerous face recognition methods have been developed for face recognition in the last few decades [1]. However, an illumination-robust face recognition system is still a challenging problem due to difficulty in controlling the lighting conditions in practical applications [2], [3]. Recently, numerous approaches have been proposed to deal with this problem. Basically, these approaches can be classified into three main categories: preprocessing, illumination invariant feature extraction, and face modeling [4]-[6]. Among them, local binary pattern (LBP) has recently received increasing interest to overcome the problem caused by illumination variation on the face [7], [8]. More recently, a centralized binary pattern (CBP) [9] and a center-symmetric local binary pattern (CS-LBP) [10] were introduced for face representation.

In this paper, we propose a novel face recognition method using a preprocessing descriptor and facial feature robust to illumination variation. We first devise an enhanced center-symmetric local binary pattern (ECS-LBP) descriptor emphasizing the diagonal component of previous CS-LBP to make a more illumination-robust binary pattern image. Here, the diagonal components are emphasized because facial textures along the diagonal direction contain much more information than those of other directions. Next, we introduce a fusion method based on a facial feature, i.e., differential two-dimensional principal component analysis (D2D-PCA). The proposed D2D-PCA can be simply derived from 2D-PCA, in which 2D-PCA is line-based local features. Since

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differential components between lines rarely vary in relation to illumination direction, we expect the proposed feature to be able to cope with illumination variation.

2 Illumination-Robust Face Recognition

2.1 System Architecture

This paper proposes a novel face recognition system that uses an enhanced facial preprocessing technique, i.e., ECS-LBP, and an illumination-robust facial feature, i.e., D2D-PCA. The ultimate aim of the proposed approach is to improve the overall recognition performance under harsh illumination conditions. The whole architecture of the proposed system is depicted in Fig. 1. The face image first undergoes the enhanced preprocessing procedure using the ECS-LBP descriptor, producing an illumination-robust image. The binary pattern image is then partitioned based on the vertical center line which is the eye center of the face region. Next, D2D-PCA is performed on the left and right images, and each distance score is computed using Euclidian distance measurement. Finally, the score normalization and fusion procedures are applied, and the nearest neighbor classifier is utilized to recognize an unknown user.

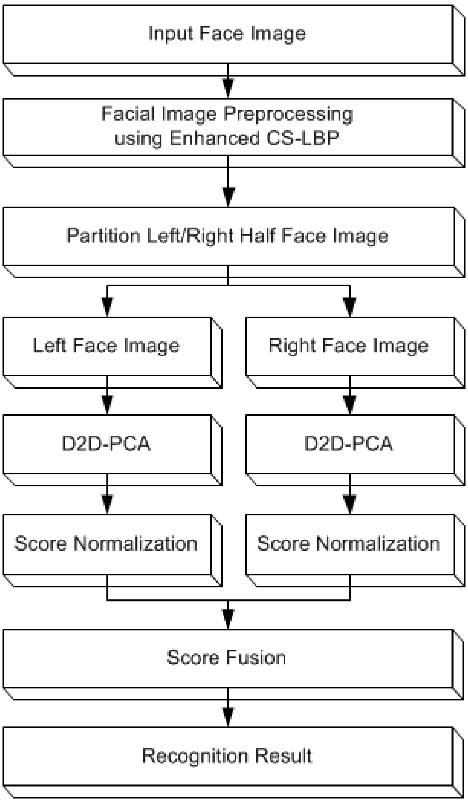


Fig. 1. Block diagram of proposed face recognition approach

2.2 Preprocessing

To make a more significant pattern, we modified the CS-LBP operator by reordering the bit priorities as pre-defined directions in this work. Generally, the decimal value of most binary pattern operators is created by combining each binary code toward continuous direction. In this view, we can suppose that each binary unit has a different characteristic in terms of facial texture. Thus, we rearrange the bit priorities in time of pattern generation as follows:

$$ECS-LBP(P,R)=\sum_{p=0}^{(P/2)-1} s(g_p - g_{p+(P/2)})\times 2^{w_{P,R}(p)}, \qquad s(x)=\begin{cases}1, & x\geq 0\\ 0, & x<0\end{cases}, \tag{1}$$

where $w_{P,R}(p)$ means a weighting function to decide the bit priority. Here, suppose that the 3x3 neighborhood pixel positions are set as shown in ref [10]. When P and R are set 8 and 1, respectively, $w(p)$ is defined by

$$w(p)=(3,1,2,0),\ \ p=0,1,2,3. \tag{2}$$

In the proposed ECS-LBP descriptor, we assign the high weight to components of diagonal directions, and we then assign weight to components of the vertical and horizontal directions as sequential steps. Fig. 2 shows facial texture images transformed by various binary pattern operators, such as LBP, CBP, CS-LBP, and ECS-LBP. As seen Fig. 2, we can confirm that the ECS-LBP operator achieves a more significant facial texture than other operators, since we set the smallest bit priority to component of the horizontal direction.

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

Fig. 2. Example of various binary pattern images; (a) original image, (b) binary pattern image obtained by LBP operator, (c) binary pattern image obtained by CBP operator, (d) binary pattern image obtained by CS-LBP operator, (e) binary pattern image obtained by proposed ECS-LBP operator.

2.3 Differential 2D-PCA

The basic idea of D2D-PCA is that 2D-PCA [11] is a line-based local feature set; therefore, the differential components between line features will be more robust against illumination variation than the original feature. In the face recognition using principal component analysis (PCA) [12], 2D face image matrices were previously transformed into 1D image vectors column by column or row by row fashions. However, concatenating 2D matrices into 1D vector often leads to a high-dimensional vector space, where it is difficult to evaluate the covariance matrix accurately due to its large size. To overcome these problems, a new technique called 2D-PCA was proposed. 2D-PCA, which directly computes eigenvectors of the so-called image covariance matrix without matrix-to-vector conversion was proposed to decrease the computational cost of the standard PCA. Because the size of the image covariance matrix is equal to the width of images, 2D-PCA evaluates the image covariance matrix more accurately and computes the corresponding eigenvectors more efficiently than PCA. It was reported that the recognition accuracy of 2D-PCA on several face databases was higher than that of PCA, and the feature extraction method of 2D-PCA is computationally more efficient than PCA. Consider an m by n image matrix A. Let $X \in R^{n \times d}$ be a matrix with orthonormal columns, $n \geq d$. Projecting A onto X yields a m by d matrix $Y = AX$. Then, the optimal projection matrix X is obtained by computing the corresponding eigenvectors of the image covariance matrix. As a result, the feature vector Y of 2D-PCA, in which Y has a dimension of m by d, is obtained by projecting the images, A into the eigenvectors as follows:

$$Y_k = (A - \overline{A}) X_k, \quad k = 1, 2, \cdots d. \tag{3}$$

Next, the D2D-PCA feature can be simply obtained from the corresponding 2D-PCA feature vector. Since 2D-PCA is local feature matrices against each m-line, the differential components are easily calculated by subtracting each 2D-PCA feature between horizontally neighboring lines. Therefore, D2D-PCA feature is computed by

$$dy_{i,j} = y_{i+1,j} - y_{i,j}, \quad i = 1, 2, \cdots, m-1, \quad j = 1, 2, \cdots, d, \tag{4}$$

where $y_{i,j}$ means 2D-PCA feature matrices, and $dy_{i,j}$ denotes D2D-PCA feature matrices. Fig. 3 shows the feature extraction procedure of D2D-PCA from the given 2D image.

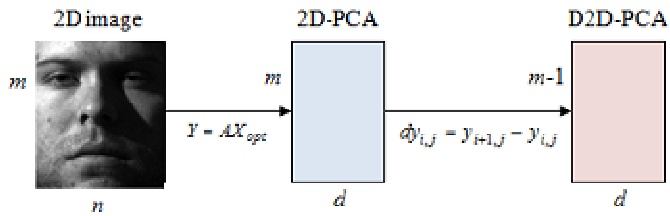


Fig. 3. Feature extraction of D2D-PCA

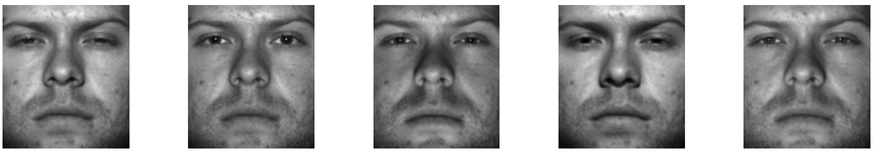
We also divide a face image into two sub-images based on the vertical center line to slightly decrease illumination effects. Since the illumination effects in the two partitioned regions of the face are different from each other, we applied the D2D-PCA to each half-face image and integrated the results generated by each half-face image at the score level. Furthermore, some performance degradation occurred in the approach using a whole face image, because line features contain horizontal information of the face, and the horizontal pixel-level intensities of the left and right regions differ according to the illumination directions. Thus, we separately considered partial face images as shown in Fig. 4, and integrated corresponding score results from sub-images. Next, we applied a sigmoid function to normalize these raw-scores from 0 to 1, since the distance scores from the left and right half-face images have different numerical ranges and statistical distributions. Then, the score fusion phase is performed using two normalized-scores, and the nearest neighbor classifier is utilized to recognize an unknown user.

(a) (b)

Fig. 4. Region partitioning of sample face images; (a) original images, (b) partitioned images

3 Experimental Results

Performance evaluation was carried out using the extended Yale face database B which consists of 2,414 face images for 38 subjects representing 64 illumination conditions under the frontal pose [13]. An example images from the extended Yale face database B are shown in Fig. 5. In this work, we partitioned the extended Yale face database B into training and testing sets. Each training set comprised five images per subject, and the remaining images were used to test the proposed system. Note that illumination-invariant images were used for training, and the illumination-variant images were employed for testing.



(a)

(b)

Fig. 5. Some face images from the extended Yale face database B; (a) training images, (b) test images

In the first experiment, we investigated the recognition performance of the proposed ECS-LBP descriptor using various recognition algorithms, such as PCA, linear discriminant analysis (LDA) [14], 2D-PCA, and D2D-PCA. The experimental results were also evaluated using several binary pattern descriptors, such as LBP, CBP and CS-LBP, for performance comparison. The recognition results obtained using the PCA, LDA, 2D-PCA, and D2D-PCA recognition algorithms with whole-face images are shown in Table 1. From the experimental results, the recognition rates were found to be 85.86%, 73.06%, 96.37% and 98.26% for PCA, LDA, 2D-PCA and D2D-PCA, when an ECS-LBP image was employed. For overall recognition algorithms, the approach using the ECS-LBP descriptor outperformed methods using the other binary pattern descriptors in terms of recognition accuracy. Also, the D2D-PCA approach with an ECS-LBP operator showed performance improvements of 13.83%, 2.38%, 19.98%, and 8.33% compared to raw, LBP, CBP and CS-LBP images, respectively. Consequently, the proposed method using the ECS-LBP descriptor and D2D-PCA feature showed better recognition accuracy than other approaches. These results confirm that the proposed ECS-LBP descriptor and D2D-PCA feature is robust to illumination variations.

Table 1. Summary of Recognition Accuracies using Whole-Face Images

Input Image	Recognition Algorithms			
	PCA	LDA	2D-PCA	D2D-PCA
Raw	49.11%	55.26%	64.58%	84.43%
LBP	73.24%	51.87%	91.46%	95.88%
CBP	50.67%	46.57%	66.55%	78.28%
CS-LBP	61.33%	49.06%	75.81%	89.93%
ECS-LBP	85.86%	73.06%	96.37%	**98.26%**

In the second experiment, we performed a fusion experiment using left and right sub-images to minimize the illumination effect, leading to performance improvement. Here, we only employed 2D-PCA and D2D-PCA in the fusion experiment, and the fusion process utilizes the sigmoid function-based normalization method and weighted-summation rule. Fig. 6 shows each recognition result of 2D-PCA and D2D-PCA obtained when a raw image and an ECS-LBP image were used. Note that this experiment was performed by employing half-face images as input images. When the ECS-LBP operator was applied, the recognition rates of D2D-PCA were 92.62% and 97.70% for left and right images, respectively. In addition, the recognition rates of 2D-PCA were 91.41% and 94.10% for left and right images, respectively. In addition, Note that the recognition rates of D2D-PCA were better than those of 2D-PCA. In particular, the 2D-PCA approach with an ECS-LBP image achieved performance improvements of 25.72% and 31.65% compared to the results of left raw images and right raw images, respectively. Also, the D2D-PCA approach with an ECS-LBP image showed performance improvements of 5.26% and 8.45% compared to left raw images and right raw images, respectively. These results also confirm that the proposed ECS-LBP operator is an effective preprocessing method against illumination variation.

Also, we performed the fusion experiments with different weights of the left face score against 2D-PCA and D2D-PCA using raw images and ECS-LBP images. The fusion results along with different weights are shown in Fig. 7, and the maximum recognition results are summarized in Table 2. From these results, we can notice that the proposed approach using the ECS-LBP images and D2D-PCA feature achieved better accuracy than the other approaches over the entire range of weights. Also, the corresponding maximum recognition rates of methods using D2D-PCA were 95.59% and 99.03%, for raw images and ECS-LBP image, respectively. In other words, the proposed fusion approach with ECS-LBP images showed performance improvement of 3.44% in comparison to the method with raw images when D2D-PCA were employed. Consequently, we confirmed the effectiveness of the proposed face recognition system under illumination-variant conditions from the experimental results.

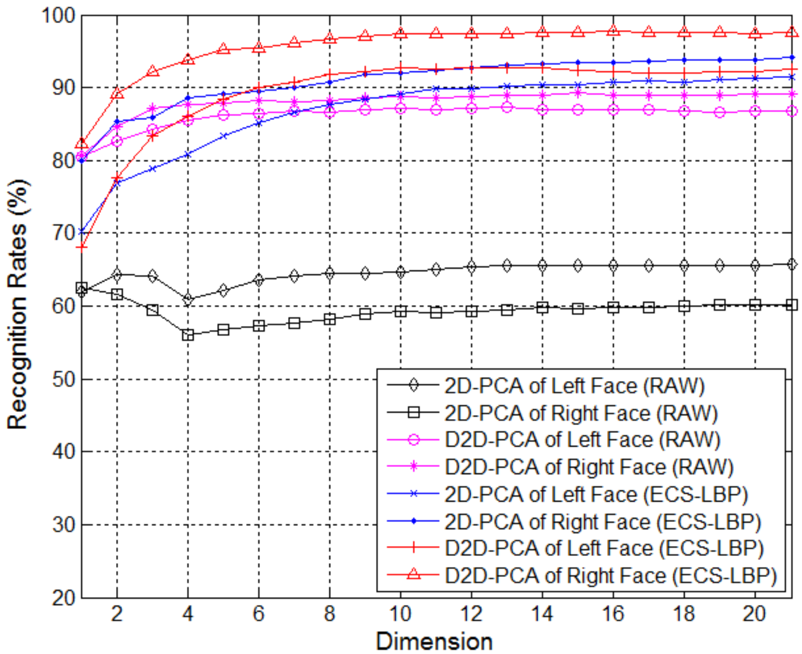


Fig. 6. Recognition accuracy when using half-face images

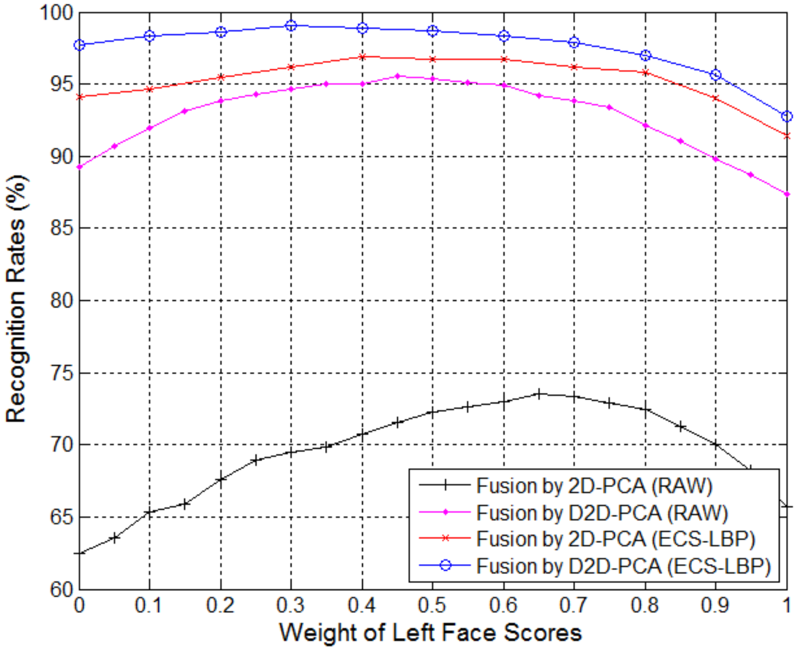


Fig. 7. Recognition results obtained using fusion approach

Table 2. Summary of Recognition Accuracies for Fusion Approaches

Recognition Algorithms		Input Image: Raw	Input Image: ECS-LBP (Proposed Approach)
2D-PCA	Left Face	65.69 %	91.41 %
	Right Face	62.45 %	94.10 %
	Fusion	73.57 %	96.94 %
D2D-PCA	Left Face	87.36 %	92.62 %
	Right Face	89.25 %	97.70 %
	Fusion	95.59 %	**99.03 %**

4 Conclusions

This paper presented an enhanced facial preprocessing and feature extraction technique for an illumination-roust face recognition system. To minimize illumination effects and maximize performance improvements, the proposed system employed a novel ECS-LBP operator, D2D-PCA feature, and a fusion technique integrating two half-face images. Performance evaluation of the proposed approach was carried out with the extended Yale B database, and the corresponding recognition results confirmed that the proposed approach achieves the best recognition rate of 99.03%. Through the experimental results, we were able to confirm the effectiveness and performance improvement of the proposed system under illumination-variant conditions.

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References

1. Zuo, F., de With, P.H.N.: Real-time embedded face recognition for smart home. IEEE Trans. Consum. Electron. 51(1), 183–190 (2005)
2. Zhao, W., Chellappa, R., Phillips, R.J., Rosenfeld, A.: Face recognition: A literature survey. ACM Comput. Surv. 35(4), 399–458 (2003)
3. Abate, A.F., Nappi, M., Riccio, D., Riccio, G.: 2D and 3D face recognition: A survey. Pattern Recognit. Lett. 28(14), 1885–1906 (2007)
4. Chen, W., Er, M.J., Wu, S.: Illumination compensation and normalization for robust face recognition using discrete cosine transform in logarithm domain. IEEE Trans. Syst. Man Cybern. Part B-Cybern. 36(2), 458–466 (2006)
5. Ruiz-del-Solar, J., Quinteros, J.: Illumination compensation and normalization in eigenspace-based face recognition: A comparative study of different pre-processing approaches. Pattern Recognit. Lett. 29(14), 1966–1979 (2008)
6. Hsieh, P.C., Tung, P.C.: Illumination-robust face recognition using an efficient mirror technique. In: International Congress on Image and Signal Processing, pp. 1–5 (2009)
7. Ahonen, T., Hadid, A., Pietikainen, M.: Face description with local binary patterns: Application to face recognition. IEEE Trans. Pattern Anal. Mach. Intell. 28(12), 2037–2041 (2006)
8. Zhang, W., Shan, S., Chen, X., Gao, W.: Local Gabor binary patterns based on mutual information for face recognition. Int. J. Image Graph. 7(4), 777–793 (2007)
9. Fu, X., Wei, W.: Centralized binary patterns embedded with image Euclidean distance for facial expression recognition. In: International Conference of Neural Computation, vol. 4, pp. 115–119 (2008)
10. Heikkilä, M., Pietikäinen, M., Schmid, C.: Description of interest regions with center-symmetric local binary patterns. In: Kalra, P.K., Peleg, S. (eds.) ICVGIP 2006. LNCS, vol. 4338, pp. 58–69. Springer, Heidelberg (2006)

11. Jian, Y., David, Z., Alejandro, F., Yang, J.Y.: Two-dimensional PCA: A new approach to appearance-based face representation and recognition. IEEE Trans. Pattern Anal. Mach. Intell. 26(1), 131–137 (2004)
12. Turk, M., Pentland, A.: Eigenfaces for recognition. J. Cogn. Neurosci. 3(1), 71–86 (1991)
13. Georghiades, A., Belhumeur, P., Kriegman, D.: From few to many: Illumination cone models for face recognition under variable lighting and pose. IEEE Trans. Pattern Anal. Mach. Intell. 23(6), 643–660 (2001)
14. Belhumeur, P.N., Hespanha, J.P., Kriegman, D.J.: Eigenfaces vs. Fisherfaces: Recognition using class-specific linear projection. IEEE Trans. Pattern Anal. Mach. Intell. 19(7), 711–720 (1997)