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Wavelet Subspace Based Integrated Face Recognition Scheme

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Abstract

In this paper, based on the study of the Two-Dimensional Principal Component Analysis (2DPCA), Two-Dimensional Principal Component Analysis (2DPCA) and fuzzy set theory, we propose a integrated face recognition algorithm based on wavelet subspace. This method can make good use of the advantages of each single method, and also can make up for the defect of each other. The comparison of the results of the different methods identification effect on the ORL、YALE and FERET face database show, the integrated method proposed in this paper improves the recognition rate, and it also reduces the training and classification time as well.

Keywords*: face recognition; Two-Dimensional Principal Component Analysis (2DPCA); Two-Dimensional Linear Discriminant Analysis (2DLDA); fuzzy set theory; feature extraction*

1. Introduction

In recent 20 years, face recognition has become a hot topic in the research field of computer vision and pattern recognition, and it is through the modern information processing technology and computer technology to complete the understanding and recognition of the facial image [1]. The commonly used face recognition methods can be divided into several categories: the method based on geometric features, the method based on model、the method based on the statistical the method based on neural network method and the method of combining multiple classifiers, this paper mainly focuses on the method based on statistics. The method based on statistical、faced the image as random vector, thus using some statistical methods to analyze the face model, the most representative methods include the eigenface method based on principal component analysis which proposed by Turk M [2] and the fisherfaces method based on linear discriminant analysis which proposed by Belhumeur P N *et al.* [3]. But the PCA and LDA methods have a common disadvantage, the two methods both need deal with vector data, and they can not directly deal with image data, so before using these two methods it need transform the image data to vector data firstly, but the dimension of the processed data often is very high. In addition, the two methods both need decompose the matrix feature value, but computation for high dimensional data is very difficult and time-consuming. In order to overcome these shortcomings, Yang J *et al.* proposed 2DPCA method [4], Li M *et al.* proposed 2DLDA method [5]. They are the extension of one-dimensional PCA and LDA, the main idea of them is to construct the image covariance matrix and the image discrete matrix from the original image data matrices directly, and identification and analysis. These two methods need not do the vector operation process to the image matrix, so 2DPCA and 2DLDA greatly reduce the computational time complexity of PCA and LDA. Later, some researchers have proposed 2DPCA+2DDLA method [6], $(2D)^2$PCA [7] method and $(2D)^2$LDA [8] method one after another. According to

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2DLDA method, some researcher has proposed Fuzzy 2DLDA (F2DLDA) method [9], this method made the fuzzy set theory into the 2DLDA method, so it can effectively consider the sample structure information and fully add the distribution information of the overlapped samples to the definition of the discrete degree matrix, so this method can improve the accuracy of classification. Kwak K [10] proposed face recognition method based on wavelet transform and fuzzy integral combination. Hu H F [11] *et al.* studied the variable illumination face recognition problem based on wavelet transform. But these face recognition based wavelet transform mostly chose the low frequency sub image for face recognition, and completely discard the identification information in the high frequency sub image, so it caused that the recognition rate has been greatly reduced.

This paper compared and analyzed the above methods, and proposed an integrated face recognition method based on wavelet transform during the analysis result. This method retains the advantages of the original method at the same time, and used the integrated advantages to make up for the deficiency of the original method, so this method will achieve a good recognition effect.

2. Describe about the Relevant Principles and Methods

2.1. Wavelet Transform

Let the f(x, y) is the size of the image M×N, then the discrete wavelet transform should be express as follow:

$$W_{\varphi}(j_0,m,n)=\frac{1}{\sqrt{MN}}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}f(x,y)\varphi_{j_0,m,n}(x,y) \tag{1}$$

$$W_{\psi}^{(d)}(j_0,m,n)=\frac{1}{\sqrt{MN}}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}f(x,y)\psi_{j,m,n}^{(d)}(x,y),\ \mathrm{d}=\{\mathrm{H},\mathrm{V},\mathrm{D}\} \tag{2}$$

Explain:

$$\varphi_{j,m,n}(x,y)=2^{\frac{j}{2}}\varphi(2^j x-m,2^j y-n),$$

$$\psi_{j,m,n}^{(d)}=2^{\frac{j}{2}}\psi^{(d)}(2^j x-m,2^j y-n),$$

d = {H, V, D}

The wavelet transform of f(x, y) includes two steps: the filtering in horizontal direction (x direction) and vertical direction (y direction), and sampling. The low-pass filter along the horizontal (x direction) is implemented by low pass filter L which has impulse response l (n), while the high-pass filter is implemented by high pass filter H which has impulse response h (n), the filter along the vertical direction (y direction) is similar to the horizontal direction. So the low-frequency component along the two direction of horizontal and vertical is expressed as f_{LL}; the high-frequency component along the horizontal direction and the low-frequency component along the vertical direction is expressed as f_{HL}; the low-frequency component along the horizontal direction and the high-frequency component along the vertical direction is expressed as f_{LH}; the high-frequency component along the two direction of horizontal and vertical is expressed as f_{HH}. Using the low-frequency sub image from the one layer wavelet decomposition to do the wavelet transform repeat could get low frequency sub image of two layer wavelet decomposition. The process is as follow in Figure 1:

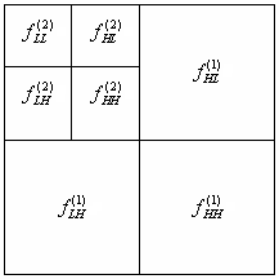

Figure 1. The Flow Chart of Image Wavelet Decomposition with 2 Levels

2.2. DPCA (Two--dimensional Principal Component Analysis) Method

The 2DPCA method applied to face recognition can be divided into two parts for feature extraction and pattern classification:

2.2.1. Feature Extracting: Suppose that there are c pattern category: ω_t (t = 1, 2, …, c), each class has n_i matrix of m×n, the total number of training samples is N. So the overall image discrete matrix can be defined as the formula 3:

$$G_t = \frac{1}{N}\sum_{i=1}^{N}(A_i - A)^T(A_i - A) \quad (3)$$

In formula 3 A is the average value of the training sample, it can be obtained by formula 4:

$$A = \frac{1}{N}\sum_{i=1}^{N}A_i \quad (4)$$

Similar to the PCA, we take the feature vectors corresponding to the K largest feature value of the whole image discrete matrix as the discriminant vector sets of the 2DPCA. Matrix X is made up of K direction vector, we can extract features Y through training samples are projected to the matrix X: Y=AX.

Let B = [y_1, y_2, … , y_K], among it $y_i = Ax_i$, then we can get the feature matrix B of A.

2.2.2. Pattern Classification: For c modes, any two images of A_m and A_n, the projection feature matrix corresponding to them is B_i = [$y_1^{(m)}$, $y_2^{(m)}$, … , $y_K^{(m)}$] and B_j = [$y_1^{(n)}$, $y_2^{(n)}$, … , $y_K^{(n)}$], so the distance between A_m and A_n can be obtained by type 5:

$$d(B_i, B_j) = \sum_{r=1}^{K}\left\| y_r^{(m)} - y_r^{(n)} \right\|_2 \quad (5)$$

Here, $\| y_r^{(m)} - y_r^{(n)} \|$ said the distance between the principal component $y_r^{(m)}$ and principal component $y_r^{(n)}$, and the feature matrix are B_1, B_2, …, B_K which correspond to all training samples, and they belong to the class ω_t. So for any test sample A, and the feature matrix B corresponding to A, if there exists $d(B, B_i) = \min[d(B, B_j)]$, if B_i belongs to the class ω_t, then we can judge that A belongs to ω_t.

2.3. Fuzzy 2DLDA (Two-dimensional Linear Discriminant Analysis) Method

Fuzzy set theory applied in 2DLDA not only can reduce the sensitivity of 2DLDA in face classification, but also can improve the rate of classification. At the same time, it also can make the 2DLDA method more robust in face recognition.

The fuzzy divide problem of sample usually is realized by constructing the membership matrix U = [u_{ij}] (i = 1, 2, ..., C; j = 1, 2, … , N). Here, u_{ij} said the membership degree of sample j belongs to the class i. Usually u_{ij} satisfies the follow three conditions:

$$\sum_{i=1}^{C} u_{ij} = 1; \quad 0 < \sum_{i=1}^{N} u_{ij} < N; \quad 0 \le u_{i,j} \le 1 \tag{6}$$

The u_{ij} can be obtained through the fuzzy K nearest neighbor algorithm the following:

Step1: Constructing the matrix D = [dj_k], here the d_{jk} said the Euclidean distance between the sample vector j and the sample vector k: $d_{j,k} = \|x_{i,j}-x_{i,k}\|_2$ (j = 1, 2, …, N; k = 1, 2, …, N);

Step2: Let the diagonal elements of D is infinite $d_{ij} = +\infty$(j = 1, 2, …,N);

Step3: Sorting the distance value of the each row of the matrix D according the ascending;

Step4: Calculating the label vector of the K nearest neighbor samples from the every sample x_{ij}, (i = 1, 2, …, c; j = 1, 2, …, N);

Step5: During the calculation to obtain the nearest matrix H = [h_{ij}], here the h_{ij} said the number of k nearest neighbors within the range of the sample which belongs to the sample j in the class i, and (i = 1, 2, …, c; j = 1, 2, …, N);

Step6: The fuzzy membership degree matrix can obtained through the formula (7), here i = 1, 2, …, c; j = 1, 2, …, N

$$u_{ij} = \begin{cases} \gamma + (1-\gamma)(h_{ij}/k) \\ (1-\gamma)(h_{ij}/K) \end{cases} \tag{7}$$

Here, N said the number of training samples, c is the number of the class, p∈(0, 1) is a parameter to control the change of the $h_{i,j}$ value, $\gamma = (N-c)/2^{p}N$.

So, we can obtain the center of every class through formula (8):

$$\overline{A_i} = \frac{\sum_{j=1}^{N} u_{ij} A_j}{\sum_{j=1}^{N} u_{ij}} \tag{8}$$

The fuzzy discrete degree matrix between class S_{fb} and the fuzzy discrete degree matrix within class S_{fw} can be obtained through the formula (9) and formula (10):

$$S_{fb} = \sum_{i=1}^{C}\sum_{j=1}^{N} u_{ij}(\overline{A_i} - \overline{A})(\overline{A_i} - \overline{A})^T \tag{9}$$

$$S_{fw} = \sum_{i=1}^{C}\sum_{j=\omega_i} u_{ij}(A_j - \overline{A_i})(A_j - \overline{A_i})^T \tag{10}$$

The objection function of the fuzzy 2DLDA can be defined through formula (11):

$$W = \arg\max_{W} \frac{W^T S_{fb} W}{W^T S_{fw} W} \tag{11}$$

3. The Design Principle and Structure Process of this Method

There are a variety of face recognition now, such as PCA, LDA, *etc*., there are some defects in much of these single recognition methods, so it has brought great difficult to improve the recognition rate. This paper has studied the basic characteristic of existing face recognition, and proposed an integrated method for face recognition based on wavelet subspace. Why this paper using the integrated method is mainly from the following several aspects to consider: A, using the two-dimensional method as the core method of this method is because the two-dimensional method can construct the covariance matrix of the image and the dispersion matrix from the original image directly, and also not need to deal with the process of the matrix vector. So it can greatly reduce the time complexity compared with the one-dimensional method. B、there is strong complementarity between 2DPCA and 2DLDA two methods: When 2DPCA method constructs projection feature matrix through the overall dispersion matrix, it can extract the feature information of the face image without know the classification of the face image. But its recognition time is relatively long, does not use the image information which can be used in classification. The 2DLDA method can make up for the lack of 2DPCA method in these aspects; it can do the classification operation on the image information, and its recognition time is relatively short, but its training time is relatively long, this can be made up by the 2DPCA method. C、Using the fuzzy set theory into the 2DLDA method, which can effectively consider the structure information of the sample, and also can add the distribution information of the overlapped samples to the definition of scattering matrix, so it can make the classification more efficient. D、firstly do the wavelet decomposition to the face images on the face image database, then using the image of different frequency domain to recognition, which can not only improve the time complexity of the identification process, but also greatly improve the accuracy of recognition. Through the experiment, the integrated method proposed in this paper is better than other methods in the face recognition efficiency and time complexity.

The specific process of the integrated face recognition method based on wavelet transform proposed in this paper is as follows:

(1) To do the three layers wavelet decomposition to the images;

(2) Constructing four face image database of wavelet sub section, through the average sub graph of the three high frequency sub graphs and low frequency sub graphs of each layer;

(3) Using 2DPCA method to do the feature extraction to the four face image database, and obtain K characteristic value, then obtain the projection feature matrix Y;

(4) Using 2DLDA method to de the feature selection to the feature matrix Y, and obtain K1 characteristic value, then obtain the new projection feature matrix Y1;

(5) Using the nearest neighbor method to classify, there are the feature matrix B_1, B_2, …, B_K corresponding to all the training samples, and each feature matrix belongs to the class ω_t, for a test sample A, the feature matrix B corresponding to A, if it exists that $d(B, B_i)=\min[d(B, B_j)]$, and B_i belongs to class ωt, then let's judge A belongs to class ωt;

(6) Integrating the four classifiers which have been trained through the vote method.

Figure 1 is the flow chart of the integrated face recognition method based on wavelet subspace.

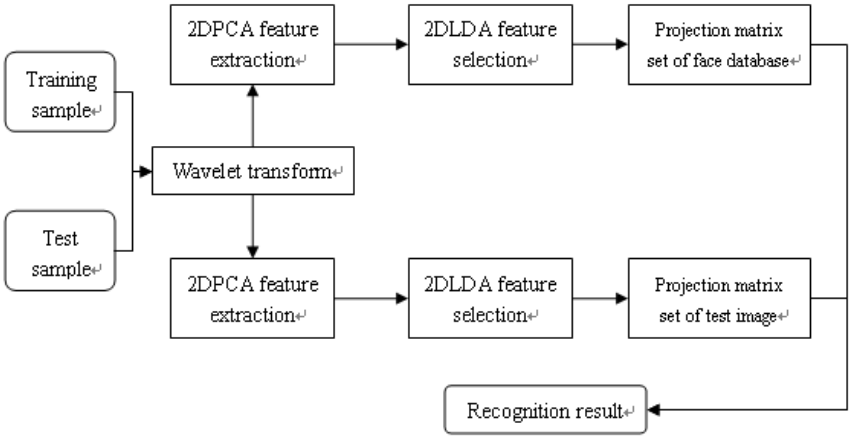

Figure 1. The Flowchart of Face Recognition Algorithm

4. Experimental Results and Analysis

4.1. The Experimental Data and Description

To verify the validity of the method, we use three commonly used face image database as test data. The three face databases are ORL face database, YALE face database and FERET face database. The ORL face database contains face images from 40 individuals, there are 10 images each person with different expressions, a total of 400 images, the image resolution is 92×112. Figure 2 is the 6 face images in the ORL face database. The YALE face database contains face images from 15 individuals, there are 11 images each person with different illumination conditions, different expressions, a total of 165 images, the image resolution is 320×243. Figure 3 is the 6 face images in the YALE face database. The FERET face database contains face images from 200 individuals, each person 7 pieces, a total of 1400 images, the image resolution is 80×80. In order to improve the calculation speed, we select face images from 30 individuals for this experiment. Figure 4 is the 6 face images in the FERET face database.

Figure 2. The Six Sample Images in the ORL Face Database

Figure 3. The Six Sample Images in the YALE Face Database

Figure 4. The Six Sample Images in the FERET Face Database

4.2. The Experimental Environment Description

In this paper, the integrated face recognition method based on wavelet subspace is designed and implemented in the Matlab2010 development environment. Each method is described and implemented by using the Matlab language. The machine configuration is as follows: Intel 4 core processor, frequency of 2 HZ, memory 4GB, the operating system is Window XP; the wavelet basis function which we select is BIOR3.1.

4.3. Comparison of Experiment Results

In the experimental process, we use the same test data to test the method of this paper, the 2DPCA method in literature 4, the 2DLDA method in literature 5, the 2DPCA+2DLDA method in literature 6 and the wavelet transform and fuzzy integral method in literature 10 respectively. Then the result were compared and analyzed. Table 1, 2, 3 respectively is the result of recognition in ORL, YALE and FERET database. For convenience of description, the method in literature 4 is called as method 1, the method in literature 5 is called as method 2, the method in literature 6 is called as method 3, and the method in literature 10 is called as method 4.

Table 1. The Average Identify Rates of the Different Methods on ORL Database

	The recognition rate on different number of test sample %				
Method	2	3	4	5	6
Method1	73.24	78.25	83.05	87.24	90.01
Method2	74.91	79.12	84.69	88.62	93.52
Method3	77.36	83.25	88.56	92.56	94.54
Method4	72.16	75.36	83.64	87.02	89.77
This method	83.55	87.54	91.55	94.42	96.64

Table 2. The Average Identify Rates of the Different Methods on YALE Database

	The recognition rate on different number of test sample %						
Method	2	3	4	5	6	7	8
Method1	86.77	89.53	90.63	91.51	91.13	91.19	92.06
Method2	87.13	91.23	93.33	94.53	95.09	95.21	95.36
Method3	90.22	91.42	93.05	93.54	94.93	95.61	97.06
Method4	85.69	88.79	89.92	90.53	90.68	91.05	91.57
This method	91.12	93.92	95.41	95.83	96.01	97.21	97.89

Table 3. The Average Identify Rates of the Different Methods on FERET Database

	The recognition rate on different number of test sample %				
Method	2	3	4	5	6
Method1	76.76	83.45	88.05	89.03	92.01
Method2	71.08	75.50	76.24	82.94	86.54
Method3	75.53	84.25	89.56	90.56	95.03
Method4	76.02	83.34	87.91	88.67	91.06
This method	83.21	88.52	92.55	93.68	95.53

We can see from the experimental results that the method of this paper is better than other methods in identification efficiency. This is because of considering the characteristic of different methods, and then getting the effect of the complementary advantages through the integrated approach, so this method is better than other method. In addition, this method combines the use of low frequency subspace and high frequency subspace, which can not only save time, but also can ensure the rate of recognition.

5. Conclusion

From the face recognition technology has been put forward to now, it has become one of the most popular, the most challenging tasks in pattern recognition filed. And it has achieved some results, but also put forward many feasible method and design. Based on the study of face recognition methods available, fully analyzes their advantages and disadvantages, this paper proposes an integrated face recognition method based on wavelet subspace, and the principle of this method and implementation process are described in detail. Through the test on ORL, YALE and FERET face database, we can see that this algorithm in the recognition efficiency relative to other algorithm has been greatly improved, but also is robust to illumination changes.

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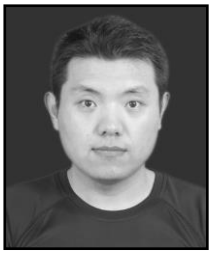

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