Research on Face Recognition Technology Based on ESN Multi Feature Fusion

Shuang Liu[1,2], Deyun Chen[1], Zhifeng Chen[3], Changhai Ru[4], Ming Pang[5]

[1] Center for post-doctoral studies of computer science and technology, Harbin University of Science and Technology, China
[2] School of computer and Information Engineering, Harbin University of Commerce, China
[3] College of Energy and Architectural Engineering, Harbin University of Commerce, China
[4] Research Center of Robotics and Micro System & Collaborative Innovation Center of Suzhou NanoScience and Technology, Soochow University, China
[5] College of Automation, Harbin Engineering University, China
yscls2013@163.com, 251042466@qq.com, liushuanghrc2018@163.com, guanglongriyue@163.com, pangm@hrbeu.edu.cn

Abstract

Using single feature as the basis of judgement will lead to lower accuracy and robustness of face recognition. Accordingly, a multi feature Echo State Network (ESN) fusion face recognition method is designed. In this method, three invariant features are selected as the basis for face recognition, including Histogram of Oriented Gridients (HOG) features, Local Binary Patterns (LBP) features and Visual Pattern Recognition by Moment Invariants (Hu). These three kinds of features basically cover the illumination, texture, shape and other properties of face images. In the fusion stage of the three features, the HOG feature dictionary, the LBP feature dictionary and the Hu feature dictionary are first formed, and then they are replaced by the ESN to train and determine the fusion weight of the three features. Finally, the similarity measure of the three feature fusion is formed as the basis for judging the face recognition. The weight setting of different features in the process of similarity comparison is completed by ESN iteration, which improves the accuracy of each feature as the judgment basis. The experimental results show that recognition accuracy of our method is higher than the method using single feature, and it is obviously better than the multi feature method using adaptive weight and the multi feature method using the genetic algorithm.

Keywords: Multi feature fusion, HOG feature, LBP feature, HU moment feature, ESN network

1 Introduction

Face recognition technology can recognize human identity information [1]. Face recognition technology is widely used in various fields, such as identity authentication, secure landing of various network systems, criminal detection and human-machine interaction. In view of the important role of face recognition, domestic and foreign scholars have done a lot of research work in this field.

From the perspective of technological process, face recognition technology includes image acquisition, brightness correction, face area location, face recognition and so on. Among them, face recognition is the core link, and other links play a role of preparation and assistance [2-3]. Face recognition algorithm is the key to the whole face recognition technology. Up to now, there are several categories: face recognition using feature points, face recognition using local features, face recognition using global feature, face recognition using illumination features, face recognition using template feature and so on [4-8].

People's facial features are very rich. Some features including the eyes, nose, ear, mouth, hair and beard in different faces is different, which is also the basis for judging the identity of different people [9]. The same person's face also shows different expressions, angry, happy, sad, angry, frightened. The shooting angle and illumination condition also have some influence, which may lead to recognition errors [10]. In order to solve this problem, all kinds of invariance features are applied to face recognition.

Zhang proved that the gradient direction of the image has illumination invariance, and transferred the computation of the gradient domain to the first-derivative convolution kernel of Gauss function. Accordingly, he proposed a gradient domain transformation and gradient direction solving model. Image gradient direction feature can effectively eliminate the influence of illumination change on face imaging, and has strong illumination robustness [11]. Image gradient histogram feature, HOG is first applied to pedestrian recognition. The HOG features have good

*Corresponding Author: Ming Pang; E-mail: pangm@hrbeu.edu.cn
DOI: 10.3966/160792642020092105029

recognition for the contour and the edge of the target, and it has geometric invariance and illumination invariance at the same time, which makes it an important feature widely used in face recognition. Singh uses a local grid extraction scheme to successfully apply HOG features to face recognition and achieve the desired results [12]. LBP feature is a typical image texture feature. LBP feature is insensitive to illumination and image noise, so it is suitable for complex face recognition problems. He applies LBP features to face recognition. It is found that LBP features have rotation invariance, illumination invariance, grayscale invariance and fast computation speed [13]. The human face is rich in shape, such as eyes, mouth, nose and so on. Trigonometric integral features can depict shapes, so it is suitable for face recognition. Proenca combines the rectangle feature and the trigonometric integral feature to achieve a real-time face recognition [14]. Dora applies Gabor wavelet to finish face recognition, which can obtain multi scale local features from multiple directions, and make the feature information more abundant in face recognition and judgment [15].

Using single feature as the sole judgement basis of face recognition process, reliability is difficult to guarantee. A feature may have an ideal effect for a certain kind of face image, but it may also be invalid for other types of face images. So the face recognition method based on single feature is less robust [16-18]. Therefore, it is a new idea to fuse various features as the basis for judging face recognition. At present, there are many methods of feature fusion, such as face recognition based on local global feature, face recognition using multi frequency features, face recognition using multi-scale feature and so on. Genetic algorithm and neural network algorithm are also applied to this fusion, and the weights of different features can be determined more rationally [19-23].

On the basis of previous research work, we combines the three features of HOG, LBP and Hu moments, in order to further enhance the reliability and robustness of face recognition criteria, and obtain more ideal recognition accuracy.

2 Proposed Method

2.1 Method Framework

In the design of face recognition method proposed in this paper, all kinds of invariance features are chosen as the basis for judging the possible changes of the face image. At the same time, considering the unreliability of recognition process based on single feature, the identification strategy of multi feature fusion is determined. However, the simple weighted processing can not adapt well to the difference of different face images, and can not set the most reasonable fusion weight for different features of different face images. For this reason, the ESN echo state network is selected as the fusion weight trainer of various features, and the overall framework is designed as follows:

According to framework shown in Figure 1, ESN fusion face recognition method is implemented according to the following steps:

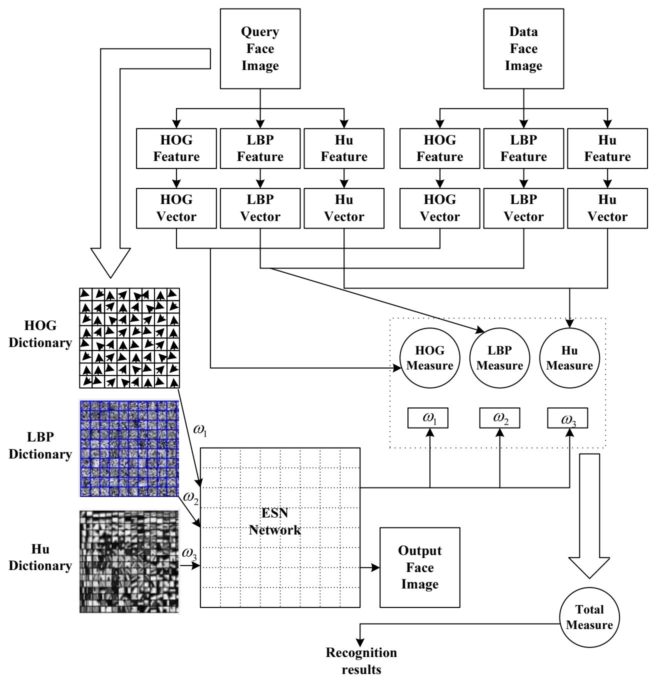


Figure 1. Method framework using ESN multi feature fusion

The first step is to generate HOG feature dictionary, LBP feature dictionary and Hu moment feature dictionary according to the content information of the face image to be recognized.

According to framework shown in Figure 1, ESN fusion face recognition method is implemented according to the following steps:

The first step is to generate HOG feature dictionary, LBP feature dictionary and Hu moment feature dictionary according to the content information of the face image to be recognized. Three dictionaries correspond to three features of a face image, and their dimensions are consistent with the vector dimensions extracted from the corresponding features. For example, if the Hu dictionary contains seven vectors, then the Hu dictionary has seven dimensions.

The second step, according to a certain initial value of the scaling factor ω_1, ω_2, and ω_3 input HOG feature dictionary, LBP feature dictionary, Hu moment feature dictionary to the ESN network, and identify the face image for output training. The initial weight of each variable is set equal. The iterative scaling factor is continuously updated in the training process until the ESN output image is sufficiently similar to the face image to be recognized. The scaling factor reflects the importance of HOG features, LBP features and Hu moments for the recognition of face images, and also as the weight of HOG measure, LBP measure and Hu moment measure in the overall similarity measure.

The third step is to extract HOG feature, LBP feature and Hu moment feature from the face image and database face image in accordance with certain rules, and form HOG eigenvector, LBP eigenvector, and Hu moment feature vector.

The fourth step is to construct the HOG feature similarity measure, the LBP feature similarity measure and the Hu moment feature similarity measure respectively.

In the fifth step, according to the weight of the second step and the sub measures in the fourth step, the general similarity measure of the multi feature ESN fusion face recognition method is constructed.

The sixth step, according to the global similarity measure, completes the similarity judgment between the recognized face image and the database face image, and outputs the recognition result.

2.2 ESN Network

ESN network is a new type of recurrent neural network, which has many characteristics, such as strong memory, strong analysis ability, strong nonlinear processing ability and so on.

The structure of the ESN network is shown as in Figure 2.

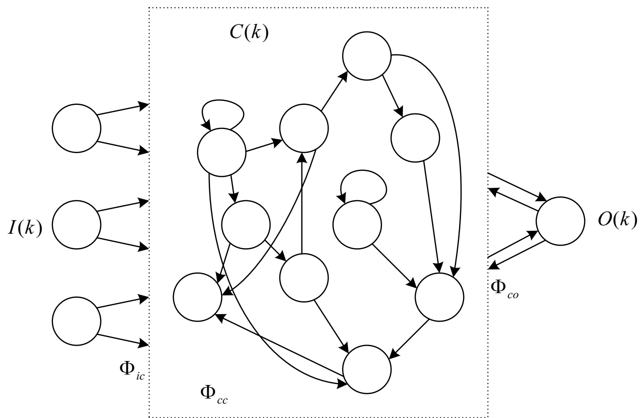


Figure 2. Structure of ESN

As illustrated in Figure 2, the ESN structure contains three levels: input, hidden, and output layer neurons. The input layer neurons form a reserve pool through sparse connections between them.

$$\begin{aligned} I(k) &= (i_1(k), i_2(k), \cdots, i_l(k))^T \\ C(k) &= (c_1(k), c_2(k), \cdots, c_m(k))^T \\ O(k) &= (o_1(k), o_2(k), \cdots, o_n(k))^T \end{aligned} \quad \textbf{(1)}$$

Where, $I(k)$, $C(k)$, and $O(k)$ represent vectors corresponding to neurons at three levels respectively.; l, m, and n represent the number of three types of neurons respectively; k represents the sampling time for the entire network.

When ESN performs iterative operations, the sampling time changes from k to $k+1$, which can be updated according to the following formula:

$$C(k+1) = \Theta_1(\Phi_{ic} I(k+1) + \Phi_{cc} C(k)) \quad \textbf{(2)}$$

$$O(k+1) = \Theta_2(\Phi_{co} C(k+1)) \quad \textbf{(3)}$$

Where, Θ_1 and Θ_2 indicate the activation function of hidden and output layer with nonlinear processing ability.

ESN has 4 key parameters: the first parameter is the reserve pool size N, that is, numbers of neurons in hidden layer. If it is too small, expressive power of ESN will decrease; if it is too large, the complexity of ESN will increase. The second parameter is the spectral radius R, that is, the absolute value of its maximum eigenvalue. If it is too small, ESN memory capacity is insufficient; If it is too large, the reserve pool is unstable. When its range is (0, 1) interval, ESN can achieve stable echo performance. The third parameter is the scaling factor ω. If it is smaller, ESN linear analysis performance is strong; If it is larger, ESN nonlinear analysis performance is strong. The fourth parameter is the degree of sparsity D. When D is in the interval of (0.01, 0.1), the ESN buffer pool is more active.

2.3 HOG Feature Extraction

HOG features can not only describe local features, but also describe the characteristics of the whole image. It was originally used to identify people in various complex scenes, and was later used for recognition of other objects and faces. The extraction process of HOG features mainly includes the following 4 steps:

(1) Gamma color correction

For monitors, brightness does not vary linearly with the increase of input voltage. In this way, the output image is output bright compared with the input image. In order to compensate for this deficiency, we need to use the inverse effect compensation curve to restore the true input image. In this way, the ideal output results can be obtained.

(2) Gradient calculation of the entire image

Traverses the X axis and Y axis of the image respectively with templates $h_x = [-1 \quad 0 \quad 1]$ and $h_y = [1 \quad 0 \quad -1]^T$. If the image is colored, the gradient of the 3 channels of RGB can be separately computed and the maximum will be taken as the gradient of the pixel.

(3) Statistical histogram of gradient direction

A cell unit is composed of multiple pixels, and a plurality of cell units form a block area. In the block area, the weight is determined by the Gauss weight window to eliminate the influence of the boundary of the block region. In the cell unit of the prescribed size, the gradient direction is weighted according to the gradient of each pixel to vote in the direction bucket in advance, and the histogram of gradient direction is finally obtained.

(4) Normalization of HOG histogram

The image is divided into nW*nH blocks. In blocks, gradient histograms in the same direction are counted. Then, histograms are normalized using the truncated form of L2 norm, such as formula (4).

$$HOG(i) = \frac{HOG(i)}{\sqrt{\sum_{n-1}^{n} HOG(i)^2 + \varepsilon}} \quad \textbf{(4)}$$

Where, $i = 1, 2, \cdots, n$; n is sum of histogram. ε is small normal constant number. Next, we compare and truncate the histogram value with the cut-off threshold T. Finally, regularization is applied to get the histogram of the gradient direction of the corresponding region block.

(5) HOG eigenvector

The histograms of normalized blocks are linked up from top to bottom and left to right to form the feature vectors as the final visual features. In this paper, every 4 pixels is set as a basic bag of HOG dictionary, and each basic bag contains 9 feature vectors. Then an image of 256 pixels will form 64 basic packets, thus including 576 feature vectors.

2.4 LBP Feature Computation

Firstly, $f(x_c, y_c)$ is chosen as center pixel and threshold. Other pixels should be binarized as follows:

$$s(g_i, g_c) = \begin{cases} 1, & g_i \geq g_c \\ 0 & g_i < g_c \end{cases} \quad \textbf{(5)}$$

Where, g_c is the gray value of center pixel, g_i is other pixel in local image.

$s(g_i, g_c)$ will be fused, and decimal number corresponding to binary number is LBP feature value of the center pixel.

An example of LBP feature computation is shown as Figure 3.

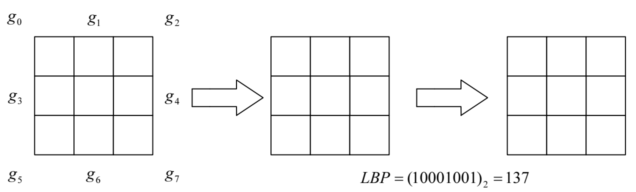


Figure 3. Example of LBP feature computation

2.5 Hu Moment Feature Extraction

There are many shape feature vectors that are successfully applied to pattern recognition, such as interior angular vector, gradient vector, Hu moment vector, moment of inertia vector, Harris corner vector and so on. Among them, the Hu moment vector can reliably describe the shape features of the image, but the computational complexity is high. For this purpose, we use a contour based Hu moment vector extraction method to satisfy the expression of shape features. This Hu moment extraction method is completed according to the following steps:

The first step is to compute linear integrals based on image pixel information, as shown in formula 11.

$$\Re_{pq} = \int_C m^p n^q ds \quad \textbf{(6)}$$

Where, C represents the characteristic of the curve in the image; (m,n) represents the pixels that C passes; $ds = \sqrt{(dm)^2 + (dn)^2}$ represents a microelement; p and q are integers; When $p = q = 0$, $\Re_{00}$ is length of surve C .

The second step is to calculate the central moment $(p+q)$ of the curve C , as shown in formula (12).

$$\theta_{pq} = \iint_C (m - \overline{m})^p (n - \overline{n})^q ds \quad \textbf{(7)}$$

Where, $\overline{m} = \frac{\Re_{10}}{\Re_{00}}$, $\overline{n} = \frac{\Re_{01}}{\Re_{00}}$.

The third step is to calculate the 7 Hu moment components of the image shape.

Accordingly, the 7 Hu moment components are combined to form the expression vector of image shape feature, as shown in formula (8).

$$Hu = \{h_1, h_2, h_3, h_4, h_5, h_6, h_7\} \quad \textbf{(8)}$$

2.6 Similarity Measure

HOG feature, LBP feature and Hu moment feature are used in the multi feature ESN fusion face recognition. In the similarity calculation, the similarity measure of HOG feature, the similarity measure of LBP feature and the similarity measure of Hu moment are first calculated, and then the 3 measures are fused into the overall similarity measure.

The similarity measure of HOG features is calculated as shown in formula (9).

$$S_{HOG}(q, D) = \left\| HOG_C^q - HOG_C^D \right\| \quad \textbf{(9)}$$

The similarity measure of LBP features is calculated as shown in formula (10).

$$S_{LBP}(q, D) = \left\| LBP_T^q - LBP_T^D \right\| \quad \textbf{(10)}$$

The similarity measure of Hu moment feature is calculated as shown in formula (11).

$$S_{Hu}(q, D) = \left\| Hu_S^q - Hu_S^D \right\| \quad \textbf{(11)}$$

Combined with the three weights derived from ESN training, the overall similarity measure of the retrieval algorithm can be obtained, as shown in formula (12).

$$S = \omega_1 S_{HOG}(q,D) + \omega_2 S_{LBP}(q,D) + \omega_3 S_{Hu}(q,D) \quad \textbf{(12)}$$

Where, $S_{HOG}(q,D)$, $S_{LBP}(q,D)$, and $S_{Hu}(q,D)$ is similarity measure HOG, LBP, and Hu feature, ω_1 is the weight of HOG feature, ω_2 is the weight of LBP feature, ω_3 is the weight of Hu feature.

3 Experimental Results and Analysis

This experiment is carried out on the FRGC v2.0 database. The database is the largest public face database that has been publicly available, including more than 40 thousand pictures in controlled and uncontrolled environments. The sample pictures in the database are shown as Figure 4.

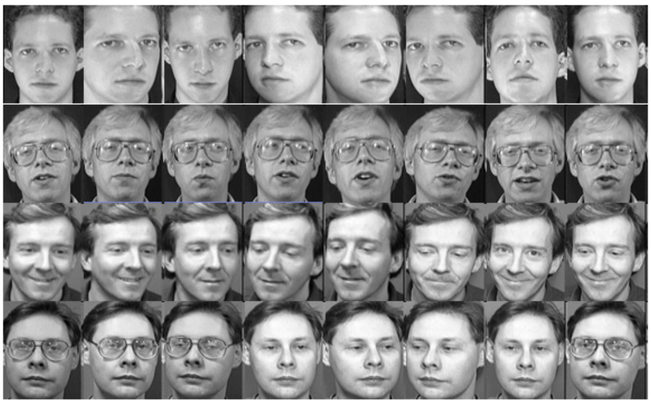


Figure 4. Images in the database using in this paper

The measurement images are all the deformation forms of the existing images in the database, such as different angles, different expressions. If the recognition result image and the measurement image are the same person, the recognition accuracy can be determined.

There are many training sets in the test protocol provided by the database itself. We randomly select 10 pictures from each group to form a new training set. In this way, there are 2200 pictures in the new training set. For the validation set, 466 users were randomly selected to register 1 controlled photos per person as target set (target). The detection set was set up in accordance with the list of the most difficult FRGC standards, which contained 466 photos of 8014 uncontrolled conditions. There is no intersection between the target set and the probe set. The reason for the design of this experiment is that the number of user photos that can usually be obtained in the actual application is very limited, so the set of the target set is one image per person. It is relatively easy for the same user to get more test pictures. The test performance index used in each experiment is the preferred recognition rate.

First of all, HOG single feature recognition method, LBP single feature recognition method and Hu moment single feature recognition method are adopted respectively as the contrast method of this method. The comparison of the four methods for recognition accuracy is presented as Table 1 and Figure 5.

Table 1. Comparison of three single feature recognition methods and the method in this paper

Number of training images	Recognition accuracy			
	HOG	LBP	Hu	Proposed method
20	0.583	0.567	0.489	0.621
40	0.591	0.571	0.523	0.663
60	0.572	0.586	0.537	0.685
80	0.613	0.592	0.558	0.726
100	0.654	0.581	0.572	0.743
120	0.667	0.603	0.581	0.752
140	0.681	0.612	0.580	0.761
160	0.692	0.633	0.591	0.775
180	0.703	0.624	0.602	0.788
200	0.685	0.651	0.588	0.793
220	0.724	0.665	0.611	0.817
240	0.715	0.671	0.633	0.827
260	0.733	0.684	0.651	0.846
280	0.741	0.712	0.669	0.852
300	0.768	0.758	0.724	0.873
320	0.802	0.771	0.735	0.888
340	0.833	0.794	0.771	0.881
360	0.859	0.845	0.756	0.899
380	0.861	0.821	0.782	0.905
400	0.854	0.835	0.745	0.901

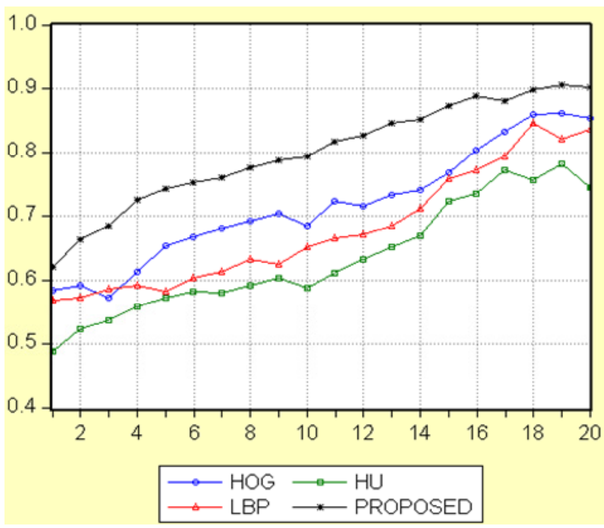


Figure 5. Comparison results of four methods

From the results of Table 1 and Figure 5, we can see that with the increase of number involved in training, multi feature ESN fusion face recognition method is significantly higher than recognition method of three single features. When number involved in training is increased to 400, the accuracy of face recognition has reached 90%. The reason for this result is that a variety of features are used in the proposed method at the same time, and the feature weights are set in the process of similarity judgment more reasonably through ESN network iteration.

The recognition results of the algorithm, the multi feature adaptive weighted fusion method (Its weight forming process is adjusted linearly in sections)and the multi feature genetic algorithm fusion method(Its weight is calculated by genetic algorithm) are compared. The effect of recognition accuracy is presented as Table 2 and Figure 6.

Table 2. Comparison of two kinds of multi feature fusion recognition methods and the method of this paper

Number of training images	Recognition accuracy		
	Multi feature weighted fusion	Multi feature GA fusion	Proposed method
20	0.631	0.602	0.621
40	0.642	0.623	0.663
60	0.628	0.645	0.685
80	0.654	0.637	0.726
100	0.660	0.631	0.743
120	0.671	0.659	0.752
140	0.680	0.662	0.761
160	0.688	0.673	0.775
180	0.693	0.681	0.788
200	0.702	0.690	0.793
220	0.695	0.712	0.817
240	0.714	0.735	0.827
260	0.729	0.756	0.846
280	0.739	0.779	0.852
300	0.752	0.801	0.873
320	0.779	0.818	0.888
340	0.848	0.846	0.881
360	0.839	0.844	0.899
380	0.855	0.839	0.905
400	0.841	0.852	0.901

Figure 6. contrast results of three methods

From the results of Table 2 and Figure 6, we can see that with the increase of the number of face images involved in the training, the multi feature ESN fusion face recognition method is obviously higher than multi feature adaptive weighting recognition method and the multi feature GA recognition method.

The above two sets of experimental results show that recognition accuracy of this method is high. This is not only because of the simultaneous adoption of the three features, but also by the use of ESN network for training of various features.

For different images, the proportion of different features is different, and the influence on the process of similarity judgment is also different. Simple weighting obviously ignores this different effect. Through the weight configuration of ESN training, the influence of different features on image composition is better reflected, and the accuracy of recognition results is improved.

4 Conclusion

The key of face recognition technology is whether it can extract more abundant, more comprehensive and more accurate feature information from the face image, and use these information as the judgment basis of the recognition stage. Changes in light conditions, geometric positions and facial expressions can also cause changes in certain features in face images. Therefore, single features and variable features are not the best choice for face recognition technology.

In this paper, HOG feature, LBP feature and HU moment feature are selected as the basis of face recognition. These three kinds of features are invariance features, and cover the light, texture and shape of the face image, which can make the facial image feature information more accurate. In order to achieve more reasonable fusion of the three types of features, the feature dictionary corresponding to the three types of features is used as the input of the ESN network, and the fusion weights of the three types of features are obtained by training the ESN network, and then the similarity measure of multi feature fusion is formed as the basis for judging the face recognition.

Two groups of experimental studies have been carried out: the first group of experiments, comparing this method with three kinds of single feature face recognition methods. Recognition accuracy of the multi feature ESN fusion method is higher than other three single feature recognition methods; the second groups of experiments and two multi feature fusion methods are used. In comparison, one is the adaptive weighted fusion method, the other is the fusion method based on genetic algorithm. Recognition accuracy of the multi feature ESN fusion method is also higher than the two multi feature fusion face recognition methods. The results of these two groups of experiments show that the proposed method achieves the goal of improving the accuracy of face recognition.

Our work is of great value to improve the accuracy of face recognition and expand the application of face recognition software.

Acknowledgments

This study was supported by National Natural Science Foundation of China (Grant No. 61774107). And supported by the University Nursing Program for Young Scholars with Creative Talents in Heilongjiang Province (UNPYSCT 2017086), Fundamental Research Fundation for Universities of Heilongjiang Province (LGYC 2018JQ014) and Heilongjiang Postdoctoral Scientific Research Developmental Fund (LBH Q17080).

Contribution

Shuang Liu, and Deyun Chen proposed the algorithm framework and wrote the full text. Zhifeng Chen programmed the algorithm in this paper. Changhai Ru, and Ming Pang revised and wrote in English.

References

[1] F. Juefei-Xu, M. Savvides, Multi-class Fukunaga Koontz Discriminant Analysis for Enhanced Face Recognition, *Pattern Recognition*, Vol. 52, pp. 186-205, April, 2016.

[2] H. Nguyen, W. Yang, B. Sheng, C. Sun, Discriminative Low-Rank Dictionary Learning for Face Recognition, *Neurocomputing*, Vol. 173, pp. 541-551, January, 2016.

[3] M. Dewan, E. Granger, G. Marcialis, R. Sabourin, F. Roli, Adaptive Appearance Model Tracking for Still-to-video Face Recognition, *Pattern Recognition*, Vol. 49, No. C, pp. 129-151, January, 2016.

[4] R. Ahdid, E. Azougaghe, S. Safi, B. Manaut, Two-Dimensional Face Surface Analysis Using Facial Feature Points Detection Approaches, *Journal of Electronic Commerce in Organizations*, Vol. 16, No. 1, pp. 57-71, January, 2018.

[5] C. Li, S. Zhao, K. Xiao, Y. Wang, Face Recognition Based on the Combination of Enhanced Local Texture Feature and DBN under Complex Illumination Conditions, *Journal of Information Processing Systems*, Vol. 14, No. 1, pp. 191-204, February, 2018.

[6] P. Karczmarek, W. Pedrycz, A. Kiersztyn, P. Rutka, A Study in Facial Features Saliency in Face Recognition: An Analytic Hierarchy Process Approach, *Soft Computing*, Vol. 21, No. 24, pp. 7503-7517, December, 2017.

[7] Y. Kim, H. Kim, S. Kim, H. Kim, S. Ko, Illumination Normalization Using Convolutional Neural Network with Application to Face Recognition, *Electronics Letters*, Vol. 53, No. 6, pp. 399-401, March, 2017.

[8] M. Lim, S. Verma, G. Mai, P. Yuen, Learning Discriminability-preserving Histogram Representation from Unordered Features for Multibiometric Feature-fused-template Protection, *Pattern Recognition*, Vol. 60, pp.706-719, December, 2016.

[9] F. Alvi, R. Pears, A Composite Spatio-temporal Modeling Approach for Age Invariant Face Recognition, *Expert Systems with Applications*, Vol. 72, pp. 383-394, April, 2017.

[10] L. Boussaad, M. Benmohammed, R. Benzid, Age Invariant Face Recognition Based on DCT Feature Extraction and Kernel Fisher Analysis, *Journal of Information Processing Systems*, Vol. 12, No. 3, pp. 392-409, September, 2016.

[11] T. Zhang, Y. Tang, B. Fang, Face Recognition under Varying Illumination Using Gradientfaces, *IEEE Transactions on Image Processing*, Vol. 18, No. 11, pp. 2599-2606, November, 2009.

[12] G. Singh, I. Chhabra, Effective and Fast Face Recognition System Using Complementary OC-LBP and HOG Feature Descriptors with SVM Classifier, *Journal of Information Technology Research*, Vol. 11, No. 1, pp. 91-110, January, 2018.

[13] C. He, J. Zhang, A Face Recognition Algorithm Based on Completed LBP, *Boletin Tecnico/technical Bulletin*, Vol. 55, No. 9, pp. 624-629, September, 2017.

[14] H. Proenca, S. Filipe, Combining Rectangular and Triangular Image Regions to Perform Real-time Face Detection, *International Conference on Signal Processing*, Beijing, China, 2008, pp. 903-908.

[15] L. Dora, S. Agrawal, R. Panda, A. Abraham, An Evolutionary Single Gabor Kernel Based Filter Approach to Face Recognition, *Engineering Applications of Artificial Intelligence*, Vol. 62, pp. 286-301, June, 2017.

[16] Y. Chu, L. Zhao, T. Ahmad, Multiple Feature Subspaces Analysis for Single Sample Per Person Face Recognition, *Visual Computer*, Vol. 35, No. 2, pp. 239-256, February, 2019.

[17] M. Aslan, Z. Hailat, T. Alafif, X. Chen, Multi-channel Multi-model Feature Learning for Face Recognition, *Pattern Recognition Letters*, Vol. 85, No. C, pp. 79-83, January, 2017.

[18] J. Pontes, A. Britto, C. Fookes, A. Koerich, A Flexible Hierarchical Approach for Facial Age Estimation Based on Multiple Features, *Pattern Recognition*, Vol. 54, No. C, pp. 34-51, June, 2016.

[19] P. Sukhija, S. Behal, P. Singh, Face Recognition System Using Genetic Algorithm, *Procedia Computer Science*, No. 85, pp. 410-417, 2016.

[20] L, Tian, C. Fan, Y. Ming, Multiple Scales Combined Principle Component Analysis Deep Learning Network for Face Recognition, *Journal of Electronic Imaging*, Vol. 25, No. 2, Article ID 023025, April, 2016.

[21] T. Kitajima, E. Murakami, S. Yoshimoto, Y. Kuroda, O. Oshiro, Privacy-Aware Face Detection Using Biological Signals in Camera Images for the Transactions of The Institute of Electrical Engineers of Japan, *IEEJ Transactions on Electronics, Information & Systems*, Vol. 138, No. 3, pp. 210-220, March, 2018.

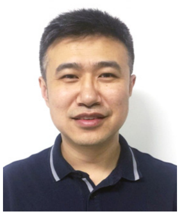
[22] P. Kavitha, K. Vijaya, Optimal Feature-level Fusion and Layered k-support Vector Machine for Spoofing Face

Detection, *Multimedia Tools & Applications*, Vol. 77, No. 20, pp. 26509-26543, October, 2018.
[23] Y. Wu, X. Sun, Text Coverless Information Hiding Method Based on Hybrid Tags, *Journal of Internet Technology*, Vol. 19, No. 3, pp. 649-655, May, 2018.

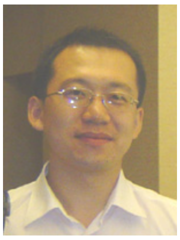
Biographies

Shuang Liu, lecturer of Harbin Commercial University, is mainly engaged in the research of face detection technology.

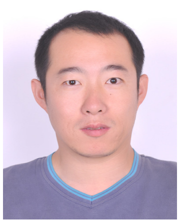
Deyun Chen, Professor of Harbin University of Science and Technology, is mainly engaged in the research of electrical capacitance chromatography and image processing.



Zhifeng Chen, associate professor of Harbin Business University, is mainly engaged in the research of image processing.



Changhai Ru, Professor of Suzhou University, is mainly engaged in the research of sensor technology.



Ming Pang, associate professor of Harbin Engineering University, is mainly engaged in biomedical image research.