PAPER Special Section on Face Perception and Recognition

Real-Time Face Detection and Recognition via Local Binary Pattern Plus Sample Selective Biomimetic Pattern Recognition

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SUMMARY Due to security demand of society development, real-time face recognition has been receiving more and more attention nowadays. In this paper, a real-time face recognition system via Local Binary Pattern (LBP) plus Improved Biomimetic Pattern Recognition (BPR) has been proposed. This system comprises three main steps: real-time color face detection process, feature extraction process and recognition process. Firstly, a color face detector is proposed to detect face with eye alignment and simultaneous performance; while in feature extraction step, LBP method is adopted to eliminate the negative effect of the light heterogeneity. Finally, an improved BPR method with Selective Sampling construction is applied to the recognition system. Experiments on our established database named WYU Database, PUT Database and AR Database show that this real-time face recognition system can work with high efficiency and has achieved comparable performance with the state-of-the-art systems.

key words: *face detection, face recognition, local binary pattern, biomimetic pattern recognition, sample selection*

1. Introduction

Although face recognition has been widely researched for the past two decades, laboratory developed promising face recognition systems trained by off-line face databases did not perform well in the practical world [1]–[3]. This is mainly because of the variation effects such as lighting, facial expression, and head pose. Accuracy may drop rapidly under uncontrolled conditions. Such conditions are often encountered in automatic identity capture for video surveillance and face recognition from a network camera, thus the task of robust face recognition still poses great challenges.

Robust face recognition in real complex environment and high performance real-time face detection are the two main difficulties in the video based face recognition system. For the still-image face recognition, promising results have been reported in the literature. For example, the well-known methods such as Principal Component Analysis (PCA) [1], Linear Discriminant Analysis (LDA) [1], Eigenfaces and Fisherfaces methods [4], Eigenspace-based face recognition [5], Sparse Representation Classification (SRC) [3], Biomimetic Pattern Recognition methods [6] et al. Another important task for face recognition in a video clip is simultaneous face detection. In order to capture the frontal face images accurately and timely, many face detection methods have been proposed, such as the discriminating feature analysis and Support Vector Machine (SVM) classifier for face detection [7], neural network-based face detection [8], face detection in color images based on fuzzy theory [9], et al. Face color information is an important feature in the face detection. In Ref. [10], the quantized skin color regions are adopted for face detection.

In this paper, a real-time face recognition system via Local Binary Pattern (LBP) [11] plus Improved Biomimetic Pattern Recognition (BPR) has been proposed. This system comprises three main processes: real-time color face detection process, feature extraction process and recognition process. Firstly, a color face detector is proposed to detect face simultaneously, eye alignment is employed to solve the asymmetric face image problem. While in feature extraction step, LBP method is adopted to eliminate the negative effect of the light heterogeneity. Finally, an improved BPR method with Selective Sampling construction is applied to the recognition system.

The rest of the paper is organized as follows. In Sect. 2, a color based face detector with eye alignment and simultaneous performance is presented to detect face images. The proposed face recognition algorithm based on LBP feature extraction and improved sample selective construction BPR method is given in Sect. 3. Experimental results are discussed in Sect. 4. Section 5 concludes the paper and gives directions of future work.

2. Real-Time Face Detection

In this paper, skin color based detection algorithm is adopted in face detection process. Skin color is easy to obtain and split, and has plentiful information which makes the algorithm more easily achieved. In addition, it is less influenced by illumination, complex background and the rotation angle of the face. Different from the feature trained method like support vector machine and neural network method, it needs no training beforehand. Thus face detection can be implemented efficiently and simultaneously.

Manuscript received June 10, 2012.
Manuscript revised October 20, 2012.

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DOI: 10.1587/transinf.E96.D.523

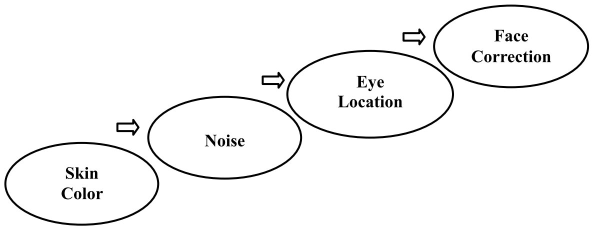


Fig. 1 Flow diagram of skin color based face detection algorithm.

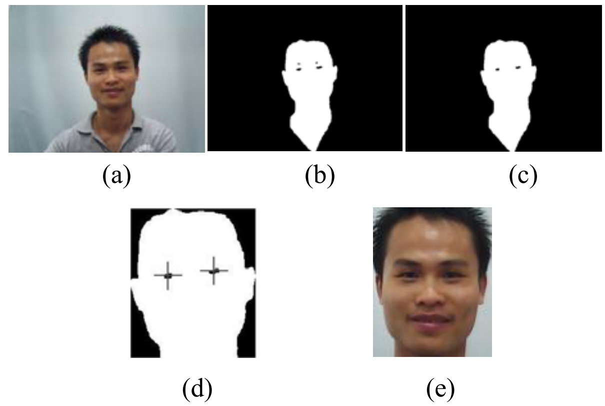


Fig. 2 Results of face detection. (a) Original image, (b) Output image of skin color transformation, (c) Output image of noise processing, (d) Output image of eyes location, (e) Output image of detection.

2.1 Diagram of Skin Color Based Face Detection Algorithm

The skin color based face detection algorithm consists of four parts: skin color extraction, noise processing, eye location and face correction. Flow diagram of the algorithm is shown in Fig. 1.

For a real-time detection system, optimized results of each part of the algorithm are required. The detection speed and true detection rate are both important to enhance the stability of the detection system. Details will be discussed in the following.

2.2 Skin Color Extraction

The skin color includes sufficient discriminative information of human face from background. Although it looks very different in various people's skin color, it is basically the same color tone to overcome the impact of the brightness. So it's feasible to split the color from the background by utilizing this characteristic. Because there is no specific brightness dimension in the RGB color space, it's poor for color clustering and difficult to split the skin color area. Here, YIQ color space is adopted to find a better color space, because the skin color had a strong clustering in this space and extensively experimental results show that it is only clustering in the 'I' dimensional space. It means that the skin color can be easily split and the detection algorithm is simple to implement, thus it can meet the speed requirements of real-time detection system. The YIQ color space can be transformed from the RGB color space via the following equation

$$\begin{pmatrix} Y \\ I \\ Q \end{pmatrix} = \begin{pmatrix} 0.229 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.211 & -0.523 & 0.312 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix} \tag{1}$$

Three steps of skin color extraction are as the following:
(1) Color space transformation from RGB to YIQ.
(2) Extract the 'I' dimensional image data from YIQ color space.
(3) Set the threshold value and separate the skin color and the background from the binary image, as shown in Fig. 2 (b).

2.3 Noise Processing

The purpose of noise processing is to filtering noise while retaining the useful characteristics of the skin color. Noise or background object jamming exists when extracting the skin color and it will result in distortion for the extracted skin color. Thus it needs to be further processed to reduce the impact of noise on the original image. There are some ways for noise processing. Image filters and morphology can be used to process grayscale images and binary image respectively. In this paper, morphology method is used to process the noise and eliminate interference. The non-face area in the original image will be filtered out after the morphological processing method in the binary image such as corrosion, padding, deleting the border and so on, but the eye regions still remain at the same time. Figure 2 (c) shows the result of noise processing, in which eyebrow regions has been eliminated.

2.4 Eye Positioning

Eye positioning is a critical step in the algorithm. In this paper, the centroid location method is used for eye positioning. After the processing above, the eye area of the binary image is located as Fig. 2 (d). Therefore, by calculating the centroid of the eye region, the location of the face can be navigated accurately. Experimental results show this method is simple and can reduce the deviation of the face location. The eye centroid is calculated in binary image by following conversion

$$A = \sum_{i=0}^{n-1} \sum_{j=0}^{m-1} B(i, j) \tag{2}$$

Where $B(i, j)$ is the binary image pixel value of the corresponding coordinate (i, j) in face image; the eyes area in image is defined as follows

$$S = \sum_{i=q}^{u} \sum_{j=p}^{v} B(i, j) \tag{3}$$

Where the value of q, p, u, v is less than the scope of the image; the coordinates of the eyes region in the image are calculated as follows

$$x = \frac{\sum_{i=q}^{u}\sum_{j=p}^{v} jB(i,j)}{A}, \quad y = \frac{\sum_{i=q}^{u}\sum_{j=p}^{v} iB(i,j)}{A} \tag{4}$$

After the face region processing, only the region of the eyes is left ideally. The positioning of the eyes in the original image can be located by calculating the centroid coordinate of the eye region, which is shown in Fig. 2 (d). However, it is difficult to eliminate the noise jamming in the face region, such as the eyebrows region, mouth region and glasses region or other interference, further filtering needs to be done in practical applications. This can exclude the interference and improve the detection accuracy rate mainly by the specific location, size or other information of the eyes in the face.

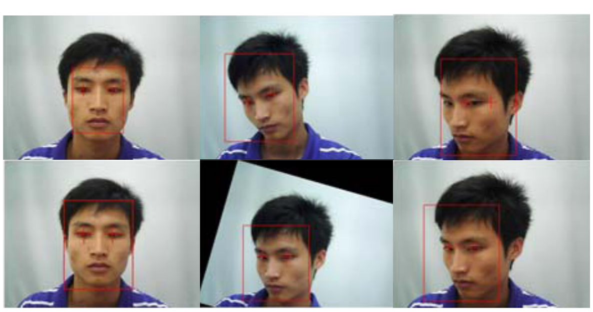
2.5 Face Correction by Eye Alignment

The purpose of face correction is to ensure the output detected face images are with correct location, right size and complete information. In addition, it can improve the quality of all the output face images. This requires performing multi-directional correction on the detected image. The face image can be accurately extracted from the original image when doing the appropriate scaling, rotation and shift correction based on the coordinates of the eye in the whole image. Assumption by the available binocular eye location in the original image coordinates as follows: (x_1, y_1) and (x_2, y_2). This can be achieved by the following corrections.

(1) Resize Correction
The magnification of η can be adjusted based on the proportional relationship between the distance of Δl required by output image of the eye and the distance of original image (Fig. 3 (a))

$$\eta = \frac{\Delta l}{|x_2 - x_1|} \tag{5}$$

Its role is to make the scaling of original image is in the appropriate size and ensure the output face image is in the same size.



(a) (b) (c)

Fig. 3 Results of correction. (a) Resize correction (b) Rotation correction (c) Shift correction

(2) Rotation Correction
According to the eyes coordinates and the horizontal axis into the angle regulates to the rotation of original image (Fig. 3 (b)), where θ is

$$\theta = \arctan\frac{y_1 - y_2}{x_1 - x_2} \tag{6}$$

Its role is to make the detected face image is in correct position and ensure the output face image having the appropriate angle.
(3) Shift Correction
According to the distance of Δd from eyes to the facial skin color edge, the eyes abscissa is moved adaptively (Fig. 3 (c))

$$x_1' = x_1 \pm \Delta d, \quad x_2' = x_2 \pm \Delta d \tag{7}$$

Its role is to make the detected face image is in the location center of the image, so that the output face image is more complete.

Experimental results show that the proposed face detection method can achieve wonderful results via the above three correction steps. Face correction is critical to improve the true recognition rate in face recognition process, and it can reduce the probability of the false recognition effectively due to information missing or misalignment in detected face image, thus enhance the stability of the system. Therefore, the output of well detected face images is an important part of face recognition system.

3. The Proposed Face Recognition Algorithm

3.1 Feature Extraction Based on Local Binary Pattern

Local Binary Pattern (LBP) [11] is a very simple, yet efficient approach to analyze local texture features of an image. From the proposed paper, its basic idea is to use the center pixel's value of a local window as a threshold to compare with its neighborhood pixels' values, and then a string of binary code can be got and used to represent the local texture features. For details, now we define T in a local window of an image as the joint distribution of the gray levels of P ($P > 1$) image pixels

$$T = t(g_c, g_0, \ldots, g_{p-1}) \tag{8}$$

where g_c corresponds to the gray value of the center pixel of the local window, and g_p ($p = 0, \ldots, p-1$) corresponds to the gray values of P pixels which are equally distributed around the center pixel in radius of R ($R > 0$). Without losing information, g_c can be subtracted by g_p, then we get

$$T = t(g_c, g_0 - g_c, \ldots, g_{p-1} - g_c) \tag{9}$$

If we assume that difference $g_p - g_c$ is independent of g_c, Eq. (9) can be written as

$$T \approx t(g_c)\, t(g_0 - g_c, \ldots, g_{p-1} - g_c) \tag{10}$$

Generally, the $t(g_c)$ describes the overall luminance of the image, which cannot reflect the local texture of an image, so

1	2	3
9	5	4
8	7	6

(a)

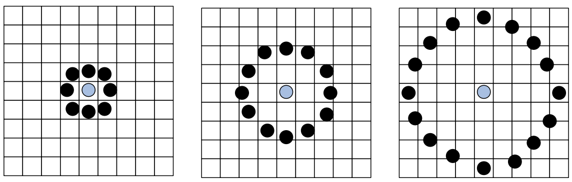
0	0	0
1	5	0
1	1	1

(b)

1	2	4
128	5	8
64	32	16

(c)

Fig. 4 Diagram of LBP operator. (a) Local image; (b) Transformation; (c) Auxiliary matrix.



(a) (b) (c)

Fig. 5 Symmetric neighborhood of different (P, R): (a) $P = 8$, $R = 1.0$; (b) $P = 12$, $R = 2.5$; (c) $P = 16$, $R = 4.0$.

Eq. (10) can be rewritten as

$$T \approx t(g_0 - g_c, \ldots, g_{p-1} - g_c) \tag{11}$$

Finally, a unique value can be calculated as

$$LBP_{P,R} = \sum_{P=0}^{P-1} s(g_p - g_c)\, 2^P \tag{12}$$

where

$$s(x) = \begin{cases} 1, \, x \geq 0 \\ 0, \, x < 0 \end{cases} \tag{13}$$

Functionality of LBP operator is illustrated in Fig. 4. It can effectively achieve gray scale invariance with simple local binary computing. Therefore, we use LBP in feature extraction of the system to eliminate the negative effect of the light heterogeneity. Figure 5 illustrates circularly symmetric neighbor set for various (P, R).

3.2 Improved Biomimetic Pattern Recognition

3.2.1 Basic Principle

Biomimetic Pattern Recognition (BPR) [6] was first proposed as a new pattern recognition model by academician Wang Shoujue in 2002. According to BPR theory, the differences between any two samples from the same class are continuous. In other words, there exists a gradual process for one class that includes all the possible samples in which one sample may be slightly different from the other samples.

Different from the "division" concept of traditional pattern recognition, BPR emphasizes the view point of the function and mathematical model of pattern recognition on the concept of "cognition", which is much closer to the function of human being. Moreover, BPR aims at the optimal coverage of the samples of the same type, while traditional pattern recognition aims at the optimal classifications of different types of the samples in the feature space. Particularly, the construction of the subspace of a certain type of samples depends on analyzing the relations between the specific types of samples and utilizing the methods of "coverage of objects with complicated geometrical forms in the multidimensional space".

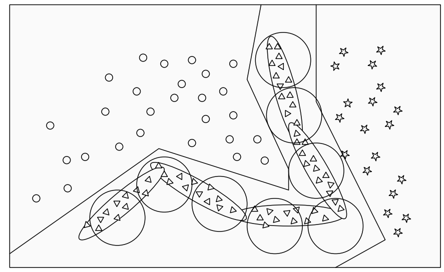


Fig. 6 The schematic diagram of the difference of BP, RBF, and BPR.

For example, in Fig. 6, the triangles represent the samples to be recognized, and the small circles and crisscrosses represent the samples of the other types. Then the broken lines represent the division methods of Pattern Recognition based on BP network, the large circles represent those of RBF network (these methods are equal to the ones based on template matching), and long ellipses represent the "recognition" methods of BPR.

An important and essential focus of attention in BPR is the principle of homology-continuity (PHC):

In the feature space R^n, we assume that set A includes all the samples which belong to class A. And if there exist any two samples x and y, there must be a set B for any $\varepsilon > 0$

$$\begin{aligned} B = \{x_1, x_2, x_3, \ldots, x_n \,|\, x_1 = x,\ x_n = y,\ n \subset N, \\ \rho(x_m, x_{m+1}) < \varepsilon,\ \varepsilon > 0 \,|\, n-1 \geq m \geq 1,\ m \subset N\} \end{aligned} \tag{14}$$

where $B \subset A$, $\rho(x_m, x_{m+1})$ is the distance between x_m and x_{m+1}.

3.2.2 High Dimensional Space Covering Method

In this paper, an n-dimensional hyper-sausages neuron is applied in the implementation of BPR. According to the theory of high dimensional hyper-surfaces [8], a neuron can construct various types of complex closed hyper-surface. For easier implementing the BPR, an n-dimensional hyper-sausages neuron is introduced here. So the union of hyper-sausages, the topological product of line segments and hyper-surface, can be a suitable basic shape (sets P_i) to cover the region of samples of the same class in the feature space approximately (set P'_a).

Consider the original samples set Y, let Y' be a subset of Y with j elements, as follows

$$\begin{aligned} B = \{x \,|\, x = Y'_i\ (i = 0, 1, 2, \ldots, n),\ \rho(Y'_i, Y'_{i+1}) \leq \\ d \leq \rho(Y'_{i-1}, Y'_{i+1}),\ Y'_0 = Y'_j)\},\ Y' \subset Y \end{aligned} \tag{15}$$

where d is selected constant.

Let j neurons cover P_a approximately, and then the covering of i-th neuron P_j is

$$P_i = \{x \mid = \rho(x, y) \leq k,\ y \in B_i,\ x \in R^n\} \tag{16}$$

$$B_i = \{x \mid x = \alpha Y' + (1 - \alpha) Y'_{i+1},\ \alpha \in (0, 1)\} \tag{17}$$

The covering of all j neurons is: $P'_a = \bigcup_{i=0}^{j-1} P_i$.
The function of Hyper-Sausages Neuron (HSN) [6] is

$$f_{HSN}(x) = \operatorname{sgn}\left(2^{\frac{d^2(x, \overline{x_1 x_2})}{r_0^2}} - 0.5\right) \tag{18}$$

Where

$$d^2(x, \overline{x_1 x_2}) = \begin{cases} \|x - x_1\|^2, & q(x, x_1, x_2) < 0 \\ \|x - x_2\|^2, & q(x, x_1, x_2) > \|x - x_2\| \\ \|x - x_1\|^2 - q^2(x, x_1, x_2), & otherwise \end{cases}$$

$$q(x, x_1, x_2) = \left\langle x - x_1, \frac{x_2 - x_1}{\|x_2 - x_1\|} \right\rangle$$

Where x is feature vector of a testing sample. While x_1 and x_2 are feature vectors of two training samples which determine a line segment.

3.2.3 Improved BPR Method with Sample Selection

Biomimetic pattern recognition (BPR) is a new method in pattern recognition field, which utilized the continuous characteristic of samples from the same class to construct the high dimensional geometry coverage to implement recognition algorithm. However, in video face recognition, large pose variation, occlusion and expression variation of face would decrease this continuous characteristic, and the high dimensional geometry coverage is inaccurately constructed. This will finally drop the true recognition (or rejection) rate in face recognition. The original BPR focuses more on selecting samples from construction process and discarding large amount of worthless samples one by one at the same time, this is a wasted of time in practical face application due to longtime taken in judging worthless samples. In order to ensure the system can work both in real time and reliably, an improved biomimetic pattern recognition algorithm is presented in this paper to resolve the contradiction. Its basic idea is to select samples in the training samples, which are similar with the specific test sample by calculating the Euclidean distance, to construct the hyper sausage neuron links instead of using all the training samples. It is easy to find that the improved BPR allows us to utilize large training samples so that face images captured in various conditions can be reliably identified. For each test sample, we repeat the following steps to select samples for hyperlink construction. To note that the samples we mentioned here are all feature vectors that have been extracted by LBP. BPR Hyper Sausage Neuron Links Construction Process with Sample Selection is shown as Algorithm 1. And the Recognition Process of the Proposed LBP plus Sample Selective BPR Algorithm is shown in Fig. 7.

Algorithm 1. BPR Hyper Sausage Neuron Links Construction Process with Sample Selection

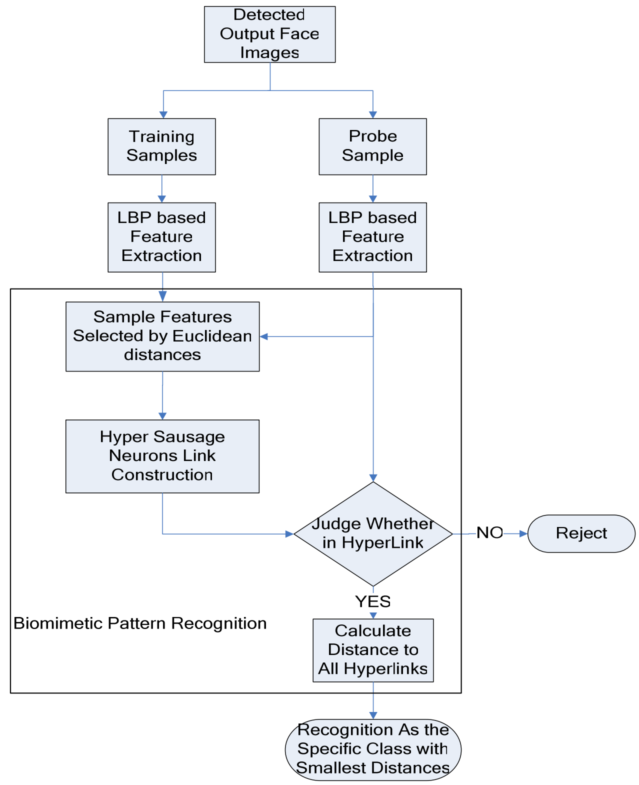


Fig. 7 Recognition process of the proposed LBP plus sample selective BPR algorithm.

Input: Test sample feature vector p ($n \times 1$ dimension).
Output: Hyper sausage neuron links of all the training classes.
Start.
Step 1. Assume that there are I training classes and in each class with J samples. Calculate the Euclidean distance as follows

$$D(i, j) = \sqrt{\sum_n (p - t)^2} \tag{19}$$

where $i = 1, 2 \ldots, I,\ j = 1, 2, \ldots, J$. t denotes a training sample in a class and n denotes the dimension of feature vectors.
Step 2. Sort the D matrix in descending order by row and an index matrix *Idx_D* can be achieved. According to the *Idx_D*, select the first N samples in each class and generate a set R for constructing.
Step 3. For certain class in set R, find out the nearest two samples (t_i and t_j) among these N samples, that is

$$t_i t_j = \arg\min\{t_x t_y\} \tag{20}$$

where $t_x,\ t_y \in \{1, 2, \ldots, N\}$.
Step 4. Build single hyper sausage neuron with samples t_i and t_j, and then calculate the Euclidean distances from the rest $N - 2$ samples to the neuron. If there are any sample distances less than a threshold K,

it is considered to be worthless samples and this sample should be discarded.

Step 5. After removing the worthless samples, calculate the distances again from the rest samples to the t_i and t_j, assuming that the newly added sample is t_k.

Step 6. Repeat step 4 and step 5 with t_j and t_k. A hyper sausage neuron link can be constructed after all N samples have been trained.

Step 7. Keep looping step 3 to step 5 until all classes have been trained. Finally, I hyper sausage neuron links have been constructed.

End.

4. Experimental Results

In this section, we present both face detection and recognition experimental results on publicly available databases (PUT database and AR database) and our established database named WYU database. In order to evaluate the efficiency performance of the proposed real-time face detector, 3 computers with different configurations are used here. Their configurations are Laptop with Intel 2.1 G CPU & 2 G memory (Computer I named C1), Laptop with i5 M520 2.4 G CPU & 4 G memory (Computer II named C2) and PC with Intel Xeon 3.3 G CPU & 32 G memory (Computer III named C3) respectively. The experiments are all run 10 times. Demos of our face detection and recognition system are available in the website: http://www.wyu.cn/teacher/zhai/links.asp.

4.1 Face Detection Experiment

A face database is established via a Logitech Camera with 8 megapixels, and named WYU database. It consists of 10 people, 15 samples per person, a total of 150 images in WYU face database. And the PUT face database [12] includes 25 people, 15 per person, a total of 375 images. All the original images are jpg format with the resolution of 640×480. And the output detected images are jpg format with the resolution of 112×92. The experimental results are shown in Table 1. The proposed algorithm can achieve true detection rate of 96.7%, 95% and 95.5% in WYU database, PUT database and WYU+PUT database respectively. While for the detection time, the speed of detector can achieve the performance from 0.09 second to 0.32 second on computer C3 and C1 in the union WYU+PUT database.

To further evaluate the effect of pose variation and glasses occlusion in face image in video, experiments are performed on the instance video. The output detected face and the performance are shown as Fig. 8 and Table 2 respectively. For the frontal face, the proposed detected algorithm can achieved 100% detection rate. While for the face with less than 45° pose variation and the face with glasses, the proposed method has achieved 97.36% and 96.58% true detection rate respectively. But for the face with both pose variation and glasses occlusion, the true detection rate drops to 89.68% only. For the face image with pose variation and glasses occlusion, it takes more time to output the detected face because of the more correction of pose and image preprocessing in the detection process.

Table 1 Face detection results and average detection time comparison of different computers on WYU and PUT databases.

Database	WYU	PUT	WYU+PUT
Detection Rate	96.73%	95.00%	95.50%
False Detection Rate	1.3%	0	0.4%
Undetected Rate	2%	5%	4.1%
Average Detection Time in C1	0.34s	0.3s	0.32s
Average Detection Time in C2	0.26s	0.21s	0.23s
Average Detection Time in C3	0.11s	0.08s	0.09s

Fig. 8 One session detected samples of a person in camera video.

Table 2 Face detection results and average detection time comparison of different computers of proposed algorithm in video under pose variation and glasses occlusion.

Face image	Frontal face	Face within 45° pose variation but without glasses	Face with glasses but without pose variation	Face within 45° pose variation and glasses
Accuracy	100%	97.36%	96.58%	89.68%
Average Detection Time in C1	0.32s	0.36s	0.33s	0.41s
Average Detection Time in C2	0.19s	0.28s	0.29s	0.33s
Average Detection Time in C3	0.09s	0.12s	0.12s	0.13s

To note that, the experiments are all performed in the MATLAB simulation environment. While in practical environment, C language should be adopted to further improve its efficiency and achieve real-time performance in reality.

4.2 Face Recognition Experiment

Since AR database is substantially more challenging, it was used to demonstrate the effective of proposed recognition algorithm here. AR database [13] consists of over 4,000 frontal images for 126 individuals. For each individual, 26 pictures were taken in two separate sessions, one session samples of a person are shown in Fig. 9. These images include more facial variations, including illumination change, expressions, and facial disguises comparing to other existing databases. A subset of the data set consisting of

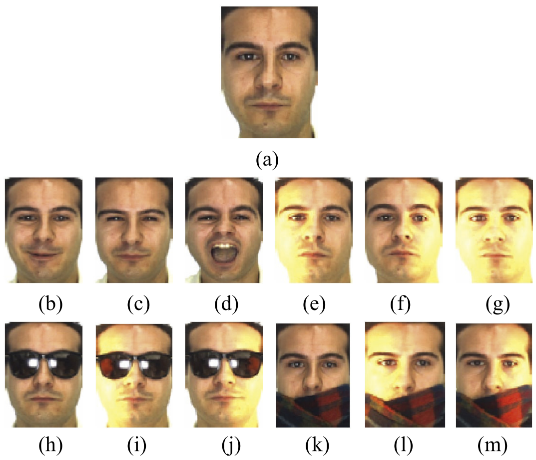


Fig. 9 One session samples of a person in AR database.

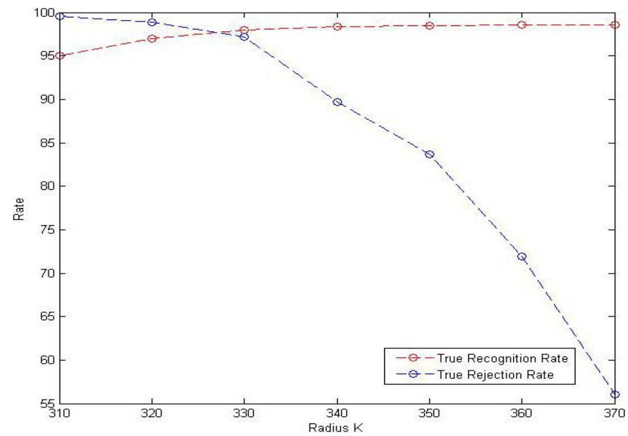


Fig. 10 True recognition rate and true rejection rate by the proposed algorithm under varying radius of hyper-sausage neuron.

Table 3 True recognition rate (TRR), false accept rate (FAR), and false reject rate (FRR) of genuine users by the proposed algorithm under varying radius K of sausage neuron.

K	TRR	FAR	FRR
370	98.57%	1.36%	0.07%
360	98.54%	0.82%	0.31%
350	98.44%	1.05%	0.51%
340	98.33%	0.95%	0.71%
330	**97.96%**	**0.51%**	**1.53%**
320	96.97%	0.34%	2.69%
310	95.03%	0.41%	4.56%

Table 4 True reject rate (TRR) and false recognition rate (FRR) of imposters by the proposed algorithm under varying radius of sausage neuron.

K	TRR	FRR
370	56.03%	37.62%
360	71.90%	28.10%
350	83.65%	16.35%
340	89.68%	10.30%
330	**97.22%**	**2.78%**
320	98.89%	1.11%
310	99.52%	0.48%

50 male subjects and 50 female subjects is chosen for the experiment.

We will first demonstrate the robustness of the proposed algorithm by the genuine users and imposters. Then a comparison of the recently proposed SRC classifiers is presented. Here, the randomly half selected images are for training, and the other half are for testing. 70 subjects are randomly selected as genuine users; the left 30 subjects are used as the imposters. Table 3 and Table 4 are test results of genuine users and imposters of the proposed algorithm respectively. From these two tables, we can figure out that the FAR and FRR performance of the proposed recognition algorithm vary by the value of hyper-sausage neuron radius K. For the high security environment we can choose a lower FRR rate, while in the casual security one a lower FAR rate can be chosen. Figure 10 shows the relationship between True Recognition Rate and True Reject Rate by the proposed algorithm under varying radius K of sausage neuron. If the value of K is chosen as 330, we can

Table 5 Comparison of equal error rate (EER) and average recognition time on different computers by the proposed algorithm and the state-of-the-art algorithms.

Algorithms	SRC [3]	Smooth l_0 SRC	PCA+BPR[6]	LBP+BPR	Proposed
EER	1.57%	1.93%	2.32%	1.71%	0.81%
Time in C1	24.56s	1.026s	0.3654s	0.2943s	0.2635s
Time in C2	16.81s	0.826s	0.2780s	0.1654s	0.1514s
Time in C3	9.43s	0.234s	0.0701s	0.0578s	0.0458s

achieve a high 97.96% True Recognition Rate of genuine users, while keeping a high 97.22% True Rejection Rate of imposters.

In order to compare the performance of the proposed recognition algorithm with other different algorithms, Equal Error Rate (EER) where FAR = FRR is used here. Table 5 shows that LBP plus BPR method outperforms the original PAC plus BPR one due to the effectiveness of LBP based feature extraction and LBP is more efficient in extracting time compared with PCA. Moreover, the EER of our proposed recognition algorithm can achieve the minimum EER. Because of the improvement in continuous characteristics of samples from the same class, coverage of high dimensional geometry is constructed more accurately, thus the proposed algorithm can perform best among the five algorithms. SRC method also achieves relatively best results, but it costs plenty of time to solve the inversed model which can not meet the real-time face recognition application demand. Smooth l_0 [14] plus SRC can improve its efficiency due to the smooth approximation of l_0 norm but the performance drops a little bit.

5. Conclusions

A real-time face recognition system with skin color based face detector and sample selection BPR is presented in this paper. LBP operator is used to extract the features, and BPR algorithm is improved by the sample selection construction. Experiments show that the proposed detection algorithm can output a detected face image within 0.11 s, and recognition it within 0.046 s in MATLAB environment on Computer

III with leading powerful CPU and memory configuration, while for practical system C language should be used to improve its efficiency further. This would be our future work. Moreover, the proposed recognition algorithm can achieve a high 97.96% True Recognition Rate of genuine users, and keeping a high 97.22% True Rejection Rate of imposters in AR database, and performs better results than the existing face recognition system.

Acknowledgments

This work is supported by National Natural Science Foundation Under Grand No.61072127, & No.61070167, Natural Science Foundation of Guangdong Province, P.R.C. Under Grand No.10152902001000002 & No.S2011040004211 & No.S2011010001085; and Foundation for Distinguished Young Talents in Higher Education of Guangdong, China Under Grand No.2012LYM_0127.

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