Comput Syst Sci & Eng (2018) 5: 327–334

International Journal of
Computer Systems
Science & Engineering

Face detection method for public safety surveillance based on convex grouping

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Face detection is very important in video surveillance of public safety. This paper proposed a face detection method based on the best optimization convex grouping to detect the face regions from different face shape images at actual conditions. Firstly, the basic principle of convex grouping was discussed, the main rules of convex and the structure of the convex polygons was described. And then the best optimization convex grouping algorithm of the convex polygons was designed. At last, all of the algorithms, which used the best optimization convex grouping to detect the face region on the data set of MIT single face sample library were tested. This sample library contains positive faces, side faces and other sorts of posture. The experiment result showed that the best optimization convex grouping method could detected the face regions accurately, even if the face postures are positive, side or others, our proposed method was effective, and it was not affected by color and light. Compared with other typical algorithms, this proposed method had higher detection accuracy, and it could be used directly without training. Meanwhile, there was a better stability and reliability in the actual processing, which could satisfy the requirements of practical application.

Keywords: Public safety surveillance; face detection; convex attribute; convex grouping; best optimization decision

1. INTRODUCTION

Face detection and location in images is an important prerequisite to solute the face recognition, face tracking and face pose estimation. It is an important research hotspot in the field of machine vision and image information processing [1, 2]. Face detection is also a research field with challenge because it is need to deal with face pose, scale, facial features (such as whether or not wear glasses, have beards and different hair styles), as well as the light and the interference of background. There have been many attempts to detect human faces in images automatically. These approaches can be broadly classified into three categories: (i) methods based on detecting facial features (e.g., eyes, nose and mouth) [3-5], (ii) methods based on face models (e.g., templates) [6-8], (iii) methods based on face representations that learned from a large number of examples (face images) using statistical approaches (e.g., Eigen faces) [9,10] or neural networks [11,12].

In recent years, research scholars have done some fruitful works in the field of face detection, such as the detection method based on face feature [11-13], which first obtained test objects on facial features such as eyes, nose and mouth to establish feature database, and then matched the input image feature to detect the face area. This method has a very good effect on the front view face image when the feature points reaching the preset requirements, it can be extended around the center of the characteristic point. So this method can effectively detect the human face location and segmentation. However, when the face in the image is a side face or only the head is displayed, it will be difficult to detect the face or head area effectively [14,15]. That means if in the case of features are lost or incomplete, the method based on face features cannot determine human face accurately. With the improvement of computer technology, the image processing technology move from the gray image processing into color

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image processing, a variety of face detection method based on skin color [16, 17] had been put forward. It can extract the face region through the face skin color model, but the skin color and detection accuracy could be disturbed easily if only rely on color model. Then another face detection method was proposed which based on skin color model and face feature [18,19]. Firstly, the skin color area was detected using skin color model, due to the reason that the skin color area could include all of the skin parts, so the second step is to detect the skin color area using the human face feature. This method can improve the accuracy of the face detection significantly. However, as for the side face and human head, it is also difficult because it could not extract enough features. In order to improve the detection accuracy for the side face and human head, some researchers applied machine learning methods to detect the face, such as Support Vector Machine(SVM)[20], Convolutional Neural Network(CNN)[22], Deep Learning[23,24] and so on. However, these methods need a lot of samples to train and need more time [25]. So a fast and effective method of face detection and location method will be beneficial to promote the practical application of face recognition.

In this paper, a face detection method was presented based on the best optimization convex grouping model. The convex features are important nature geometric attributes for all kinds of objects [26]. Face detection method based on convex grouping can effectively remove the influence of skin-color, light of environment, face posture and face position and so on. The experiment results indicated that this method had a very good stablility and accuracy of face detection, especially for the side face and even the head of human. The proposed method was test in the face sample dataset (MIT)that include the front face, side face, human head and other various posture, the detection accuracy achieved up to 93.8%. At the same time, this method detect the face directly so that the detection speed is fast, and it don't need train and it can be used any place directly.

2. THE PROPOSED CONVEX GROUPING METHOD

2.1 Overview

The convex grouping is used to fit out the line according to the edge of the image, and then to construct the convex polygons under the rules of convex grouping. Lastly, the best convex grouping would be found through detected the best optimization of convex polygon. The basic principle diagram of convex grouping object detection was shown in Fig.1[27]. As for the original image of Fig.1(a), the first step is to detect the edge using Canny edge detector, then linear fit all of the edges, shown as in Fig.1(b). Due to the reason that the fitting straight line is discrete, in order to construct boundary of closed polygons, the fitting line should be grouped according to the convex rules. Some closed convex polygon was constructed as shown in Fig.1 (c). Finally, using the optimization function to determine the object area from all of the closed convex polygons and to find an optimal polygon as a potential object, which is shown in Fig.1 (d).

2.2 Principle of convex grouping

2.2.1 The definition of convex grouping

Convexity is one of the basic concepts of optimization theory, of which the definition is: for a set $C \subset R^n$, taking two points $(x, y) \in C$ in any space and a real number $\theta \in [0, 1]$, which should satisfy the following conditions:

$$\theta x + (1 - \theta) y \in C \tag{1}$$

Then C is an efficient convex grouping. As shown in Fig. 2, for any two points (x, y) in set C, x and y and their attachment points are also in set C, so (a) is called the convex grouping. But for (b), it is not satisfy the conditions, so it is not convex grouping.

2.2.2 Construct and determine the convex polygon

For every line that is used to fit the image edges, the simplest method was to permutate and combine the lines, and then identify the efficient convexity using the convex definition. The convex polygon will be constructed through filling the gap between each line which has an efficient convex. But in order to ensure the accuracy of the object detection, the lines are much more fitting so that lots of convex group sets will be constructed, and it can be calculated by using the Permutation And Combination method. The permutation means to select r none duplicate elements from n elements, which is defined as $P_n^r = n(n-1)\cdots(n-r+1) = \frac{n!}{(n-r)!}$, then the combination can be define as:

$$C_n^r = \frac{P_n^r}{r!} = \frac{n!}{r!(n-r)!} \tag{2}$$

If there are n lines, all of the convex groupings can be constructed is:

$$m = C_n^2 + C_n^3 + C_n^4 + \cdots C_n^{n/2} \tag{3}$$

So it needs much more time to do this work. In fact, according to the characteristics of the object, if the gap between lines is larger than a certain value, it is impossible to construct a real convex polygon. So the convex polygon can be reduced through analyzing the ratio of line segment and the distribution. If a set of line segments is $(l_1, l_2, \ldots, l_n)$, the length of the line l_i is $L_i (i = 1, 2 \ldots n)$, the length of the gap-filling between line l_i and l_{i+1} is $G_i (i = 1, 2 \ldots n)$, as indicated in Fig. 3.

So the total length of the line can be calculated by:

$$L_{1,n} = \sum_{i=1}^{n} L_i \tag{4}$$

The total length of the gap-filling is:

$$G_{1,n} = \sum_{i=1}^{n} G_i \tag{5}$$

From the experiment we can know that for one convex polygon, if the gap length equal or bigger than the line length, the convex polygon is not a real object area, as indicated in formula (6), if $\sigma \leqslant 0.5$, the convex polygon will not be an object area.

$$\sigma = \frac{L_{1,n}}{L_{1,n} + G_{1,n}} \tag{6}$$

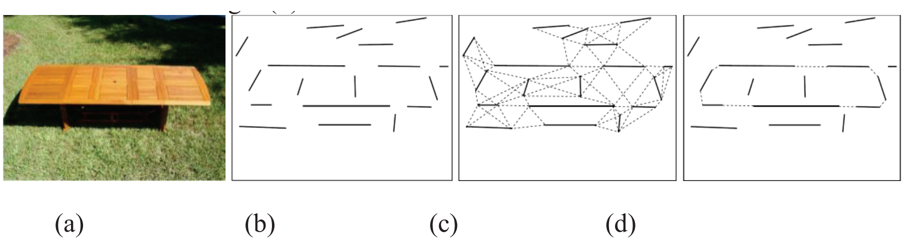


Figure 1 Object detection using the convex grouping. (a) is the original input image,(b) is the linear fitting of the edge, (c) is all of the convex polygons which is constructed by lines, and (d) is the best convex polygon selected by the optimization function.

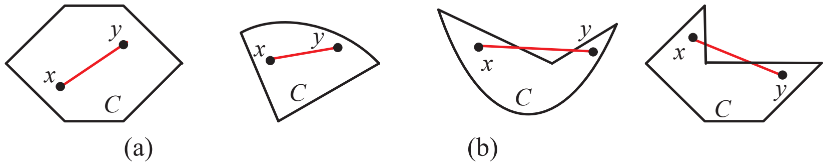


Figure 2 The definition of convex grouping, (a) is an efficient convex grouping and (b) is not a convex grouping.

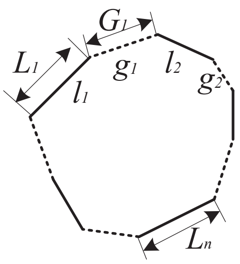


Figure 3 A boundary of detected segments and gap-filling segments.

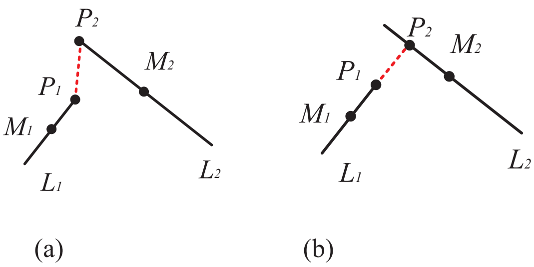


Figure 4 The special boundary line processing, (a) is not a convex group before processing, in fact line L1 and L2 may be a convex group, so after processed (b) is a convex group.

2.2.3 Processing of special boundary line

As shown in Fig. 4, during the construction of the convex polygon, the endpoint P_2 of line L_2 may be lengthened because of the noise interference. If P_1 and P_2 are combined directly, then $M_1P_1P_2M_2$ will become a non-convex structure. But from fig. 4 we know the line L_1 and L_2 may be a real fitting line of object edges. So for these lines like L_1 and L_2 in Fig. 4(a), we will extend the line L_1 and intersect with L_2 to generate a polygon vertices, which is showed in Fig. 4(b). This processing method is able to ensure the convex polygon, and ensure the detection accuracy of potential objects.

2.3 Determination of the best optimization convex grouping

From above steps, lots of alternative convex polygons are constructed. But only one polygon is the real object area. So the determination function which used to determine the best optimization convex grouping from lots of convex polygons need researched. It includes two parts: the boundary lines and the image pixels in closed area. We design a function which includes these two parts to optimize all of the convex polygons:

$$L = \int_R \sigma(t)dt \tag{7}$$

Where B is the closed boundary of convex polygon, $\sigma(t)$ is the constructor of boundary B, which includes line and gap. During the calculation processing, the line equal 0 and gap equal 1. After every convex polygon is detected, the smaller L means the line is bigger than gap, and it more likely to be a real object.

As for the image pixels in the closed area R, it need to calculate the horizontal gradient and vertical gradient separately:

$$D = \int\int_R |\nabla(I(u,v))|\,dudv \tag{8}$$

If the gradient value D is smaller, which means this convex polygon is more likely to be a real object because in the same object, the gradient value changes less. Finally, we calculate convex polygon of the area:

$$S = \int\int_R dudv \tag{9}$$

Combined with formula (7), (8) and (9), we can design the best optimization determination function:

$$\xi(B) = \frac{L+\lambda D}{S} = \frac{\int_B \sigma(t)dt + \lambda \int\int_R |\nabla(I(u,v))|\,dudv}{\int\int_R dudv} \tag{10}$$

Where λ is a adjust parameter, which is used to adjust the proportion of pixel gradient in that area. After every convex polygon is calculated, the best convex polygon is the one that with the minimum $\zeta(B)$. The area of best convex polygon is the object needs to be detected.

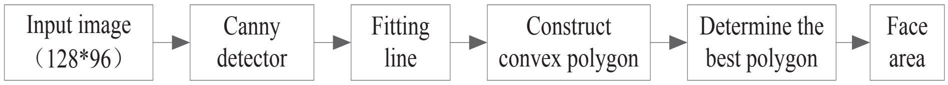


Figure 5 Face detection flow.

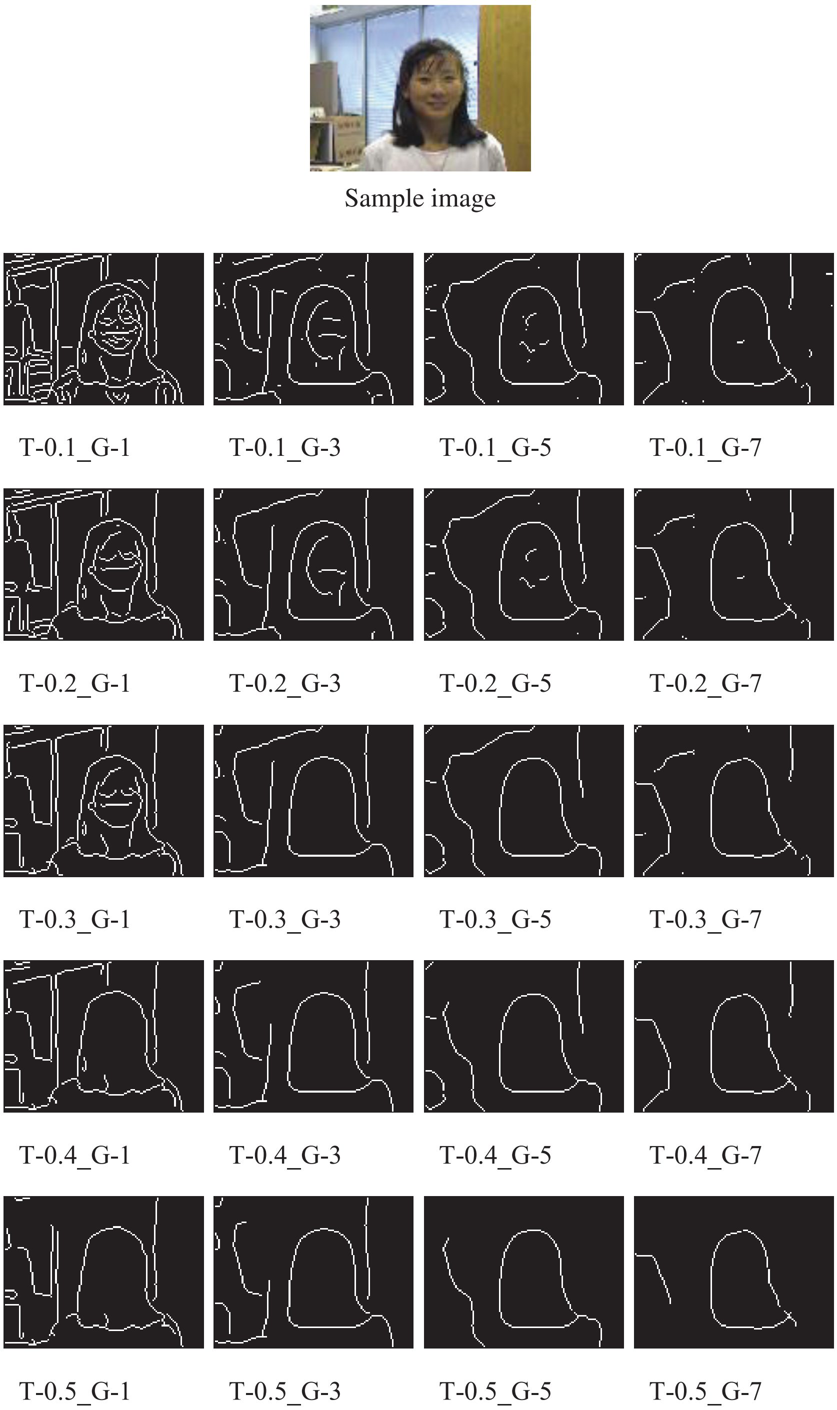


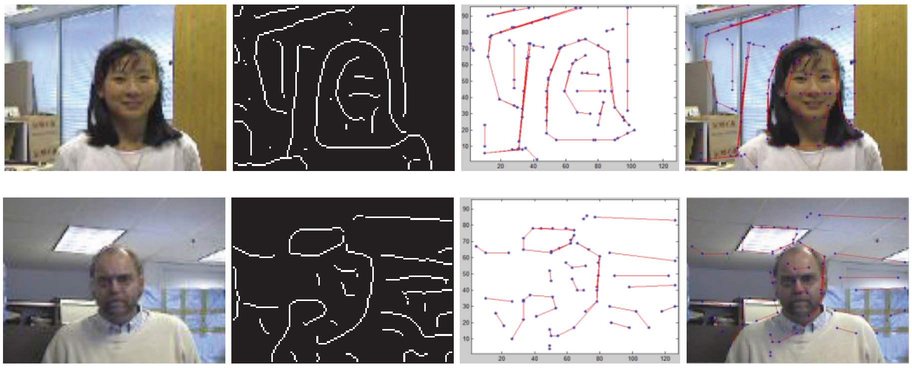
Figure 6 The detection results of difference parameters using Canny.

3. FACE DETECTION USING CONVEX GROUPING

Fig. 5 shows the face detection flow which using the proposed best optimization convex grouping method, the test database is the MIT face data set.

3.1 Parameters setting of Canny detector

Edge detection is very important because it is need to fit the line according to the edge of the object. An improved Canny detector is designed to detect all of the edges from the images. The parameters can be changed to detect lots of edges and then select



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

Figure 7 The edge fitting results, (a) is the input images, (b) is the images' edges using Canny detector, (c) is the fitting lines, (d) is the results of fitting lines added into the original images.

Figure 8 Some convex polygons are constructed from fitting lines, the first image is the fitting lines, and the others are parts of construction convex polygons.

Table 1 Results contrast of different methods.

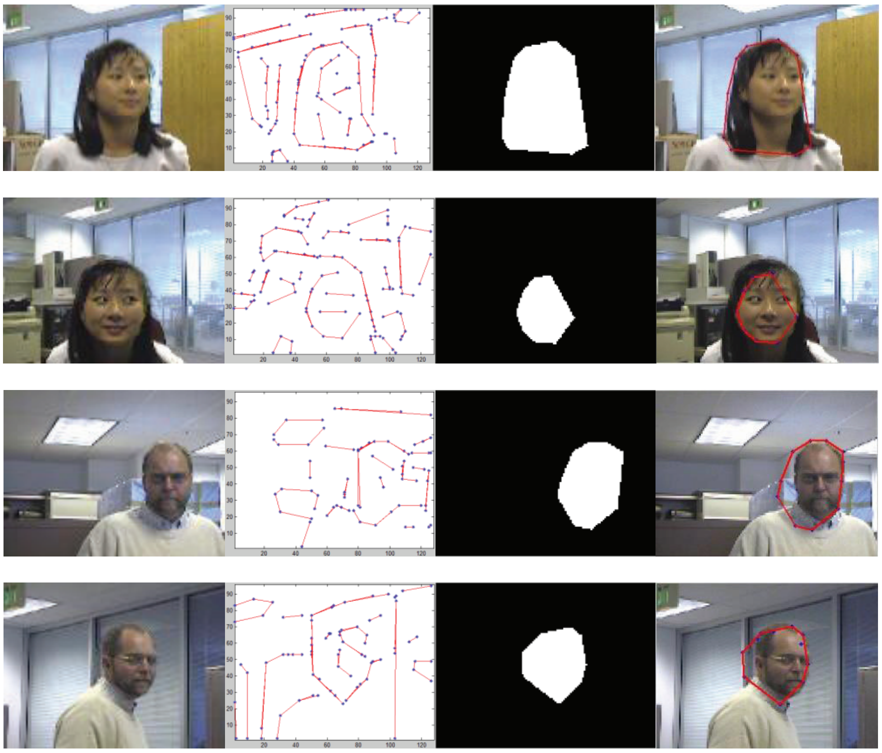
Detection methods	Detection accuracy (%)			
	Positive	Side	Different posture	Total
Feature [11]	91.7	-	-	-
Skin-color [16]	92.4	83.5	-	-
AdaBoost [13]	96.7	76.3	68.5	80.5
SVM [20]	95.6	79.8	71.6	82.3
Neural network [22]	95.3	78.2	-	-
Our method	96.2	94.8	90.5	93.8

the best parameter to process the face image. The main parameters include Gaussian and threshold. In the experiment, the parameters of Gaussian and threshold are changeable to process the input image, some results are showed in Fig. 6.

By analyzing the results of Canny edge detection method under different parameters, we know that when the threshold and the Gaussian window increase, the edge number decrease, and when the edges less than a certain amount, the edges of the object maybe lost. So taking the processing speed and the detection effect into consideration, in this paper, we set the Canny parameters of Gaussian as G-3, and the threshold as T-0.1

3.2 The line fitting of face contour

The edges of an image have been detected using Canny detector with parameters G-3 and T-0.1. And then it is need to fit lines from all of the edge points. The linear fitting method is used to delete the line when the length less 10 pixels and the curve to fit a period line of 50 pixels. The results are showed in Fig.7,from which we can know that the fitting line of the face object has a good shape, so all of these lines can be used to construct convex polygons.



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

Figure 9 The best convex polygon and its correspond face area, (a)are the original images, (b) are the fitting lines, (c) are the best convex polygons, and (d)are the correspondent face areas of the best convex polygons.

Figure 10 Some test samples of various postures.

3.3 The construction of convex polygons

The convex polygon can be constructed from the fitting line under the construction rules. In the experiment, according to the characteristics of the image of human face, some lines can be deleted when they are not accord with the convex function. which can increase the processing speed. Fig.8. shows some construction polygon results for one sample image.

3.4 Determination of the best convex polygons

In this section, we use the best optimization function to determine the best convex polygon from all of the alternative convex polygons which has been constructed. After analyzing lots of experiment results in the processing of face region determination, we find out that the adjustment parameter λ with the value 0.001 can detect the best convex polygon,. Based on which some seleced results using the best convex polygons are showed in Fig.9. The results indicate that the correspondent face area using the best convex polygon can be detected accurately.

3.5 Experiment results and analysises

In this section, we use the MIT face database to test our proposed face detection method and make comparison with other typical methods. We selected 870 individuals face samples from dataset, which including positive face, side face and different postures, different backgrounds, different lighting conditions and different

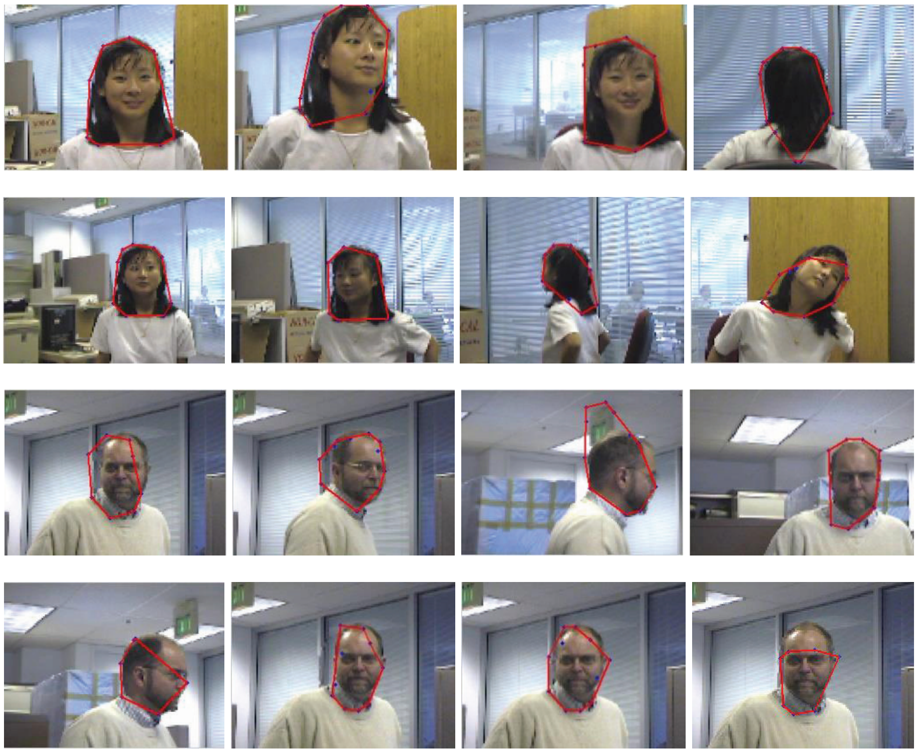


Figure 11 The detection results of face area, which include positive face, side face, different postures, and even the heads turn back.

directions of the faces. The size of the face sample image is 128 * 96. Fig.10 show part of face samples.

The experimental platform is dell T5500 graphics workstation, its configuration is Xeon E5620 CPU, 6GB memory, and the simulate software is MATLAB2013. We test our method using the samples in MIT face dataset, the test results and the detection time are recorded for each image. Some test results are showed in Fig. 11. It can be seen that the face detections, both positive face and side face, even the face region is partly or completely covered, have good accuracy and stability,. Although some test results had a bigger scope of inspection on the face region, it has more real face area, and it can ensure the accuracy of face detection, also the good stability and reliability.

Using the same face database, we make a comparison between our proposed method and the other 5 typical face detection methods. As described in Table 1.

From Table 1 we can know that the comprehensive detection accuracy rate of our method reaches up to 93.8%. For positive face, side face and different posture, it also has good detection accuracy. In addition, compared with other face detection methods, our proposed method does not need training and it has a good generality, which are an obvious advantages in potential practical application, and also it can be used in any environment directly. The other 5 methods have a good effect for the positive face detection, but for the side face and different postures, the detection accuracy drop substantially. As for the detection time, the average test time for every image of our method is about 0.1 second, which is much faster than the other 5 methods.

4. CONCLUSIONS

In this paper, we proposed the best optimization convex grouping method and used it in face detection. This method fully combined the convex attributes of the face object, it can achieve a very good effect on face detection. The structure of convex polygons would not be affected by the posture, positive, side of the human face, and other conditions such as environment change, our method could obtain high face detection accuracy and reached the requirement of practical application. During the simulation process, in order to detect the image edge as much as possible, the Gussian and threshold parameters were set as small as possible. However, from the detection results we knew some of the detection face area is bigger than the real face area That will be improved in the next step research, include to optimal the decision function, increase the constraint conditions, improve the detection accuracy and speed. This method can be promoted in others field such as multi-face detection, or other objects detection and so on.

Acknowledgements

We should like to acknowledge that this work was supported in part by Hunan Provincial Natural Science Foundation (2016JJ2064, 2017JJ3099) and Open Fund of Education Department of Hunan Province(15K051). The experiment of this work also was supported in part by the Research Fund of Key Laboratory of Hunan Province (14k042), Science and Technology Program of Hunan Province (2016TP1021) and Fund of Education Department of Hunan Province(16C0723). Its contents are solely the responsibility of the authors and do not necessarily represent the official views. At the same time, we are thanks to provide lots of experimental support by the Key Laboratory of Optimization and Control for Complex Systems, College of Hunan Province.

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