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Block Based Face Detection Scheme Using Face Color and Motion Information

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Abstract

In a sequence of images obtained by surveillance cameras, facial regions appear very small and their colors change abruptly by lighting condition. This paper proposes a new face detection scheme, robust on complex background, small size, and lighting conditions. The proposed method is consisted of three processes. In the first step, the candidates for the face regions are selected using face color distribution and motion information. In the second stage, the non-face regions are removed using face color ratio, boundary ratio, and average of column-wise intensity variation in the candidates. The face regions containing eyes and mouth are segmented and classified, and then they are scored using their topological relations in the last step. To speed up and improve a performance the above process, a block based image segmentation technique is used. The experiments have shown that the proposed algorithm detects faced regions with more than 91% of accuracy and less than 4.3% of false alarm rate.

Key Words : face detection, surveillance system, relation score.

Ⅰ. Introduction

Most surveillance systems have a function that automatically detects motion of objects from a sequence of input images[1,2]. When motion is detected, surveillance systems start to record the input images or to track the moving objects. Conventional surveillance systems have not had an interest in what the objects are. They just record whole images following the objects. However, surveillance systems are nowadays required to be smart enough to know what the moving objects are and to identify faces if they are human beings.

To satisfy this requirement from market, many researches have proposed various approaches such as facial feature based methods[3,4], template matching methods[5], neural network based methods[6], statistical analysis methods[7,8,9], etc. Facial feature based method uses skin color, shape and position of eyes and mouth, and face contour as features of a face[3,4]. Although they are robust on size and pose variation of facial features, they are not easy to extract from surveillance images that are shaded or smeared by lights. Specially, skin color is significantly sensitive to variation of lighting condition[10]. Instead of extracting individual features, template matching method predefines an entire or partial face template and compares with an input image whether it contains an area similar to the template[5]. Although this approach has an advantage of finding even partially matching faces, it still suffers from variation of pose and size of facial features, and also from lighting conditions. Approaches based on statistical analysis establish a face model that describes the relationships between facial features statistically[7,8,9]. These approaches have shown a good performance when an input image contains only facial features. However, their performance decreases and time complexity increases when noisy features such as mustache are included in the input image. The ones based on neural network can be more efficient for the images varying by lighting conditions if enough image models can be obtained as a training set[6]. However, the application is restrictive to a couple of specific lighting conditions to maintain a certain level of accuracy, since the overall performance degrades if the training set contains too many cases. Therefore, when the background is complex, it is not suitable to use neural network approaches.

These approaches have shown reasonable performance on specific cases, however they have a couple of significant problems in common. The first one is that they cannot detect faces of small size less than 11×11 pixels[8,11]. This restriction hinders the application of surveillance system from being used for covering large area. The second one is their performances are significantly affected by variation of lighting condition. The environments such as underground parking lots and banks with many windows where surveillance systems are installed have very poor lighting conditions in most cases. The third one is that most of them spend long time to detect face area. This is the most serious

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problem for surveillance systems requiring a fast response time. Although its results are still useful for restricted applications, the approach of Zhao and Huang[13] that fuses skin color and motion information to detect face regions provides a good clue to solve these problems. The skin color regions in the motion region are selected as the candidates for face region and the non-skin areas encircled by the skin color regions are considered as possible facial features. They segment a face region into four quadrants and each facial features are searched in the pre-specified quadrant only.

This paper proposes a new approach of using face color and motion information. Motion information is used for separating humans from complex background and also for detecting small face areas. The proposed algorithm has the following flow shown in Fig. 1.

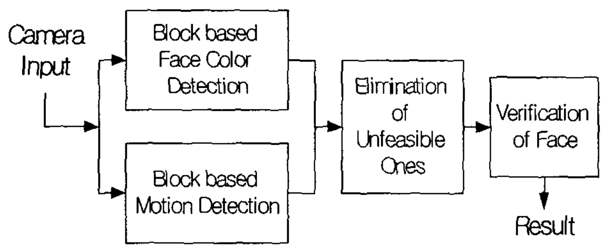


Fig. 1: Flow of face detection algorithm.

In the process of fusing face color and motion for selecting candidates for face regions, the block based analysis technique is used for reducing the computation time and also the effect of lighting conditions. Specially for eliminating infeasible ones among the candidates for face regions, new features are tested such as the average of vertical intensity variation and the slope of vertical high frequency component distribution. Then those candidates are considered as the face regions in the final verification process if they have a low score in the test of topological relationship among facial features.

Ⅱ. Detection of Candidates for Face Regions

Most surveillance systems have been using CCD cameras whose output format is NTSC. Recently CMOS cameras are developed to reduce the camera price, but they still need to be enhanced to achieve the image quality of CCD cameras. Although there exists difference to some extent, imaging devices of both cameras have a common problem that lighting conditions affect significantly the image quality. That is, depending on brightness and position of lights, images appear in too much different shape and color. When colors in images are changed, it is very difficult to detect face area using color feature only.

To solve this problem, motion information is also used as well as face color. Since the imaging devices produce slightly different values even under the same lights, the input image is obtained after eliminating lower 3bits of 8bit pixel values and then difference image is calculated to detect motion by subtracting two sequential images. A difference image $S_m(i,j)$ is segmented by blocks so that each block contains 4×4 pixels. Then a block is classified as a MB(motion block) if the sum of pixel values in the block, $f_m(i,j)$, is larger than a specific threshold, as follows.

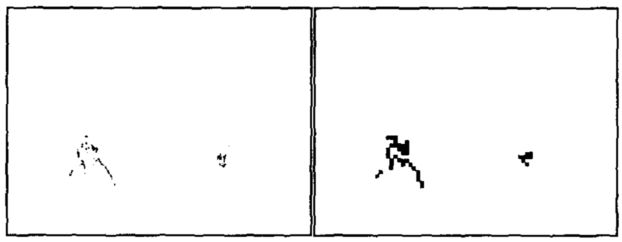
$$MB(i,j)=\begin{cases}1, & \text{if } f_m(i,j)>Th_m\\ 0, & \text{otherwise}\end{cases}$$

$$f_m(i,j)=\sum_{k=0}^{3}\sum_{l=0}^{3}S_m(4\times i+k,4\times j+l),\ 0\le i<\frac{M}{4},0\le j<\frac{N}{4} \quad (1)$$

In Eq. (1), M and N represent the numbers of columns and rows respectively in the image, and Thm is determined by experiments.

Fig. 2 shows the pixel based and block based difference images in (b) and (c), which are obtained from two sequential images given in (a). Fig. 2(c) shows more stable detection of motion by ignoring isolated pixels which are possibly noisy ones.

(a) Two sequential input images



(b) Pixel based DI (c) Block based DI

Fig. 2: Motion detection using the block based DI (difference image).

Similarly, each block in the present image (for example, the second one in Fig. 2(a)) is marked as a FB(face block) if it contains the face color pixels more than a specific threshold, as follows:

$$FB(i,j)=\begin{cases}1, & \text{if } f_s(i,j)>Th_{sc}\\ 0, & \text{otherwise}\end{cases}$$

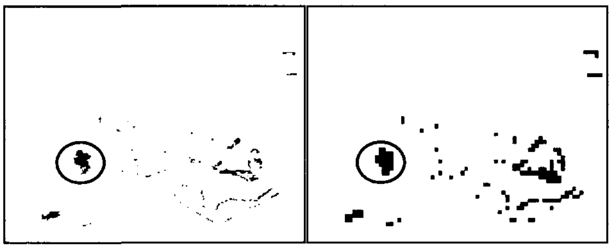
$$f_s(i,j)=\sum_{k=0}^{3}\sum_{l=0}^{3}f_{sc}\left(S(4\times i+k,4\times j+l)\right),\ 0\le i<\frac{M}{4},0\le j<\frac{N}{4} \quad (2)$$

In Eq. (2), since f_{sc} is the function that returns 1 if

$S(i,j)$ has a face color or 0 otherwise, $f_S(i,j)$ becomes the number of the pixels in the block (i,j) having face color. Here Th_{sc} is 1, but it can be adjusted by experiments. The reason why Th_{sc} has a low number like 1 is not to lose even a pixel which can be a part of a face. A pixel is considered as a face color one if its C_r and C_b in YC_bC_r color space and H in HLS color space are within the following range[12].

$$152 < C_r < 173,$$
$$77 < C_b < 127,$$
$$0^\circ < H < 16.941^\circ \text{ or } 357.196^\circ \leq H \leq 358.588^\circ$$

Fig. 3 shows the pixel based and block based face color images in (a) and (b), obtained from the second image in Fig. 2(a). The neighboring face color pixels in (a) are shown as if they are merged in (b). In other words, the block based approach eliminates a process to connect neighboring face color pixels and also results in an enlarged image containing the face region completely. For example, the face region in (a) marked by a circle does not include all pixels of a face, but the one in (b) includes.



(a) In pixel level (b) In block level

Fig. 3: Face color regions.

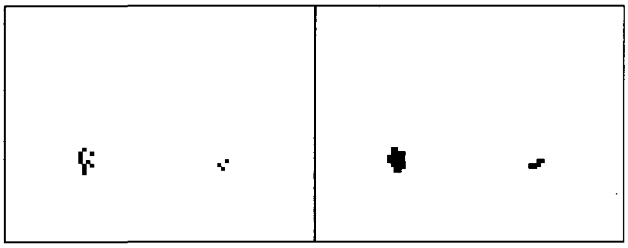
Once the face block and motion block images are determined, the candidates for face regions (CF) are selected as shown in Fig. 4(a) by fusing both images in Fig. 2(c) and Fig. 3(b) using the logical AND (•) operation defined as follows:

$$CF(i,j) = MB(i,j) \bullet FB(i,j) \tag{3}$$

Based on the result of fusing the block based motion and face color images, the candidates for face regions are determined by connecting those pixels in the face color image neighboring with the pixels remained in the fused image. Fig. 4(b) shows the regions expanded in the face color image given in Fig. 3(b) using the pixels in the fused image given in Fig. 4(a).

III. Elimination of Infeasible Ones Among the Candidates for Face Regions

The approach explained above has an advantage that it almost does not miss a possible face region. However, it may include even non-face regions in the candidates, if objects in background include skin colors in themselves. To select the real face regions among candidates, the following conditions are tested which are constructed using the general features of faces.



(a) Fusing Fig. 2(c) and Fig. 3(b) (b) Candidates for face regions

Fig. 4: Candidates for face regions obtained by fusing Fig. 2(c) and Fig. 3(b).

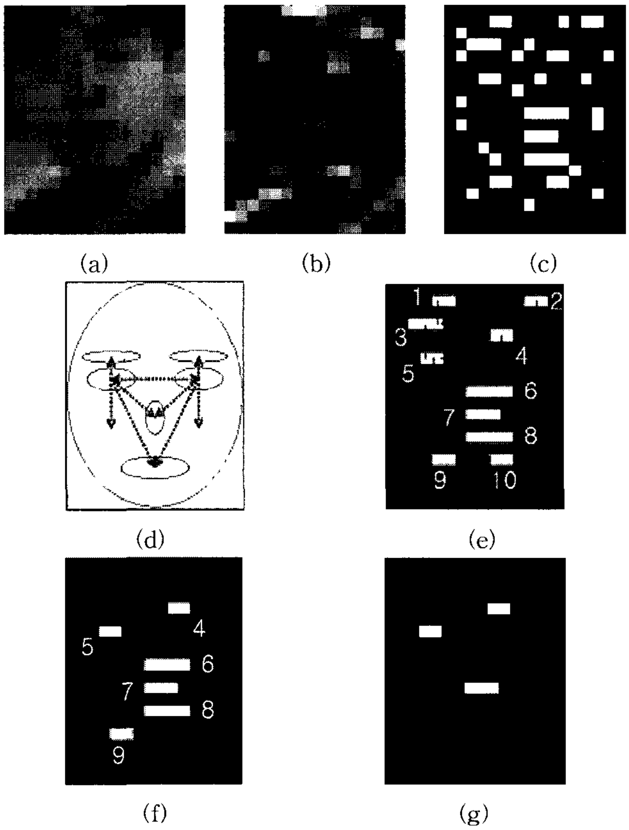


Fig. 5: Face feature selection using the proposed conditions: (a) normalized face region, (b) vertical intensity difference, (c) facial feature regions, (d) rules on facial feature regions constructed using face color and topological relations, (e) result of eliminating infeasible facial feature regions using size, (f) result of classification using the given rules, (g) finally selected feature regions.

Condition 1: More that 60% of the pixels in a face region should have a skin color. Since any block containing at least one pixel with skin color is marked as a face block, there is a chance that a face region candidate may consist of the blocks with only one skin color pixel. Such regions cannot include facial features, thus should be eliminated from the candidate list.

Condition 2: The ratio of width and height of a face region should be between 0.5 and 1.2. On average, the ratio is about 0.7. However, the range is expanded to include the possible variations in size and pose depending on persons. Depending on applications, this range may be adjusted.

Condition 3: The high frequency portion in a face region should be greater than a specific threshold. It is tested with the intensity difference image where each pixel value is the difference between two vertically adjacent pixels in the face region image. For convenience, the size of a candidate for face region is normalized as 16×20 pixels as shown Fig. 5(a). Fig. 5(b) shows the intensity difference image obtained from Fig. 5(a). Pixels in the intensity difference image may also have values ranging from 0 to 255. Then the high frequency portion in a face region is represented by the following equations:

$$D_{AVG} = \frac{\sum_{i=0}^{M-1}\sum_{j=0}^{N-2}|v(i,j)-v(i,j+1)|}{M\times(N-1)} > 0.90\times D_{th}$$

$$M_{AVE} = \frac{\sum_{k=0}^{L-1}|P(k)-P(k+1)|\times P(k)}{L} > 0.95\times M_{th} \quad (4)$$

In Eq. (4), M and N represent the number of columns and rows, and $v(i,j)$ is the intensity of face region candidate at the (i,j)th pixel, $|v(i,j)-v(i,j+1)|$ is the intensity difference, $P(k)$ is the probability whose value is k in the intensity difference image, and L is the number of the results where $|P(k)-P(k-1)|$ is not zero. By experiments, it is confirmed that the slope of the vertical high frequency component distribution in a face region, $|P(k)-P(k-1)|\times P(k)$, appears smooth in a face region and sharp in a non-face region, as shown Fig 6. Table 1 summarizes the mean and variance of column-wise intensity difference and the distribution of vertical high frequency components, in face and non-face regions. Dth and Mth are determined so that most of the face model images can be determined as the face region, respectively.

By testing the above three conditions, most of infeasible ones are removed from the list of the candidates for face region. In the next step, the remained ones are assumed as face regions and tested whether they include facial features. In a face region normalized as explained above, facial features may occupy at most two pixels width.

The proposed algorithm classifies each pixel in the normalized face region as facial feature one or non-facial feature one by testing its magnitude in the intensity difference image. A pixel is classified as one with facial feature if its value is larger than that of any neighboring pixel, except left and right pixels, in 8-connectivity window. Fig. 5(c) shows the facial feature pixels obtained from (b). Then the facial feature pixels are merged to form a candidate for feature region, using a 4-connectivity window. On each candidate for feature region, the following conditions are tested, which are generated from the sizes of eyes and mouth.

1. The size of a feature region should be larger than 2 pixels.
2. The width and height ratio of a feature region should be less than 0.5.

Those pixels not connected to other pixels and those regions vertically elongated, in Fig. 5(c), are eliminated resulting in Fig. 5(e). The remained possible feature regions are then classified into two groups, one of possible eye and another one of possible mouth, using the following rules on eyes and mouth.

Rule 1: An eye is located at left or right of the other one along its horizontal axes tilted less than 20 and above the center of the region.

Rule 2: Within a certain distance below the center of an eye, there is no other feature except a mouth.

Rule 3: Mouth contains a red color component more than other features do, and it is located between and below two eyes in the horizontal axes

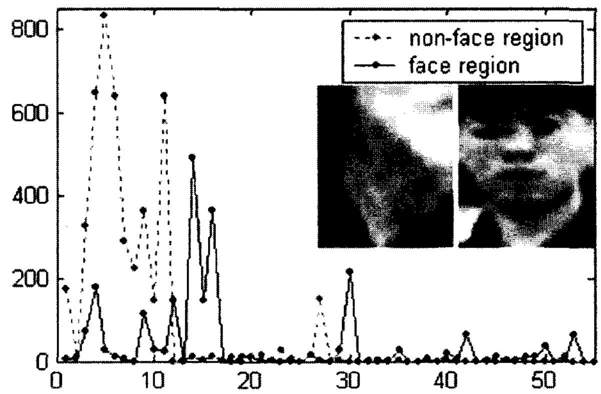


Fig. 6: The distribution of vertical high frequency components in face and non-face regions.

Table 1: The parameters evaluating the face regions in the intensity difference image

Parameters	Face Region	Non-face Region
Mean of intensity difference	25	11
Variance of intensity difference	24	11
Mean of the slope	32	120

If the first rule is applied to Fig. 5(e), the pairs of features, {(1,2), (2,3), (3,4), (4,5)}, are selected as possible pair of eye regions. Each pair of eyes is connected by line in Fig. 5(e). If the second rule is applied to the set of features, then only the component (4,5) remains. If the third rule is applied to Fig. 5(e), the features {(6), (7), (8), (9)} are selected as possible mouth regions. As the results of the above process, one set of possible eye feature regions (PEFR) and another set of possible mouth feature regions (PMFR) are obtained as shown in Fig. 5(f):

PEFR = { (4,5) }
PMFR= { 6,7,8,9 }

From these two sets of facial features, those sets of eyes and mouth are considered consisting of a face if they pass the verification process explained in the following section.

Ⅳ. Verification of Face Region Using Topological Relations of Facial Features

From two sets of feature regions, possible combinations of eyes and mouth are evaluated based on the topological rules as follows:

1. A pair of eye feature regions is selected from the set of PEFR and one mouth feature is selected from the set of PMFR.

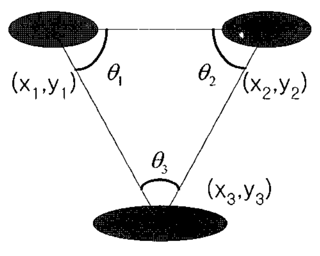


Fig. 7: Definition of inside angles of the triangle consisted of the selected face feature set.

2. Construct a triangle with the selected features as shown in Fig. 7, and calculate the three inside angles defined in Fig. 7, using the following equations.

$$\theta_1 = arctang\left(\left|\frac{y_3-y_1}{x_3-x_1}\right|\right) + sign(y_2-y_1)\times arctang\left(\left|\frac{y_2-y_1}{x_2-x_1}\right|\right)$$
$$\theta_2 = arctang\left(\left|\frac{y_3-y_2}{x_3-x_2}\right|\right) - sign(y_2-y_1)\times arctang\left(\left|\frac{y_2-y_1}{x_2-x_1}\right|\right)$$
$$\theta_3 = 180^\circ - (\theta_1+\theta_2) \quad (5)$$

In Eq. (5), sign(•) is the signum function, (x_1, y_1) is the center of the left eye, (x_2, y_2) is the center of the right eye, and (x_3, y_3) is the center of the mouth. To take most faces of common people into account, the angles in the following ranges are considered as a triangle of a face. $\theta_{ref}(k)$ given in Eq. (6), is the reference angle which is derived from the face shapes of common people.

$$\theta_{ref}(k) = \begin{cases} 65^\circ & , if \quad k = 1(left\ eye) \\ 65^\circ & , if \quad k = 2(right\ eye) \\ 50^\circ & , if \quad k = 3(mouth) \end{cases} \quad (6)$$

$$S_T = \frac{W_3}{|x_2-x_1|\times\beta}\times\sum_{k=1}^{3}\left(\alpha_k\times\left|\theta_k-\theta_{ref}(k)\right|^2\right)$$
$$\begin{cases} \alpha_k = \left(\frac{H_k}{W_k}\right)^2 & for\ k=1,2 \\ \alpha_k = \frac{S_3}{256}\times\left(\frac{H_k}{W_k}\right)^3 & for\ k=3 \\ S_3 = \frac{1}{N}\times\sum_{l=0}^{l=N-1}(Cr_l+Cb_l) & \end{cases} \quad (7)$$

Then the score of the selected triangle, S_T, is defined by Eq. (7). In Eq. (7), the errors between $\theta_{ref}(k)$ and $\theta_{k,\ k=1,,3}$ are weighted by the credibilities given on the selected feature regions. Since θ_1 is based on left eye, the error between $\theta_{ref}(1)$ and θ_1 is weighted by the credibility on the feature selected as the left eye. In the same way, the error between $\theta_{ref}(2)$ and θ_2 is weighted by the credibility on the feature selected as the right eye. The credibility on an eye feature region is defined as the square of the width and height ratio. In the case of θ_3 which is based on mouth, the error between $\theta_{ref}(3)$ and θ_3 is weighted by the credibility on the feature selected as the mouth. The credibility on a mouth feature region is also defined as the square of the width and height ratio, but weighted by the mean of C_r and C_b values included the mouth feature region. C_r and C_b are determined by the transformations, C_r=0.169R-0.331G+0.5B and C_b=0.5R-0.419G-0.081B, respectively. The weighted sum of the errors of three angles is finally weighted by the ratio of the width of mouth feature region over the distance between eyes to define the score of the selected triangle. Here is the normalization factor to make the score of non-facial region larger than 1.

3. Repeat the above process for all possible combinations of eyes and mouth remained in PEFR and PMFR.
4. The set of eyes and mouth feature regions having the score less than 1 is selected as the final facial feature regions.

Fig. 5(f) shows the scores given to all possible combinations of eye and mouth feature regions and (g) shows the set of finally selected facial features having the score of 0.0235.

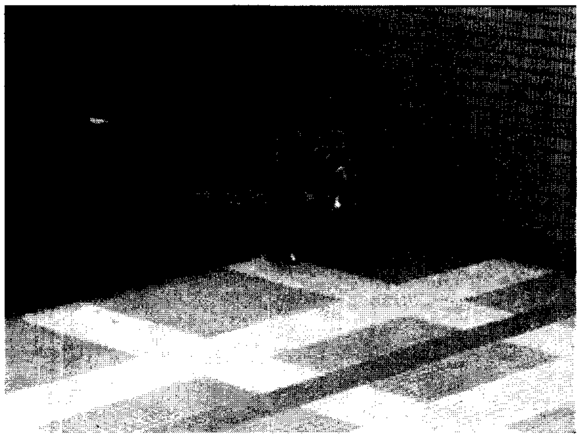
V. Experiments

The experiments have been performed to conform that the proposed algorithm is robust on face region size and lighting condition. As an input device, a plain analog camera having 350,000 pixels and NTSC output format that can be easily found in market is selected. For image processing, PC with 700MHz CPU has been used. Test images have been captured in various places including a research laboratory with complex background and an open space where lighting condition varies severely, as shown in the example pictures.

5.1 Detection of candidates for face regions

Fig. 8 show example images acquired at different locations. Some faces are right ones and others are side ones. Boxes in Fig. 8 are the candidates for face regions, selected by the proposed block based segmentation algorithm. As intended, the proposed algorithm produces a little bit larger area than actual face regions since the block is decided as a face color block even if it contains one face color pixel. However, it generates also many non-face regions as candidates, since it decides a block as a face block if it contains face color pixels more than 60% in the block. Experimental results have shown that the proposed algorithm detects stably even small size face regions of 6×6 pixels. By applying the conditions given in IV to select feasible candidates, three candidates (4, 8, 9) are eliminated. The 9th candidate in Fig. 8 is eliminated by condition 1 and the 4th and 8th candidates are eliminated by the condition 3.

(a) Inside a research laboratory



(b) Outside a building

Fig. 8: Input image where the candidates for face regions are marked by boxes.

5.2 Classification of candidates

For testing the proposed algorithm, 188 candidates for face regions are used, among which non-face regions are 100. Among the results, Fig. 9 shows 6 candidate regions whose sizes vary from 6×6 to 28×28, normalized as the same size for the demonstration purpose. They are selected among the 9 candidates given in Fig. 8, satisfying the three conditions given in section IV. Next to the candidate images, their facial feature images from the intensity difference image are shown where the selected features regions are highlighted. The score of selected feature regions is also given below the pictures.

The results obtained from the experiments with the test images are summarized in Table 2. They show the correct decision rate and the false detection rate. The correct decision rate tells the number of correct decisions that decides a face region as a face region and a non-face region as a non-face region. In Table 2, two correct decision rates are given. One for the face region is larger than 100%. It tells the fact that the algorithm selects some non-face regions as well as all face regions not to miss face region from the candidate list. One for the non-face region is smaller than 100% not to decide a non-face region as the face region. The false detection

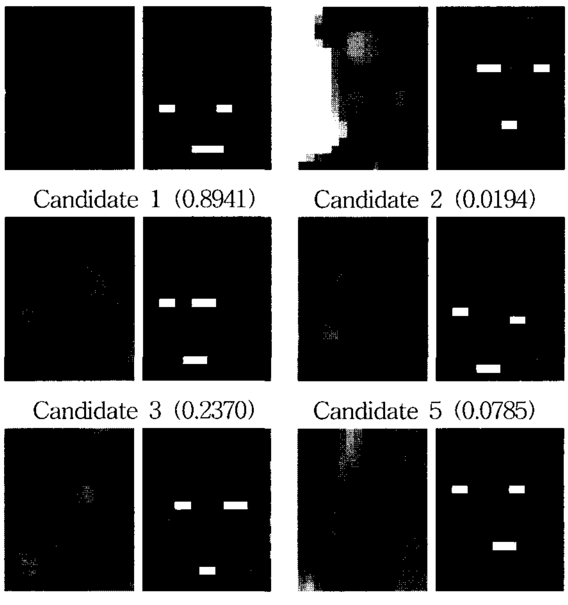


Fig. 9: Scoring candidates for face region using facial features.

rate is the rate of false decisions with reference to the total input images. False decision is to determine the non-face region as the face region. Since the 8 images are determined as face regions among 100 non-face images and the total number of input images is 188, the false decision rate becomes 4.26%. These results are superior to the other algorithms including [13] developed thus far in similar experimental environments. The proposed algorithm also shows that it can detect even those faces showing side views tilted in a certain degree.

Table 2: Summary of test results.

Region Type	Number of images	Decision results	Correct decision rate
Face	88	96	109.1%
Non-face	100	92	92%

Ⅵ. Conclusion

This paper has shown that the block based segmentation scheme solves several critical problems caused by lighting condition and small size, in face detection process. The block based approach enlarges the small face color area and thus fills the missed area in the face regions so that it may be possible to detect small face regions. The facial feature scoring scheme also contributed a lot for eliminating non-face regions and thus for enhancing the correct decision rate. The proposed algorithm has shown excellent performance even when face regions are as small as 9×6 pixels and faces are near-frontal views. The proposed algorithm takes about 0.08 second per image frame to determine face regions and has shown excellent performance under various lighting conditions in complex backgrounds.

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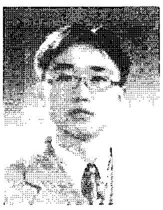

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