A Robust Iris Detection Method of Facial and Eye Movement

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Abstract

Our research aims at applying information with regard to a user's gaze to computer interaction. In this paper, we propose an iris detection method that is adaptable to various face and eye movements from a face image. First, our method determines the standard skin color from the previous frame. The face region is divided by the color difference from the standard skin color. Secondly, the eye and mouth regions are extracted from the face region by hybrid template matching, which consists of edge and color features. Using our method, facial parts can be extracted against individual variation of faces and his/her head movements. Finally, the iris regions are detected by using saturation and brightness from the extracted eye regions. Then, the iris positions are detected by the Hough Transform. We evaluated our method using facial images with various positions of faces and eyes. Our method achieved an accuracy rate of approximately 98% for eye region detection, and approximately 96% for iris detection.

1 Introduction

In recent years, various methods of iris detection for gaze detection, applied to man-machine interfaces have been proposed [1][2][3]. However, most research did not report the relationship between the accuracy rate of the iris detection and the directions of the face and the eyes in detail. Actually, the shape of facial parts are not only different depending on the person, but also dynamically change by movement of the head, facial expressions, and so on. In particular, when a person faces down, the eye regions tend to be dark. In this case, it is difficult to detect irises in the eye region. Therefore, we propose an iris detection method that is adaptable to individual variation and directions of faces and eyes. Our method extracts the eye regions before detecting irises. The facial parts extraction needs to be robust to great change in shape. We have proposed the method of the facial part extraction which utilizes the four directional features and the color distance features [4]. First, to detect irises, iris regions are extracted by saturation and brightness. Next, the position of the iris is detected by the Hough Transform.

In this paper, we will describe the eye-region extraction method in section 2. Results of the extracted eye region are shown in section 3. We will explain about the iris detection method in section 4. Section 5 presents the result of iris detection experiment, and we conclude in section 6.

2 Extraction method of facial parts

2.1 Face detection

Before detecting the irises, we think it is necessary to identify face regions in the input image. Some methods that extract face regions by color information have been proposed [5]. Popular methods often use hue and saturation values in the HSV color system. However these methods do not work well if the target objects are not bright enough. We decided to use U, V values in the CIE-LUV color system from the preliminary experiment. The CIE-LUV color system consists of lightness(L) and color values(U and V). Theoretically, the CIE-LUV color system is just as capable as humans when distinguishing between any two colors of the same lightness. Our method that extracts face regions is described as follows:

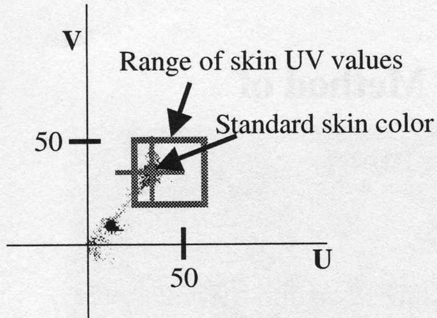


Figure 1. UV values distribution

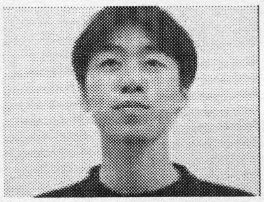


Figure 2. Original image

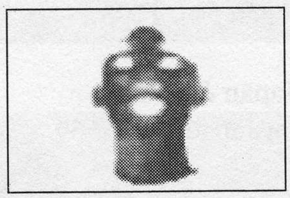


Figure 3. UV values distance image

Figure 4. Detected face region

First, a two-dimensional histogram on the UV plane is constructed using the face image of the previous frame. In the two dimensional histogram, our method determines the standard skin color, which indicate the maximum number of pixels within the range of skin UV values. The range of skin UV values is decided from a sample of several Japanese people. Figure 1 shows an example of the UV values distribution. As shown in Figure1, the rectangle shows the range of skin UV values, and the position of a cross indicates the standard skin color. The distances from the standard skin color to each pixel of UV values in the input image are calculated. Figure 2 is an original image. Figure 3 shows the UV value distance from standard skin color. In Figure3, the level of brightness indicates the distance from the standard skin color. Thus, dark areas indicate a close match to standard skin color. Next, we make a UV values difference histogram from the above results and then extract the skin region by the discriminant of Otsu. Figure 4 shows an example of the detected face region.

2.2 Extraction of facial parts

Many methods which extract facial parts have been proposed. For example, a method of eye regions detected by edge projection analysis [6]. Another method detects facial parts in Eigenspace [7]. However, these methods could not obtain the same accuracy rate when subjects tilted their heads. Therefore, we proposed a hybrid template matching method which uses the four directional features [8] and color distance features. This method allows for an improved accuracy rate, even if a person tilts his/her head.

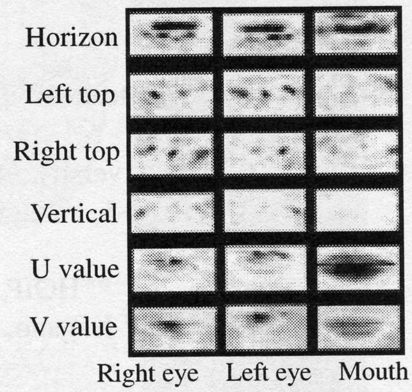


Figure 5. Facial parts template

Figure 5 is an example of the four directional features and the color distance features template for facial parts. The four directional features consist of four images which are divided by edge into horizontal, the vertical, the right top, and the left top. They are reduced to low resolution through the Gussian filter. Even if it is low resolution, this feature keeps the information of the edge directions in comparison with the feature that does not divide the direction of edge. Therefore, the four directional features are adaptable to change of shape. The color distance features find a mean of color distance from the standard skin UV values of skin to each pixel of UV values. Although the shape of facial parts dynamically change by movement of the head, this feature is useful. Because there is little change of a color compared with the shape change. Before extracting facial parts, right eye, left eye, and mouth images are prepared in order to construct the initial template. The four directional features and the color distance features are extracted from each facial part image.

Next, similarity is calculated between the templates and the input image which carried out the same processing as a template. Similarity is decided according to the following criteria. The similarity of the four directional features: E is calculated by equation (1), the similarity of color distance features: C is calculated by equation (2). $I(x,y)$ represents a feature of the input image, $t(x,y,v)$ represents a template feature. Let the size of the template be $m \times n$. v indicates a direction of an edge. U and V indicate the distance from the standard skin color for the U and V components, respectively. Total similarity S is evaluated by equation (3). w is the weight for the color similarity. In this paper, we let w equal 1. Regions whose total similarity marks higher than a threshold is registered as a candidate. After matching, our method tests all combinations that satisfy certain restrictions regarding the relative positions between the eyes and mouth.

$$E=\frac{\left\{\sum_{i=1}^{m}\sum_{j=1}^{n} I_{(x,y)}(i,j,v)\times t(i,j,v)\right\}^2}{\sum_{i=1}^{m}\sum_{j=1}^{n} I_{(x,y)}(i,j,v)^2\times\sum_{i=1}^{m}\sum_{j=1}^{n} t(i,j,v)^2} \quad (1)$$

$$C=1-\frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(I_{u(x,y)}(i,j)-t_u(i,j)\right)^2+\sum_{i=1}^{m}\sum_{j=1}^{n}\left(I_{v(x,y)}(i,j)-t_v(i,j)\right)^2}{2m\cdot n\cdot U_{\max}\cdot V_{\max}} \quad (2)$$

$$S=E+wC \quad (3)$$

3 Facial parts extraction experiment

3.1 Experimental data

We have established a multiple camera system for the collection of the experimental data. Using the multiple camera system, we gathered facial images with various positions of the head and eyes. Figure 6 shows an experimental situation. The multiple camera system consists of 15 cameras, and can take images simultaneously. The subject sits on the chair and face to index A, B, and C respectively. Thus, it is possible to take pictures of the face in 45 directions. They vary by 40 degrees in the horizontal and 20 degrees in the vertical at intervals of five degrees. These facial images collected with the multiple camera system make up data set 1. Data set 1 has 45 different kinds of directions of faces in which the eyes look forward. The subjects included eight people who did not wear glasses. Number of images on the data set 1 totals 360. The image data is input with dimensions of 640×480 pixels in 24-bit. The background is simple, because we aim to evaluate facial parts extraction in this experiment.

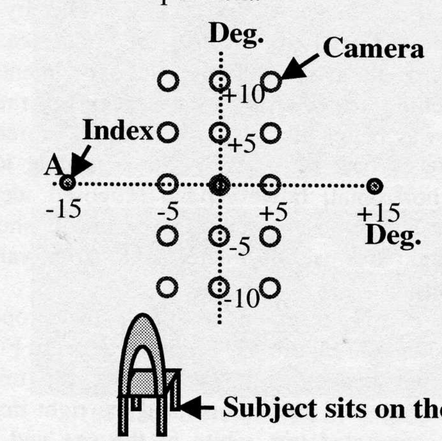


Figure 6. Experimental situation for data set 1

3.2 Results and discussion

We experimented with the extraction of eye regions from data set 1. The extracted region is 72×48 pixels. We judged whether face parts would be contained in this region. The template was constructed from the different experimental data. The results are shown in Figure 7. Figure 7(a) shows the rate of extraction when direction of a face changes from the front horizontally. Figure 7(b) shows the rate of extraction when the direction of a face changes from top downward. Examples of the experiment results are shown in Figure 8 (a), (b) and (c). In Figure 8 (a), (b) and (c), the extracted eyes and mouth regions are outlined by a rectangle respectively.

From Figure 7, the accuracy rate of extraction decreased as the subjects faced away. However, it was more than 95%, even when the subjects faced away at an angle of 20 degrees. In this experiment, the average accuracy rate of the eye region was 98.2% with the average template.

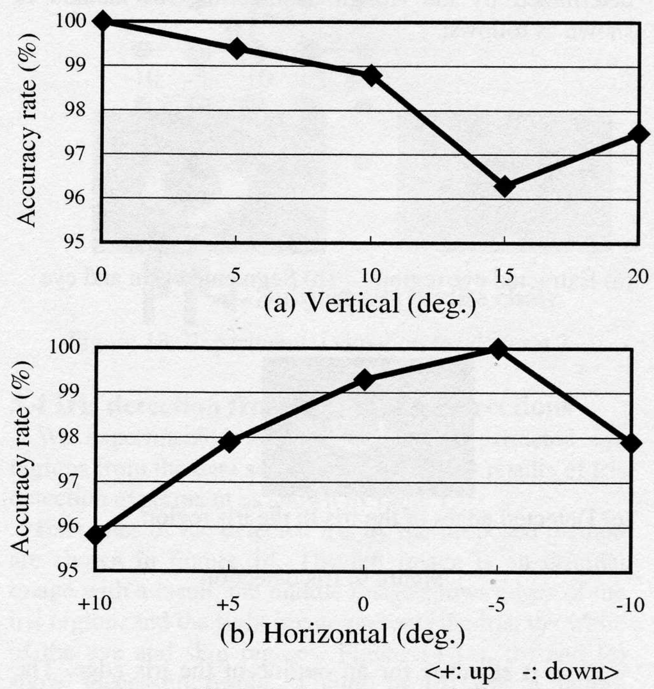
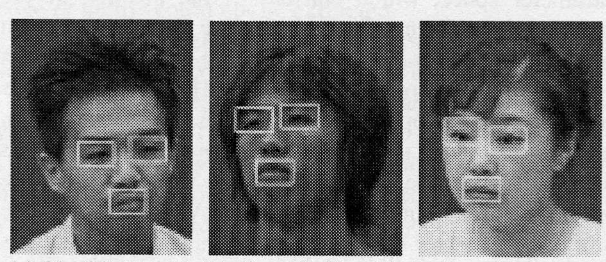


Figure 7. Accuracy rate (%)



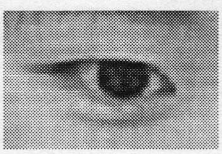
(a) H: -20, V: -10 (b) H: +20, V: +10 (c) H: +20, V: -10

H: Horizontal (deg.), V: Vertical (deg.)

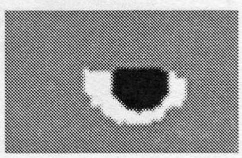
Figure 8. Examples of the result images

4 Iris detection method

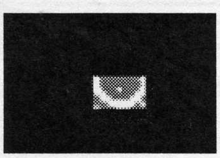
In this section, we describe iris detection from the extracted eye regions. First, since skin regions tend to be higher saturation values than eye regions, the extracted eye region is divided into the eye and skin regions by a saturation histogram using the discriminant of Otsu. Then, the eye region is divided into the iris and the white of the eye from the brightness histogram using the discriminant of Otsu. Thus, the dark region is the iris. Employing the discriminant of Otsu, we can separate the iris and the white of the eye even if the eye regions are dark. Figure 9(a) is an extracted eye region image, the result of the segmented skin and eye is shown in Figure 9(b). The iris region is calculated from the extracted dark region. Next, the edge of the iris is detected from the gray-scale image in iris region by Prewitt's operator. Figure 9 (c) shows the detected edges of the iris in the iris region. The size of Figure 9 (a), (b) and (c) is 72×48 pixels. After the edges of the iris are detected, the position of the iris is determined by the Hough Transform. Our method is shown as follows:



(a) Extracted eye region



(b) Segmented skin and eye



(c) Detected edges of the iris in the iris region

Figure 9. Iris detection

First, it searches for an outline of the iris edge. The possibility of a circle projects on a three-dimensional parameter space, which consists of the position of the center and the radius of the circle. The Hough Transform is robust against noise, and detects the iris even if only a part of the outline of the iris appears. However, many iris candidates have appeared by using the Hough transform. In order to reduce these candidates, our method restricts the edge within the iris region which is extracted in the previous process. In addition, to improve the speed of the process, the center of the circle is limited within the iris region. In this experiment, the radius is coordinated in the range from 7 to 12 pixels, which have been determined from the previous experiments.

5 Iris detection experiment

We experimented with iris detection by using our method. To evaluate our method, we compared our method with four sampling method [9], which we have proposed and enhanced. In this experiment, we conducted two kinds of experiments to detect irises. One is to detect irises from various directions of faces. The other is to detect irises from various eye directions from a frontal view of the face. In this paper, we let the four sampling method be past method.

5.1 Four sampling method

We described the enhanced four sampling method as follows:

First, two horizontal terminations of the iris edge are detected. Next, the two sampling points are searched from the bottom of the edge of the iris until the length of these points are longer than half of the length of two horizontal terminations. These four points are extracted as shown in Figure 10. Then, the circle pattern of the iris is calculated from the four points by the least square approximation.

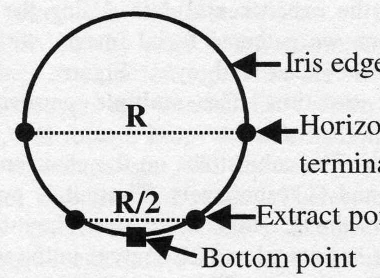
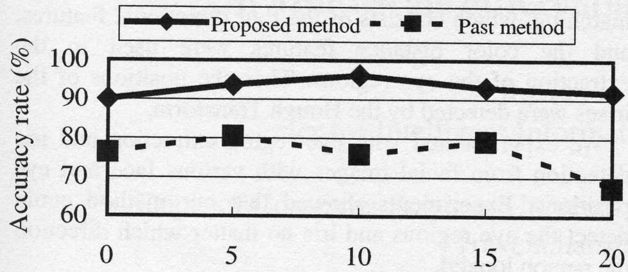


Figure 10. Extraction of four points on the outline of the iris

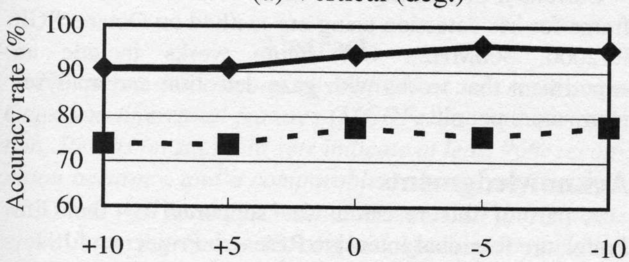
5.2 Iris detection from various face directions

In this experiment, we used data set 1, and tested to detect irises from the correct extracted eye regions. Figure 11 (a) and (b) show the accuracy rates by the past method and the proposed method respectively. In Figure 11, a solid line indicates the accuracy rate by the proposed method and a dashed line indicates the accuracy rate by the past method. In the experiment, the proposed method achieved an average accuracy rate of 93.2%, and was better than the past method. Moreover, accuracy rate of past method was down turning to 20 degrees in horizontal, however, the proposed method could keep a higher accuracy rate. Experiments showed that our method was useful to detect irises from various face directions.

Examples of the detected irises by the proposed method are shown in Figure 12. The left images in Figure 12 are original images with each result, the middle images show edges of iris regions, and the right images present the segmented iris, white of the eye and skin regions respectively. Figure 12 (a), (b) and (c) show successful results. Figure12 (d) was a failure because there were many edges which did not denote the iris.



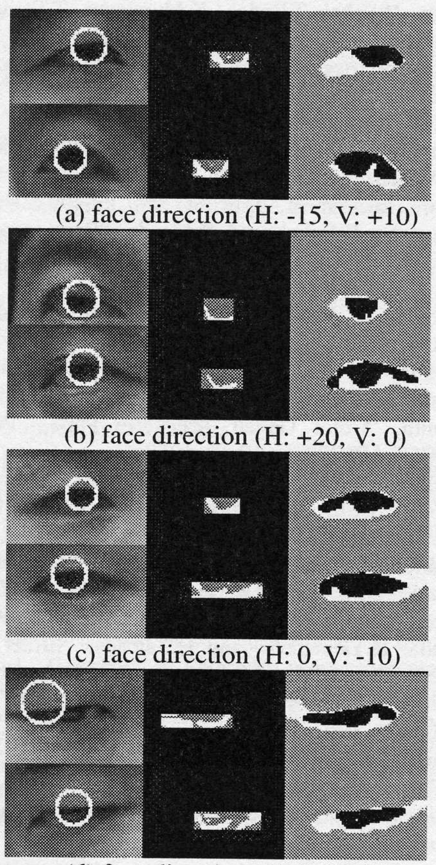
(a) Vertical (deg.)



(b) Horizontal (deg.)

<+: up -: down>

Figure 11. Iris detection for data set 1



(a) face direction (H: -15, V: +10)

(b) face direction (H: +20, V: 0)

(c) face direction (H: 0, V: -10)

(d) face direction (H: 0, V: -10)

H: Horizon (deg.), V: Vertical (deg.)

Figure 12. Examples of result images

5.3 Experimental data

The second experiment used other data which was taken by the multiple camera system. The multiple camera system can also collect face image data with the iris facing in various directions. Figure 13 shows the experimental situation to collect face image data with irises facing in different directions. We made the subjects look at the indexes in order, while they kept facing forward to "B". We setup 25 indexes as shown in Figure 13. Therefore, data set 2 consists of 25 kinds of eye directions from the frontal view of the face. Eight images were captured from each eye direction. The subjects consisted of eight people who did not wear glasses. Data set 2 includes a total of 1600 images. The resolution of the image is 640×480 pixels with 24-bit color.

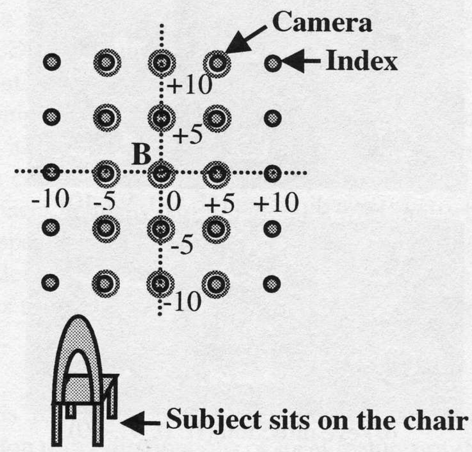


Figure 13. Experimental situation for data set 2

5.4 Iris detection from various eye directions

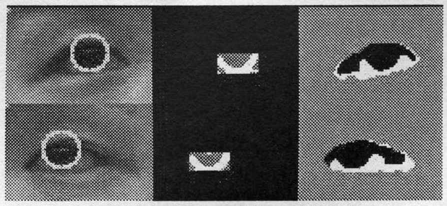
We experimented with the successful extracted eye regions from the data set 2. We checked the results of iris detection experiment as shown in Table 1.

Examples of the detected iris by the proposed method are shown in Figure 14. The left image is an original image with a result, the middle image shows edges of the iris region, and the right image presents the iris, the white of the eye and skin regions. Figure 14 (a), (b) and (c) show successful results. Figure 14 (d) was a failure because it became dark in the shadow of the face and the edge of an iris could not be extracted.

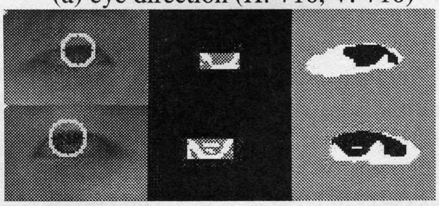
In the experiment, our proposed method achieved a success rate of 95.6%, which is better than past method.

Moreover, the results related to the direction of the gaze are shown in Table 2.

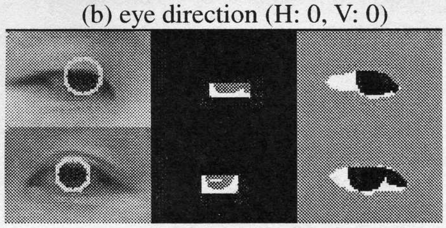
Comparing the past method and proposed method, both of the methods could detect the irises independent of various eye directions. When the subjects looked below or away, the past method decreased in accuracy. However, the proposed method maintained an accuracy rate as good as when looking up and forward. Thus, it is thought that the proposed method, which uses the Hough Transform, is robust to the movements of the irises.



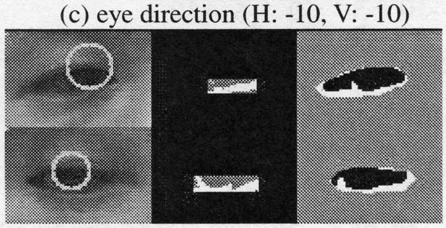
(a) eye direction (H: +10, V: +10)



(b) eye direction (H: 0, V: 0)



(c) eye direction (H: -10, V: -10)



(d) eye direction (H: 0, V: -10)

H: Horizon (deg.), V: Vertical (deg.)

Figure 14. Examples of result images

Table 1. Iris detection experimental results

	Past method	Proposed method
Accuracy rate(%)	84.9 %	95.6 %

\# of total images 3162 sheets

Table 2. Detection results from the past method and proposed method (%)

	-10 deg.	-5 deg.	0 deg.	+5 deg.	+10 deg.	Ave.
+10 deg.	95.3 94.5	93.0 97.7	93.0 95.3	89.1 89.8	88.7 96.0	91.8 94.7
+5 deg.	93.0 98.4	87.3 98.4	91.1 94.4	92.2 99.2	94.2 97.5	91.6 97.6
0 deg.	86.5 94.4	85.2 97.7	88.3 97.7	91.4 97.7	80.7 100	86.4 97.5
-5 deg.	78.1 96.1	88.1 100	85.2 100	66.4 89.8	78.1 97.7	79.2 96.7
-10 deg.	68.0 95.3	83.6 93.4	85.3 95.1	71.9 89.1	69.5 84.4	75.7 91.5
Ave.	84.2 95.7	87.4 97.4	88.6 96.5	82.2 93.1	82.2 95.1	84.9 95.6

above: past method, below: proposed method

6 Conclusions

We proposed a iris detection method that adapts to various face and eye positions. First of all template matching, which consists of the four directional features, and the color distance features were used in the extraction of the eye regions. Then the positions of the irises were detected by the Hough Transform.

We experimented with eye region extraction and iris detection from facial images with various face and eye positions. Experiments showed that our method could detect the eye regions and iris no matter which direction the person looked.

Currently, processing time takes about 0.12 seconds a frame for iris detection using our method on Octane(SGI, R12000, 300MHz). Our future works include an experiment that works with gaze detection and analyses many more people.

Acknowledgments

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