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Non-Contact Line-of-sight Detection using Color Contact Lens for Man-Machine Interface

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Abstract

The man-machine interface is an important factor in the computer system, and it is thought that line-of-sight (LOS) detection technology will allow significant advances in this field. Techniques for detecting LOS for use in human interfaces have been studied [1][2]. In earlier studies, however, LOS was detected with a head piece, goggles, or through fixing the position of the head. The limitations imposed by these fixed conditions render them unsuitable for use in interfaces, as they have adverse mental or physical effects on humans. Therefore, they have not been sufficiently developed for practical application. Research on non-contact LOS detection is expected to result in a usable LOS man-machine interface [3][4], and the current study is intended to be a step in that direction. The authors used color contact lenses for LOS detection, and applied this new method to a computer interface. The use of color contact lenses simplifies image processing. The algorithm used in this study is sufficiently accurate for practical applications. This technique can be used in input devices, in virtual reality applications, and in human engineering research.

1. Selection of color contact lens

1.1 Selection of the color

As the first step to detect the complementary color to the face color , the hues of face are measured from the RGB level (256 gradations)in a image. As shown Fig.1, in the some areas of face, the averages of the each colors (R, G, B) are calculated from ten points. Then, the complementary color is detected with the values. The complementary color to face color is blue, so we decide to use the blue lenses. In this study, 2 kinds of blue contact lens that are commercial products are tried. The one is light blue, the other one is dark blue. But the light blue lens is better than the dark one in the thresholding as described later. So, we use the light blue lens in this study. In Fig.2, the sap of line expresses the hue, so we can consider that the color (solid line in Fig.2) of lens inserted in eyes is similar to the complementary color (alternate long and short dash line in Fig.2). A color sense of this color contact lens is not different from the transparent one.

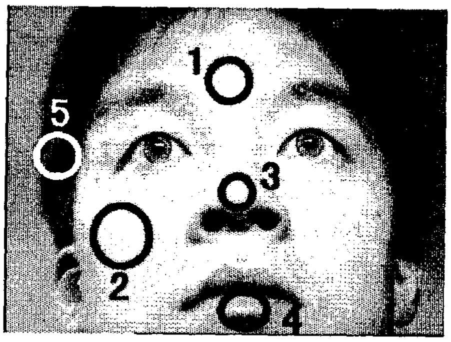


Fig.1 Measured areas on face

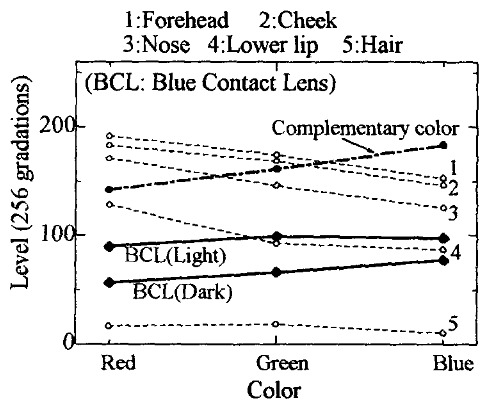


Fig.2 Face's colors and their complementary color

1.2 Selection of the kind

There are 2 kinds of contact lens. The one is hard contact lens, the other one is soft contact lens.

The diameter of hard lens is smaller than the iris one. So, it is stable by the difference of curvature.

On soft lens, the diameter of soft lens is bigger than the diameter of iris. So, it is stable by the elastic deformation. It is consider that the most suitable lens is soft lens, because the motion of soft lens is virtually same to the motion of iris, and there is little displacement of contact lens. So, we detect to use the blue soft contact lens in this study.

1.3 Displacement of contact lens

When contact lenses are used as the pointing devices, we can't ignore the displacement of contact lens. It is important to recognize the displacement of lens. In this section, we perform the 2 experiments.

In the first experiment, we confirm the displacement of lens caused the eye movement. The subject inserts the blue color contact lens in his eyes and sits in front of video camera with fixed his head. And the subject moves his eyes vertically and horizontally at intervals of 1 second. The timing at the motion of eyes is depending on the sound. At that time, the images of eyes are obtained with video camera. The 2 points (200 mm interval) that the subject gaze by turns have the distance between the subject's eyes and the points about 500 mm. In these images, a iris pattern of contact lens is used as the reference points of lens' motion. And A blood vessel pattern is used as the reference points of eyes' motion. As shown in Fig.3, both are compared for the displacement of contact lens. The Fig.3 shows the distance of movement to the vertical axis and the time to the horizontal axis. The solid line shows the motion of contact lens, and the dotted line shows the motion of eyes.

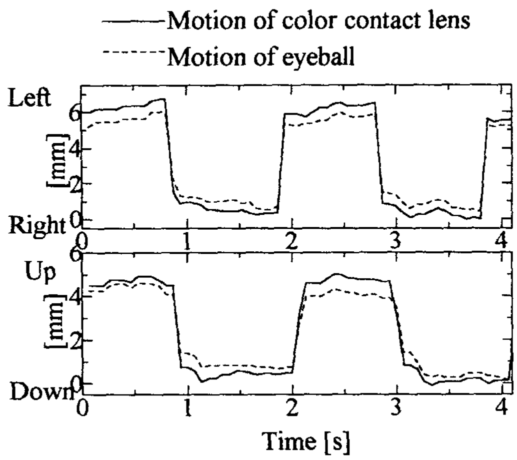


Fig.3 Displacement of contact lens caused by eye movement

In Fig.3, the both motions resemble closely each other. From this result, it can be considered that there is no effect of the displacement of contact lens.

In the next experiment, we confirm the displacement of contact lens caused by blinking. The subject blinks at intervals of 1 second and gazes a point. The motion of contact lens is consider to the displacement of contact lens by the blinking. The Fig.4 shows the distance of movement on contact lens to the vertical axis and the time to the horizontal axis. It is shown in Fig.4 that the subject is blinking at the each time of 0.3, 1.3, 2.4 seconds. Immediately after blinking, contact lens is lifted by the upper eyelid. And the contact lens gradually slide down and are stable within about 0.7 seconds . There is a little difference in the displacement whenever the subject blinks. In the blink dates of the 50 times, the maximum displacement is 1.2 mm. It is considered that the influence of displacement is small. Moreover, the processing interval as described later needs 1 second, so it is enough to use the color contact lens as the pointing devices.

2. Environment of experiment

The subject inserts the color contact lens in his eyes and sits in front of CRT, as shown in Fig.5. As a souse of light, fluorescent lamps in the experimental room are used for satiability of images. We think video camera is possibly less, so only one video camera is used in this study. When the distance between the user's eye and the CRT is about 500 mm, the subject can move the head naturally less than 150 × 100 mm that is the scope of video camera. And a computer made by Silicon Graphics Company (Indigo2) is used .

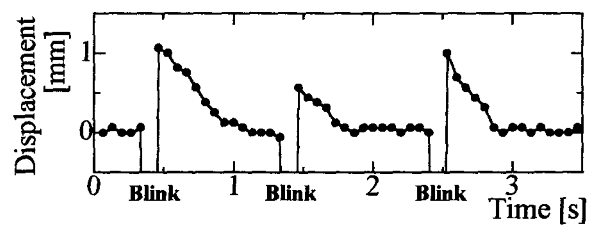


Fig.4 Displacement of contact lens caused by blinking

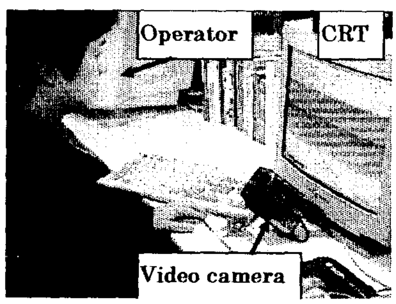


Fig.5 Experimental setup

3. Algorithm of line-of-sight detection

This algorithm can be divided into 3 parts. The first process detects the position of face, the second one detects the center of color contact lens, the third one is the transformation these dates into LOS.

3.1 Detecting the position of face

The algorithm of detecting the position of face extracts three feature points that are consisted both eye edges and between the holes of nose by image processing (Fig.6). The three feature points in plane coordinates are transformed to the space coordinates by the using the known distances between the three feature points. In addition, the size of image used by this experiment is 640×486 dots and monochrome image is used.

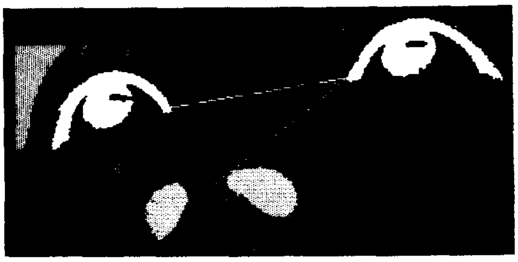


Fig.6 Extraction of the feature points on face

3.2 Detecting the center of contact lens

The algorithm flow on the detecting the center of contact lens is roughly separated some parts. The algorithm flow is shown in Fig.7.

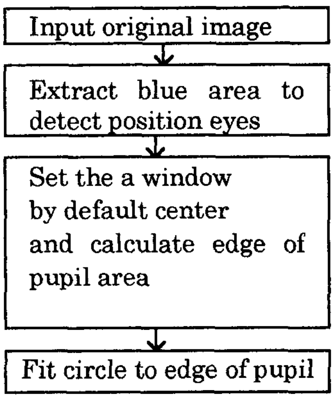


Fig.7 Algorithm flow

Extraction of blue area: The first step is the extraction of the blue area of color contact lens. As shown Fig.8, the algorithm extracts the pixels that satisfy the condition as defined by Eqs. (1). This equations are based on Fig.2. This process is not enough to detect the center of contact lens, because the blue area of contact lens is not a complete circle with high fidelity. But we can roughly get the positions of eyes by this process.

$$blue > red \quad \text{and} \quad C_1 > blue > C_2 \quad \text{and} \quad |blue - green| < C_3 \qquad (1)$$

blue, green, red : RGB level (256 gradations)

C_1 : Maximum of *blue*

C_2 : Minimum of *blue*

C_3 : Maximum of difference of *blue* with *green*

Calculation on the edge of pupil: Default center is detected by the above process. Based on the default center, a widow is set up for shortening processing time and decreasing errors in image processing. In the window, the image of pupil is transformed to the binary image by the thresholding and the edge of pupil. The detection of edge of pupil is used the first order differentiation. (Fig.9)

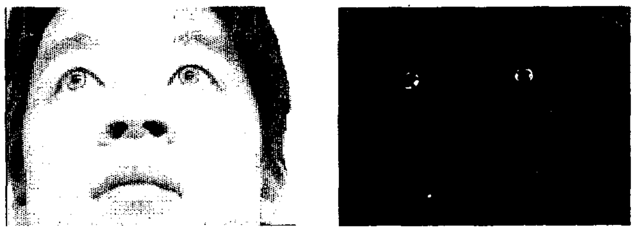
Fitting circle to the edge of pupil: Specifically speaking, the edge of the pupil area is approximated by circle for detecting more correct center of contact lens. As shown in Fig.10 , a circle is fitted to the edge of pupil area. It is based on Eqs.(2).

$$y = y_{CL} \pm \sqrt{R^2 - (x - x_{CL})^2} \quad (x_{CL} - R \le x \le x_{CL} + R) \qquad (2)$$

x, y :Coordinates of fitted circle

x_{CL}, y_{CL} :Center coordinates of fitted circle (parameter)

R : Radius of fitted circle (parameter)



(a) Original image of face (b) Binary image

Fig.8 Using thresholding to extract the position of eyes

(a) Binary image of pupil (b)Edge image of pupil

Fig.9 Detecting the edge of pupil

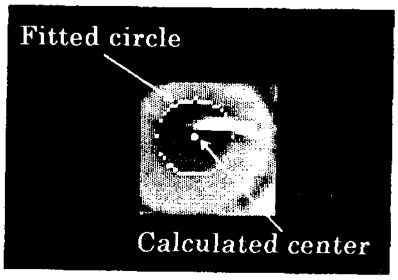


Fig.10 Calculated center of pupil

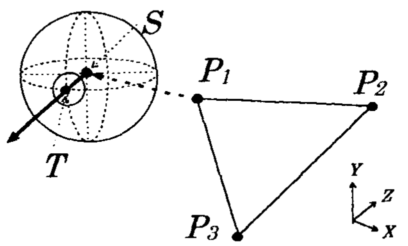
The center of contact lens in plane coordinate is transformed into a space coordinate.

In this study, the commercial products of color contact lens are used. It is considered that the natural design of color contact lens has a bad influence upon image processing.

3.3 Transformation into line-of -sight

The detected position of face and the detected center of contact lens are transformed to a LOS, and a cursor is displayed on monitor. In the initial setup, the subject sees 2 points which separated 100mm from the center of CRT to left and right. And the position of center of eyeball is beforehand calculated on the space coordinate. The vector passing through the center of eyeball and the center of iris is LOS, and the position of crossing the vector and CRT turns into a cursor as a gazing point. (Fig.11)

The processing interval is 1 second. Therefor, it offers virtually real-time processing for practical application.



P_1, P_2, P_3 : Feature Points of Face
S : Center of eyeball
T : Center of pupil

Fig.11 Feature points of face and eye

4. Evaluative experiment

The subject gazes at the 1 points that one of the nine intersection of the dotted-line (100mm interval), as shown in Fig.12. The subject naturally states without fixing head. In Fig.12, the gazing points of result in 10 times are respectively plotted. An average of distance from the gazing point is that the direction of x is 6.0mm and y is 6.5mm. The standard deviation is that x is 3.6mm and y is 7.2mm. From the above condition, the size of the icon is follows at inputting by LOS.

The direction of x : (6.0+3.6) x 2.0=19.2

The direction of y : (6.5+7.2) x 2.0=27.4

It is considered that the above result is sufficient accuracy for pointing devices. Being considered as a factors of a detection error this time, the influence of the coarseness of image data and an eyeball vibration (The maximum flick is 0.83 degree) can be considered.

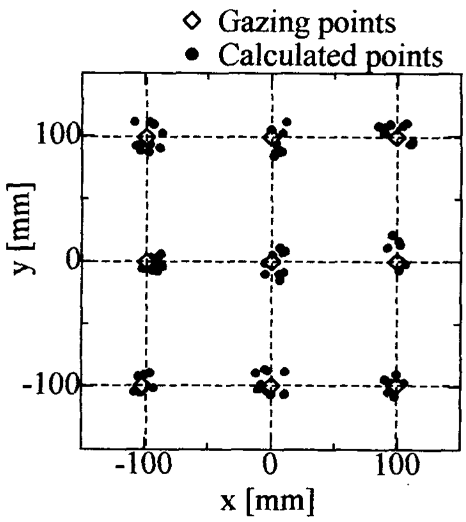


Fig.12 Result of fixation on nine points on CRT

5. Conclusion

One proposal is performed about the non-contact LOS detection using color contact lens. An image obtained with a video camera allows the algorithm to extract the feature points of the user's face without marks. By the using of the blue contact lens, the center of contact lens can be detect easily in image processing. And the processing interval is 1 second. Therefor, it offers virtually real-time processing for man-machine interface.

As the application of this method, this technology can be used in input device, in virtual reality application, or human engineering research.

Acknowledgment

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