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Keynote Lecture

Development of hands-free interface based on feature value of eye for operation of communication aid

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Abstract. It is important for the patients with neurological difficulties such as ALS and SMA to improve their quality of life. It is also serious problem for them to secure a communication device which can display their intention, therefore, various welfare interfaces have been proposed. In this research, we developed a non-contact switch focusing on eyelid shape. We have developed a system which could approximate eyelid shape by the Bezier curve. The curvature value of the approximation curve changes due to movement of gaze direction. It allowed to discriminate an operator's gaze direction by doing calibration on five points. Here we applied it to operate on communication aid system. It was possible to select eight words which previously registered. It is possible to select eight words which previously registered. And it can talk selected word. The developed system possible to convey intent by only gazing input with non-contact.

1. Introduction

Improving QOL (quality of life) for patients with neurological diseases such as ALS (amyotrophic lateral sclerosis) and SMA (spinal atrophy) is an important issue [1]. At the same time, it is indispensable to secure a communication device that displays its own intention, and various interfaces have been proposed [2]. In this study, we developed a non - contact switch focusing on the shape change of the eyelid when changing the gaze direction, and considered to reflect it on the operation of the communication support system. We have developed a system that recognizes the gaze direction of the operator by approximating the eyelid shape with a Bezier curve and finding the curvature of the curve. Furthermore, by using the developed system, we investigated a system that selects words only by eye gaze and performs sound reproduction.

2. Recognition of gazing directions

2.1 Detection of feature points

In this system, we recognize the gaze direction by capturing the face image with a USB camera. The state of image processing is shown in Fig. The vicinity of the eyes is digitized by the equation (1) as the image processing range.

$$g[i,j] = \begin{cases} 1 & (U[i,j] < \varepsilon) \\ 0 & (Otherwise) \end{cases} \tag{1}$$

Where $U[i,j]$ is the luminance of red at the coordinates (i,j) in the image processing range, and ε is the threshold. By adjusting the threshold value, the positions of the iris, the outer corner of the eyes, and the inner corner of the eyes are detected as feature points. Irregular position $P_g = (x_g, y_g)$ was calculated by Eq. (2).

$$x_g = \sum_i \{i \times g[i,j]\} / \sum_i \sum_j g[i,j] \,, y_g = \sum_j \{j \times g[i,j]\} / \sum_i \sum_j g[i,j] \tag{2}$$

Also, the corner coordinates of both ends where g $[i, j] = 1$ within the process area are obtained at the corner of the outer and inner corners of the eye, and the positions of the outer corner position and inner corner of the eye are determined.

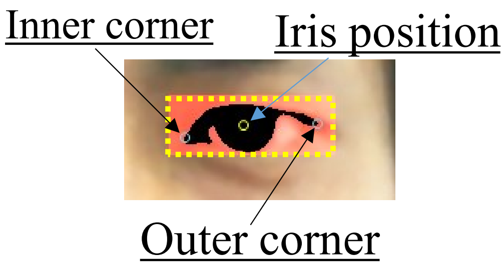


Fig. 1 Noise elimination method

2.2 Recognition

In this system, the upper and lower eyelids are approximated by a Bezier curve, and the gaze direction is recognized using the curvature of the curve. The Bezier curve of the nth order is defined by $(n + 1)$ control points $Pi = (x_i, y_i)$, and the trajectory $P(u)$ is expressed by next equation.

$$P(u) = \sum_{i=0}^{n} B_i{}^n(u) P_i \tag{3}$$

Where, $B_i{}^n(u)$ is given by Eq. (4).

$$B_i{}^n(u) = \frac{n}{n-1} u^i (1-u)^{u-1} \tag{4}$$

The domain of the parameter u is [0, 1]. Bezier curve always passes through both ends $P_0 = (x_0, y_0)$ and $P_n = (x_n, y_n)$ of the control point. Here, approximation of the shape of the eyelids is performed by using a cubic Bezier curve. In this system, the coordinates of the eye iris $P_{pl/pr} = (x_{pl/pr}, y_{pl/pr})$, the outer corner $P_c = (x_c, y_c)$, and the inner corner $P_h = (x_h, y_h)$ are acquired. After binarization, shape of the eyelids is approximated as a Bezier curve by defining the control points of the upper and lower eyelids respectively on the x-axis at both ends of the iris with the corner of the eye and the end of the eyes as the end points, as shown in Fig. The curvature K of the Bezier curve is expressed by the following equation.

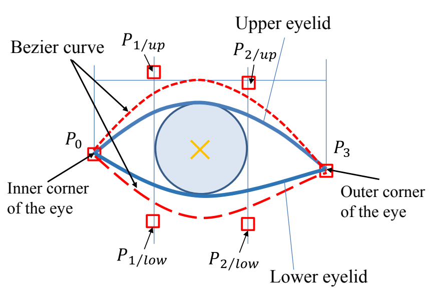


Fig.2 Iris and corner detection

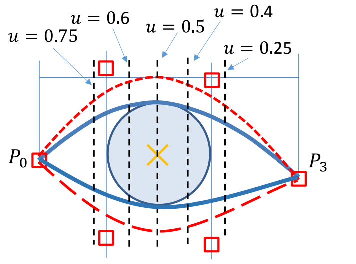


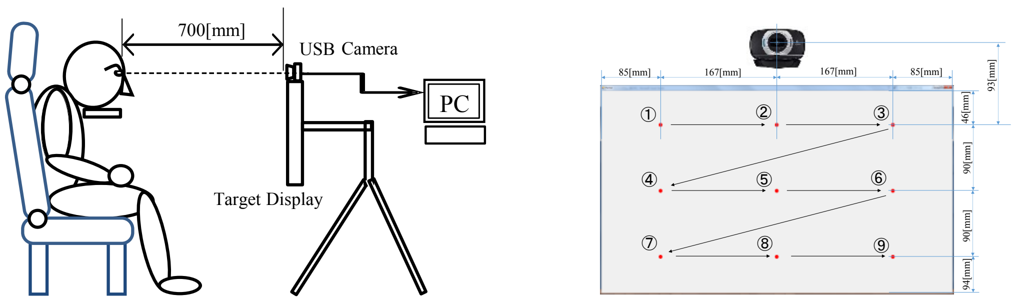
Fig.3 Position of parameter *u*

$$K = \frac{B'_x(u)B''_y(u) - B''_x(u)B'_y(u)}{\left[\{B'_x(u)\}^2 + \{B'_y(u)\}^2\right]^{3/2}} \tag{5}$$

The curvature varies depending on the position of the parameter u as shown in Fig.3. In this system, the curvature K obtained by u = 0.75 and u = 0.5 of the Bezier curve approximating the upper eyelid was obtained, and the gaze direction was recognized. Here, experimental system was shown in Fig.4. The change in the value of the curvature K when looking at the red circle shown in Fig.4 (a) on the display with the camera installed at the top is shown in Fig.5. The relationship between the values of the two curvatures is as shown in Fig.6. Focusing on the region when staring at the same row, the value changes like a linear function. Here, the average value of the curvature K of each region is plotted with a red point, and three points showing the average value corresponding to the same column are linearly approximated by a linear function and indicated by a red line. In addition, the equations linearly approximated in the figure are shown. It can be confirmed that the slope of the linear function is close to the three columns from the equation. First, on the curvature coordinate plane, a reference point for recognizing the line-of-sight direction is determined by the following procedure.

1. Calibration of the upper, lower, left, right, center of the line of sight direction, and finds the slope of the linear function passing through the upper and lower reference points with these points as reference points
2. Translate the calculated slope by the left and right curvatures
3. Based on the change amounts of the curvatures of the middle row and the upper and lower rows in the middle column, the reference points of the upper and lower rows of the right and left columns are determined

The inter-coordinate distance between each reference point and the latest four frames and the current curvature, the average value of five data in total is calculated. The reference point of the



(a) Experiment scene (b) Gazing targets

Fig.4 Experiment system

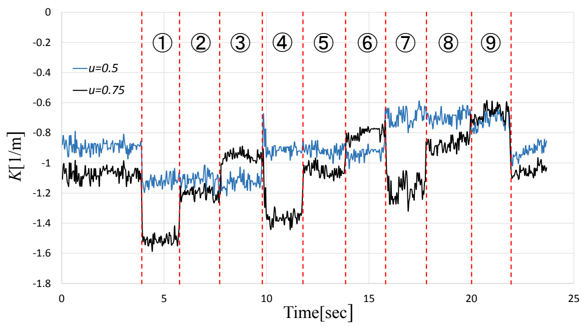


Fig.5 Time series of data of parameter K

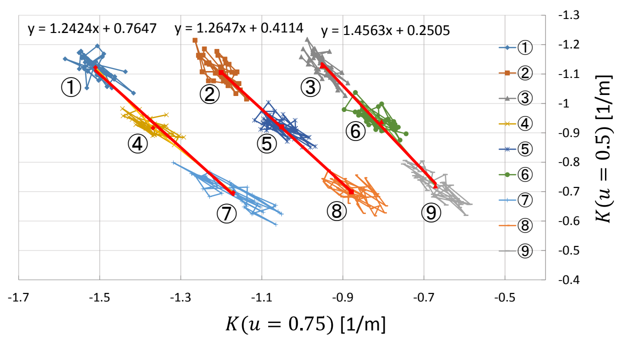


Fig.6 K(u=0.5 and u=0.75) of Scatter plot shortest distance is recognized as the line-of-sight direction.

3. Operation of communication aid

3.1 System

The outline of this system is shown in Fig.7. Facial image is obtained by USB camera, image processing is performed near the eyes, and the shape of the eyelid is approximated by a Bezier curve. After that, it becomes possible to recognize the gaze direction by performing the calibration. In this mode, if you move around the gaze as the center, it becomes the communication mode. In this mode, as shown in Fig.8, when staring at the button arranged in the direction, the word written on the button is pronounced. The progress bar placed under the button indicates the fixation time, and the operation is performed when the progress bar is satisfied.

3.2 Experiment and results

The subject sat on a chair at a position about 700 [mm] away from the camera and operated the system. Subjects moved their gaze to the button instructed from gaze of the center in the signal of the experimenter and continue gazing until the progress bar gathered. In order to get used to the operation of this system, subjects practiced for about three minutes before measurement. The subjects were ten alumni students and the operation was performed with the right eye. Operation time was measured in each trial and its results are shown in Tab.1. As a result of experiments, many subjects completed operation of each button within five seconds. Among them, many subjects started to read out words from two second level to the early 3 seconds range. On the other hand, some subjects took more than 10 seconds to complete the operation. The cause is that the line of sight shifts to the buttons other than the gazing button, the recognition is not performed correctly because

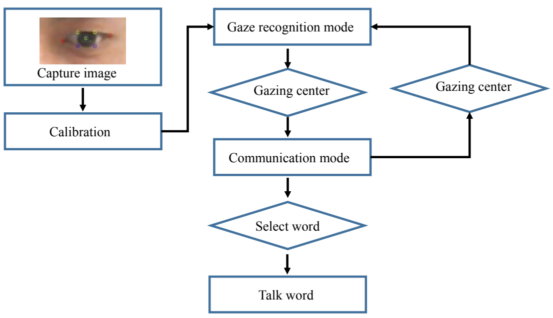


Fig.7 Iris and corner detection

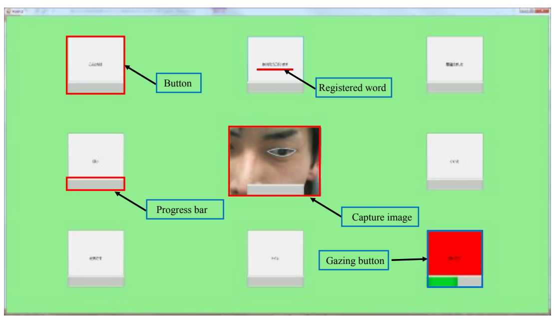


Fig.8 Communication tool

Tab. 1 Operation time (Unit: seconds)

	Up	Bottom	Left	Right	Left-Up	Right-Up	Left-Bottom	Right-Bottom
a	2.85	3.74	2.66	5.65	3.20	2.82	5.00	3.45
b	2.73	4.11	4.83	2.38	11.98	2.60	3.70	5.40
c	2.67	3.04	4.90	2.61	3.63	5.93	3.93	3.21
d	2.72	2.83	5.18	8.53	3.21	2.68	7.83	4.43
e	2.66	2.93	2.75	2.95	2.63	2.85	2.70	2.87
f	3.10	2.67	5.00	3.80	2.78	2.83	6.21	2.98
g	2.70	2.87	4.21	2.51	7.83	2.78	2.90	3.05
h	3.56	2.91	2.45	3.10	3.05	3.00	3.84	2.83
i	2.90	2.90	5.68	3.42	3.15	3.40	3.06	2.85
j	3.26	3.68	3.16	2.75	2.70	2.71	3.03	3.15
Ave.	2.92	3.17	4.08	3.77	4.42	3.16	4.22	3.42

the face is deviated after the calibration, the recognition of the staring fixation button becomes unstable and the progress bar becomes And misrecognize that gazing at another button before being satisfied. From the experiments it was shown that it is possible to recognize diagonally by five times calibration. Also, the average operation time of each button is five seconds or less and fast responsiveness was shown.

4. Conclusions

In this study, the shape of the eyelid was focused on, the approximation by the Bezier curve is performed, and its curvature is used for state judgment of the gaze direction. In this case, we constructed a system that limits the conditions of the distance from the USB camera to the face and the magnification ratio of the acquired image, and enables visual line recognition by performing simple calibration. In the developed system, it is possible to recognize gaze in upward, downward, leftward, rightward and oblique directions, and it was applied as an operation interface of a communication support system. In the experiment verifying the effectiveness of the system, many subjects were able to perform the desired operation in a short time and showed quick responsiveness.

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