

Figure 2: Position of the electrodes

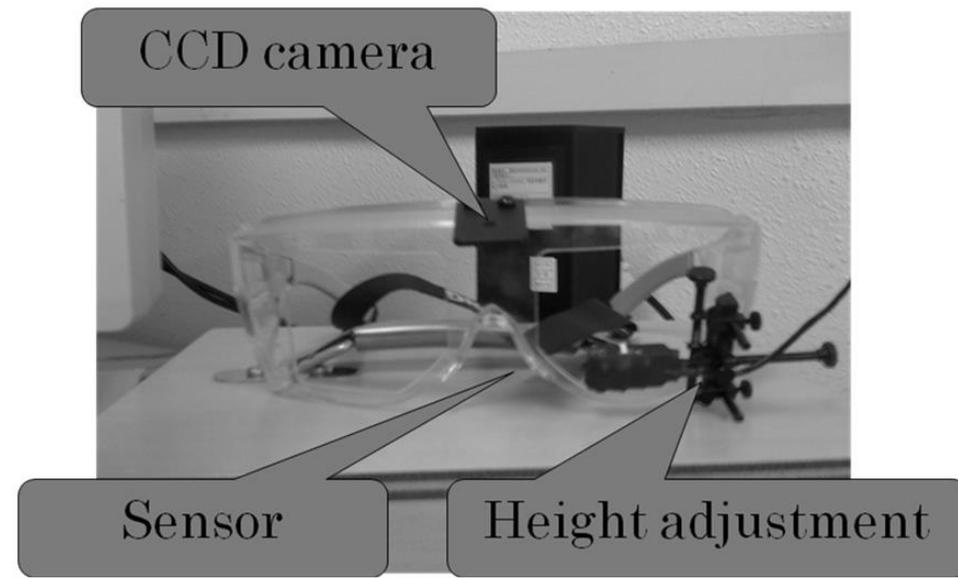


Figure 3: Goggle

3. RESULTS AND ANALYSIS

3.1. Estimation of viewpoint direction

Figure 4 shows an electro-oculogram waveform when the eyes were moved in order of right, center, left, center, up, center, down, and center. When it turns back to the right from this, it changes in the direction of (+) \rightarrow (-) \rightarrow (-) \rightarrow (+) in ch 1, whereas in ch 2 the opposite (-) \rightarrow (+) \rightarrow (+) \rightarrow (-) direction. Similarly, when looking in the left, up, and down directions, it is possible to distinguish the upward,

downward, leftward and rightward directions from the eye potential by combinations of waveforms obtained from ch 1 and ch 2.

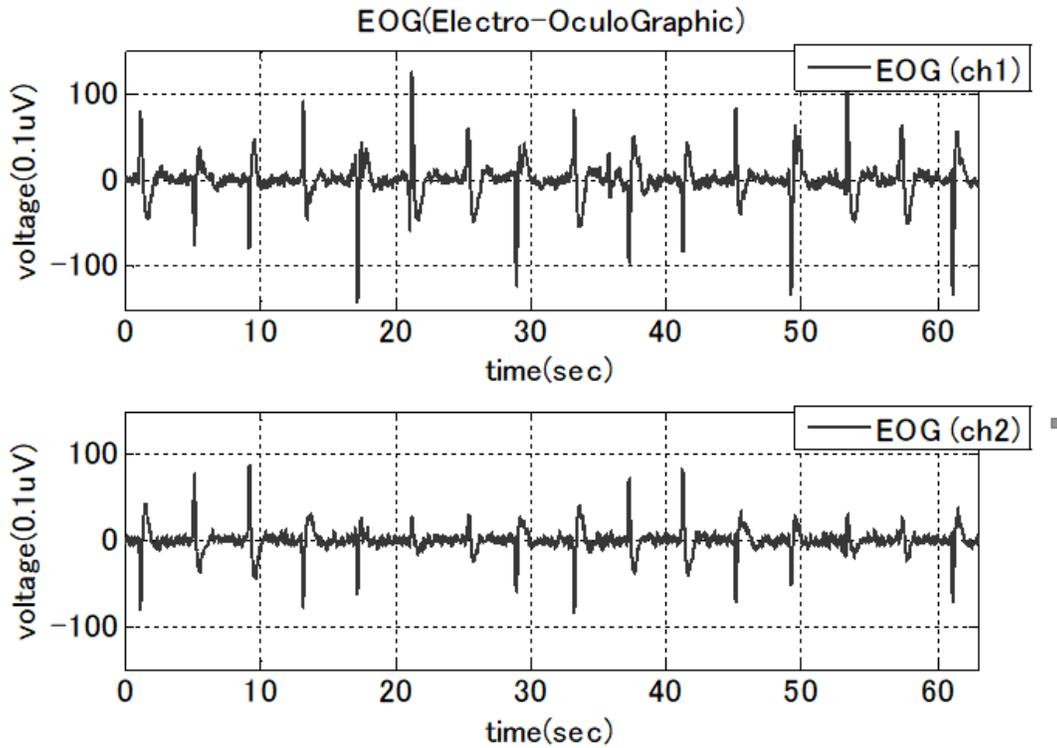


Figure 4: EOG signal (LPF = 6Hz).

3.2. Relationship between EOG and viewing angle

Since the output of the EOG is the amount of change, we plot the difference from the point where the slope changes from plus to minus, or from minus to plus before peak. The result in the upward direction is shown in Figure 5, the result in the downward direction is shown in Figure 6, the result in the right direction is shown in Figure 7, and the result in the left direction is shown in Figure 8.

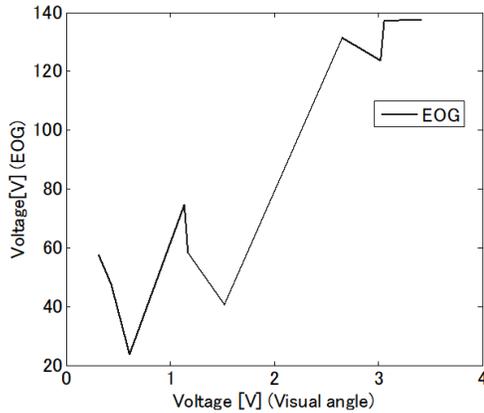


Figure 5: Look at up

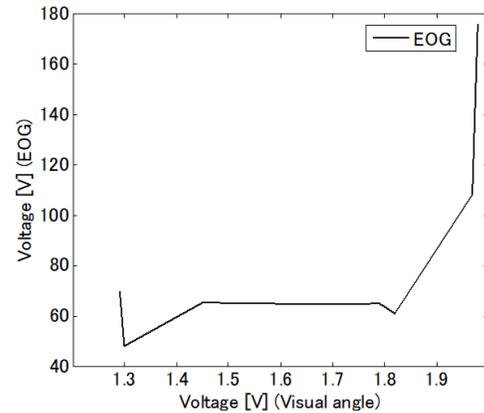


Figure 6: Look at down

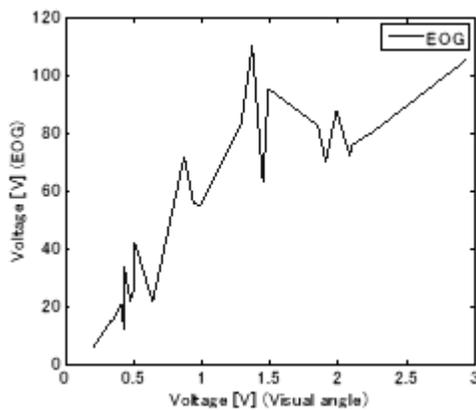


Figure 7: Look at right

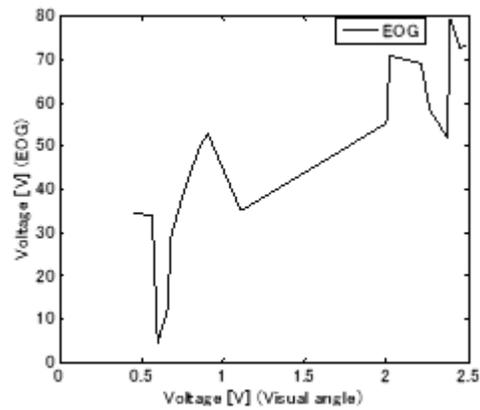


Figure 8: Look at left

From these results, the eye potential increased as the viewing angle increased, but there was a large variation due to the small amount of data. Also, as shown in Figure 9, it was difficult to associate when the target point could not be seen at one time. Therefore, correspondence was made using the integration result. At the time of visual observation, the difference between the integral value at the point where the sign of the slope of the differential value changes immediately before the eye potential exceeds the threshold and the difference between the peaks of the immediately following integration results are compared.

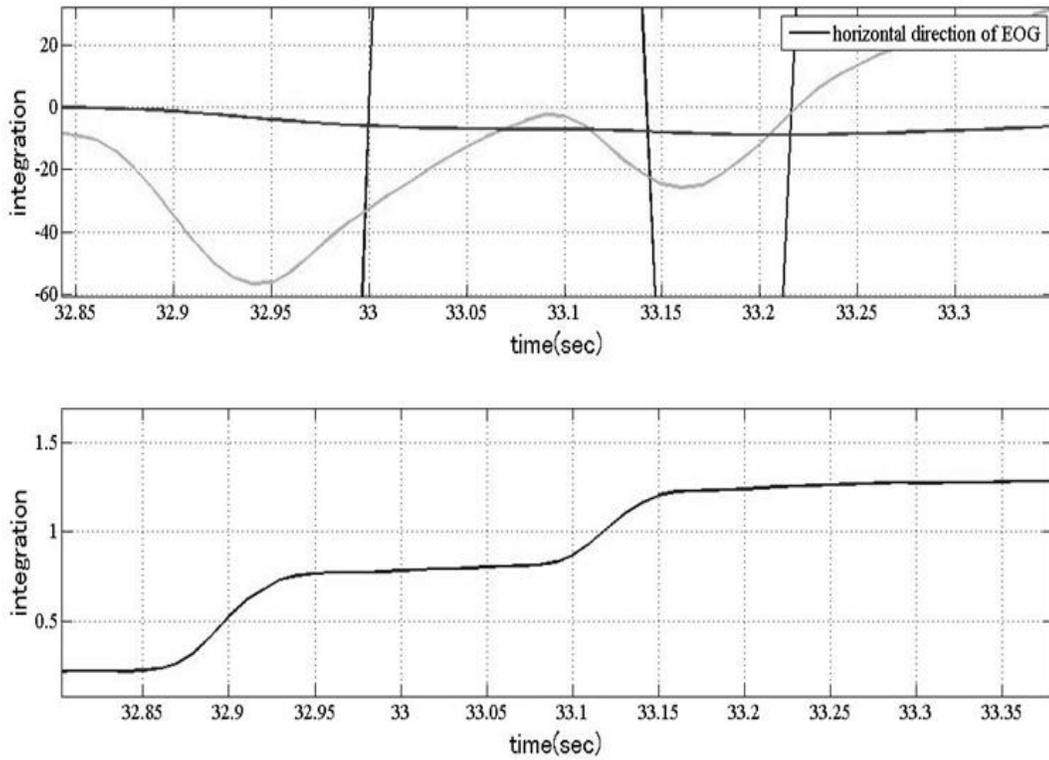


Figure 9: Look at right

The results of visual observation in the upward direction and the linear approximation by the least squares method are shown in Figure 10. Similarly, the result in the downward direction is shown in Figure 11, the result in the right direction is shown in Figure 12, and the result in the left direction is shown in Figure 13.

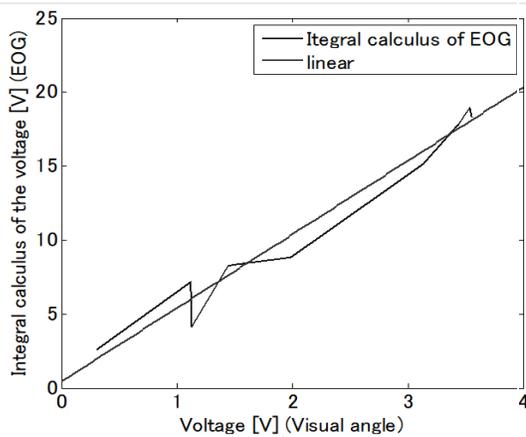


Figure 10: Look at up

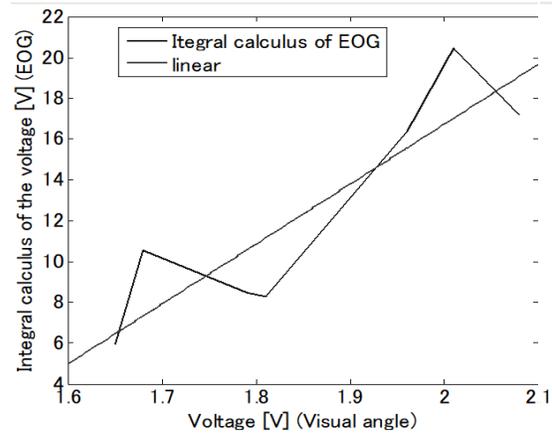


Figure 11: Look at down

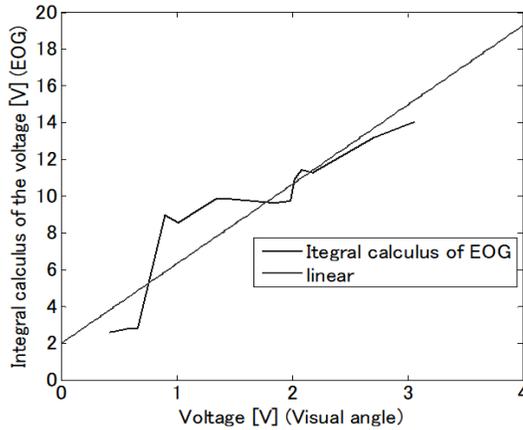


Figure 12: Look at right

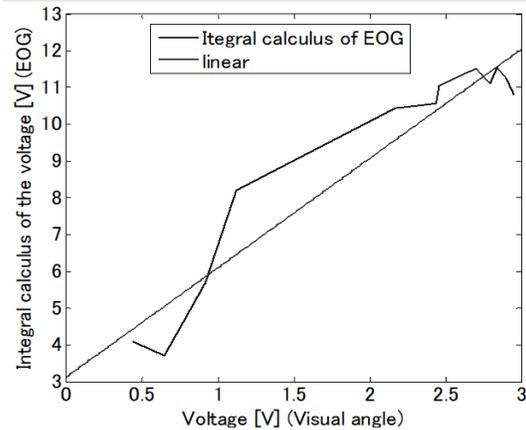


Figure 13: Look at left

As a result, even if linear approximation was performed by the least squares method in all viewing directions, some degree of linearity was observed. The approximate expression now is given by:

Right direction: $y = 4.32x + 2$

Left direction: $y = 2.98x + 3.12$

Upward direction: $y = 4.96x + 0.47$

Downward direction: $y = 29.37x - 42.01$

Next, experiments are carried out using these results.

3.3. Experiment of Direction Estimation from EOG

Using the experimental system shown in Figure 1, the EOG and viewing angle at the time of viewing the upper, lower, left and right directions were simultaneously measured. The results were then input to an analysis program created in C ++, and the relation between them was examined from the eye recognition potential, visual recognition rate, program output and actual view angle. Also, experimental conditions are set as follows:

1. It is up, down, left, right, and four directions.
2. Do not blink.
3. After visual observation, move on to the next operation after a while.

From past research, we used a region of saccadic motion with visual speed of 100 (deg / sec) or more and a viewing angle of 5 to 45 degrees [1].

3.3.1. Program Specification

The program was specified as follows:

- When the voltage of ch1 and ch2 exceeds the threshold value ($\pm 20 \mu\text{V}$) there was visual recognition.

- When the threshold value was exceeded, the time goes back and the integral value of the EOG at the point where the sign of the differential value of the eye potential changes was set as the reference point.
- From the point of exceeding the threshold, the integral value of the point where the sign of the integral value of EOG changed for the first time was the peak.
- Set the dead zone for 1 second from the peak of the integral value.
- Substitute the difference between the peak of the integrated value of EOG and the reference point in the approximate expression.

3.3.2. Visual recognition and direction recognition rates

Right: 13 out of 14 successes → 93%

Left: 12 out of 14 successes → 86%

Top: 11 out of 11 successes → 100%

Down: 10 out of 11 successes → 91%

The visual direction could be recognized 47 times out of 50 times, and it was 94% of the prevalence rate. In addition, even though the visual observation was not performed, the number of times of recognition was 2 times. From this result, it can be said that sufficient direction determination is possible by this method.

3.3.3. Relationship between EOG and visual angle

Figure 14 shows the calculated result of the EOG and the actual visual angle when viewing the upper direction. Similarly, the result in the downward direction is shown in Figure 15, the result in the right direction is shown in Figure 16, and the result in the left direction is shown in Figure 17. Although there are variations, values close to the actual viewing angle were obtained in all the directions of up, down, left, and right.

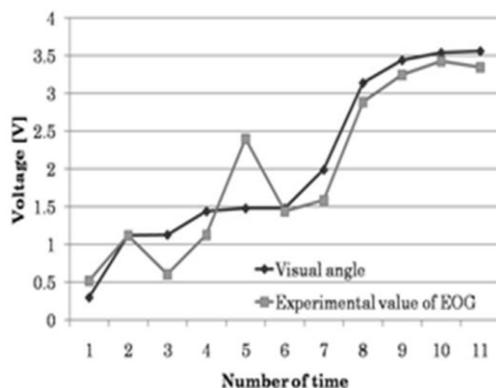


Figure 14: Look at up

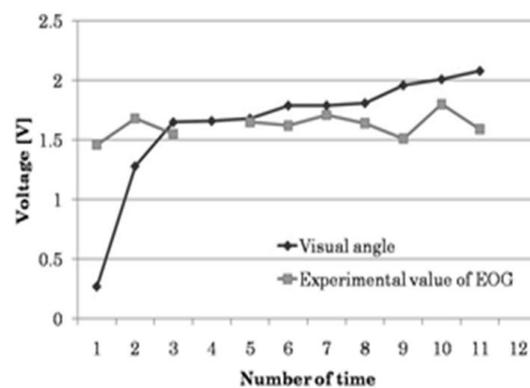


Figure 15: Look at down

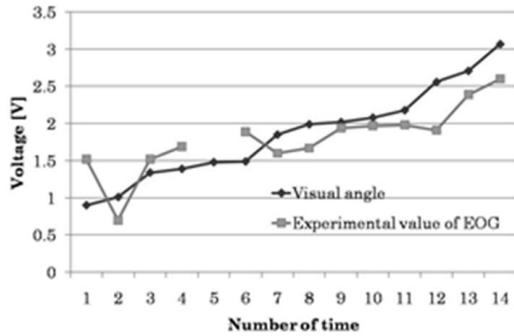


Figure 16: Look at right

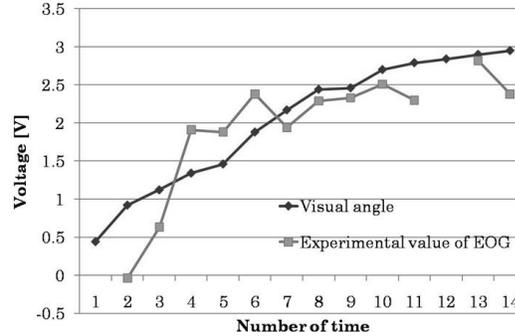


Figure 17: Look at left

3.4. Experiment of Direction Estimation from EOG

Using the program to measure and analyze in real time, we examine whether it is possible to discriminate the direction of the top, bottom, right, and left directions, and to associate the EOG with the visual angle.

In Experiment 1, the EOG low-pass filtered and its differential calculation result are prepared in advance, but in Experiment 2, these calculations need to be performed simultaneously while acquiring data.

First, the transfer function used for the low-pass filter is defined as equation (1).

$$H(s) = \frac{4\pi^2 f^2}{s^2 + 4\pi f \cos \frac{\pi}{4} s + 4\pi^2 f^2} \quad (1)$$

$f = 6$ Hz (cutoff frequency)

In addition, the differential is obtained by taking the difference between the current eye potential and the immediately preceding eye potential and using the trapezoidal integral method for integration. Under these conditions, four sets of up, down, left, right and 10 vision operations were performed for 10 times in total.

3.4.1. Relationship between EOG and visual angle

Right: 82 out of 100 successes \rightarrow 82%

Left: 70 out of 100 successes \rightarrow 70%

Above: 83 out of 100 successes \rightarrow 83%

Bottom: 48 out of 100 successes \rightarrow 48%

Although it was easy to recognize in the right direction and the upward direction, it was difficult to recognize the left direction and the downward direction. So, there were variations depending on the

direction. For this reason, I would like to consider improvements by not changing all thresholds, but by changing direction, etc. Also, if you did not concentrate then the measurement of electro-encephalopathy did not occur as expected, and the results varied depending on the degree of electrode attachment. In this experiment, data was handled only in the condition of good condition, but a method to always handle the eye potential under the same condition was necessary.

3.4.2. Error in Relationship between EOG and visual angle

Although the cause is still unknown, and yet the loop is fine, calculation is terminated halfway throughout the program, and it was almost impossible to obtain the integration result. It seems that there is a problem with measurement method etc.

3.5. False recognition due to blink

Examine the effect on eye potential when lightly blinked and strongly blinked. If it was weakly blinked, there was no effect on direction determination. However, when we blinked strongly, there was misrecognition in the direction discrimination. The result of false recognition obtained by turning blink 100 strongly is shown in Table 1.

From this result, it was found that in most cases it was erroneously recognized as the upward direction. This was because, as shown in Figure 18, the eye potential when viewing in the upward direction and the eye potential when blinking was similar.

Table 1 Direction of blinking versus number of blink times

Direction	Number of times
Rightward	7
Leftward	6
Upward	79
Downward	8

Since everyday unconscious blinking blinks are weak, so it is unlikely that it affects the eye potential. To reduce the false recognition more, it may be necessary to respond by measuring the myoelectric potential at the same time unknown.

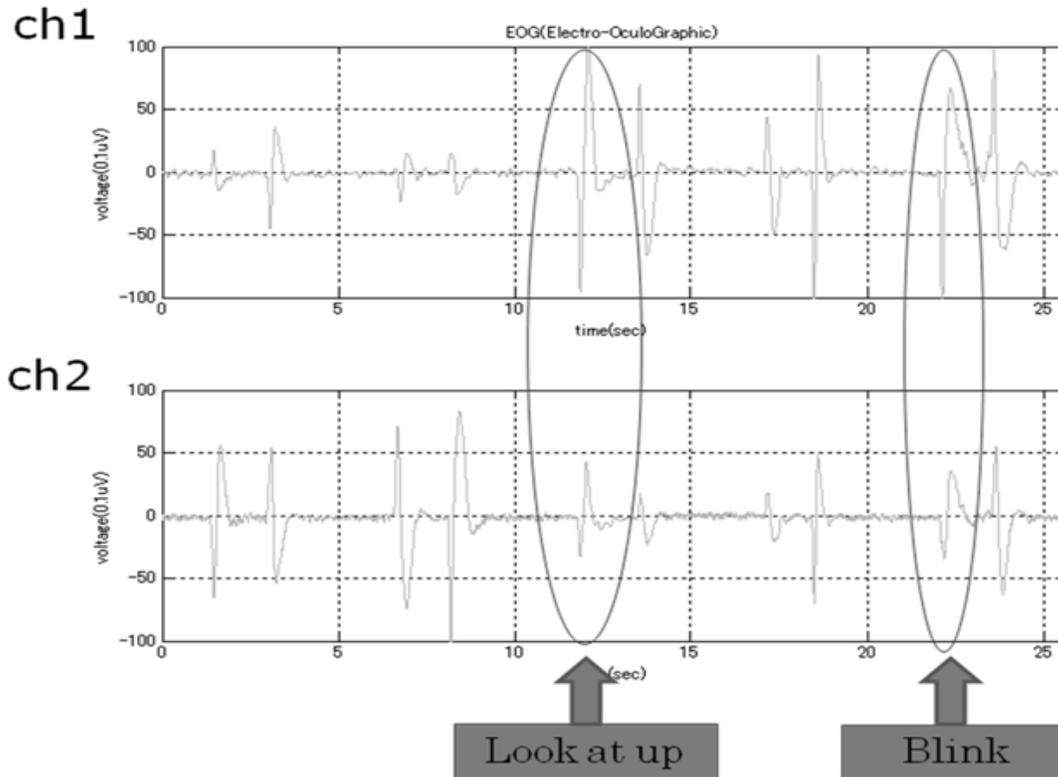


Figure 18: Misrecognition of EOG

4. CONCLUSION

In this study, attention was focused on the electro-oculogram for the biomedical signal. The electro-oculogram generated when viewing the up-down and left-right directions was correlated with the visual angle measured by using the view angle measuring apparatus, and the electro-oculogram signal was input as the position.

Basic studies on the feasibility of the man-machine interface to be used were made, and the following knowledge was obtained: First, because of experiments in the up, down, left, and right directions, the visual direction was judged to be a precise value of 94%. Also, by using the integration result, it was impossible to point the target point at once, and even if it reached the target point by going through the saccade movement more than once, it could respond. We further observed that the relationship between the EOG and the visual angle could be associated to some extent by linearly approximating the integration result of the electro-oculogram, and the EOG can be used as the position signal. In the case of direction discrimination in real time, it was 82% in the right direction, 70% in the left direction, 83% in the upward direction and 48% in the downward direction. Lastly, regarding misrecognition due to

blinking, we made a conclusion that there was a possibility that eye EOG will be generated and blindly recognized when blinking strongly. However, there was no problem because there was no misrecognition at normal blinking.

The possibility of man-machine interface development with position input of electro-oculogram signal was investigated. Based on the findings obtained in this research, we will promote the development of a man / machine interface such as a mouse pointer.

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