Development of an Eyewear to Measure Eye and Body Movements*

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***Abstract*— To enable precise detection of mental and physical states of users in a daily life, we have been developing an eyewear to measure eye and body movement in a unrestricted way. The horizontal and vertical EOG (electrooculogram) signals are measured and amplified with three metal dry electrodes placed near nasion and both sides of rhinion, of which positions correspond to the bridge and nose pads of eyewear, respectively. The user's mental states like drowsiness, sleepiness, fatigue, or interest to objects can be identified by the movements and blinking of the eyes extracted from the measured EOG. And the six-axis motion sensor (three-axis accelerometer and three-axis gyroscope) mounted in the eyewear measures the body motion. As the sensor located near the head is on the body axis, this eyewear is suitable to measure user's movement or shift of center of gravity during physical exercise with a high precision. The measured signals are used to extract various events of eye and body movement by the mounted microcontroller chip, or can be transmitted to the external devices via Bluetooth communication. This device can enable you to look into "yourself", as well as outer scenes. In this presentation, the outline of the eyewear is introduced and some possible applications are shown.**

I. Introduction

Observing mental and physical states of humans in daily life can help us to improve safety and efficiency. It is quite important for car drivers or system/machine operators to alarm to their dangers by detecting their drowsiness and mental fatigue in advance. And for office workers, breaks should be taken according to the mental states to improve the performances and to keep their health.

For such a purpose, methods to extract human's mental states from biosignals (e.g. EEG, EMG, ECG, EOG) have been studied extensively for many decades. A lot of results showing possibilities to detect mental states, e.g. drowsiness or mental fatigue, lack of attention, sleep, from biosignals during daily activities have been reported (e.g. [1]).

It is also interesting to measure human's physical states, e.g. movement, posture, or variation of the center of gravity of the body, calorie consumption due to physical practice. Recently the developments of wearable sensor systems have attracted interests [2], and many concepts or sensor systems have been opened in public.

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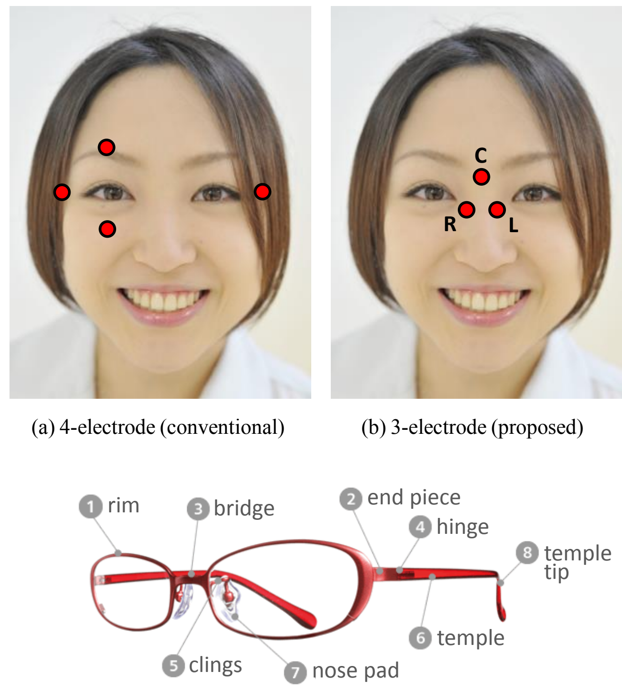

Figure 1. Electrode locations for EOG measurement and names of eyewear parts.

The eye is the windows of the heart. The eyes are as eloquent as the tongue. As many proverbs pointed out, the mental states are reflected in the movement of eyes. To extract user's mental states or intentions, brain-computer interface (BCI) has been studied (e.g. [3]). However, a few or many sensors or electrodes should be placed on the scalp of the user's head to measure brain activities. It makes BCI not easy to apply to users in a daily use.

To extract user's mental and physical states in a daily life easily, the authors has been developing an eyewear with a capability to measure user's eye and body movement. In this paper, the outline and the basic performance of the developing system are described.

II. EOG Measurements by Three Electrodes

In the conventional method, EOG is measured by using four electrodes. Two electrodes are placed to outer edges of the right and left eyes to measure horizontal EOG, and vertical EOG is measured by two electrodes placed on the top and bottom parts of one of the eyes (Fig 1(a)). The horizontal and vertical EOG are amplified bipolarly to monitor movements of eyeballs. However, this placement is not suitable cosmetically for daily use, because the electrodes and lead wires are located to the center of the face.

Figure 2. A prototype eyewear (JINS MEME)

To enable the cosmetically acceptable wireless EOG measurement in a daily life, we propose the new method to place the electrode for EOG measurement [4]. On this method, three electrodes are used to measure EOG (Fig. 1(b)). One electrode (C) is located near nasion, and the other two electrodes (L and R) are placed on left and right sides of rhinion, respectively.

When a reference electrode is placed to the temple tip to attach to the back of the upper side of the auricle, and the voltages at electrodes C, L and R are measured monopolarly (V_C, V_L and V_R), the horizontal and vertical components of the EOG (V_h and V_v) can be obtained by the following formulas. (Movements of the eyeballs rightward and upward result in positive V_h and V_v values, respectively.)

$$V_h = V_L - V_R \quad (1)$$

$$V_v = V_C - (V_L + V_R)/2 \quad (2)$$

Or when the electrode C is used as a reference, and the voltages at electrodes L and R are measured bipolarly ($V_L{}'$ and $V_R{}'$), V_h and V_v can be defined as follows.

$$V_h = V_L{}' - V_R{}' \quad (3)$$

$$V_v = -(V_L{}' + V_R{}')/2 \quad (4)$$

As the locations of the electrodes C, L and R correspond to the place of parts of eyewear: bridge, and left and right sides of nose pads, respectively (Fig. 1(c)), this arrangement system is suitable to mount to eyewear.

In this paper, the results based on bipolar measurement (Eqns (3) and (4)) are shown.

III. The Prototype Eyewear

The prototype eyewear was developed to realize the wireless measurement of eye and body movements (Fig. 2). The prototype eyewear consists of the following parts.

A. EOG electrodes

Three metal electrodes were placed to the bridge and both sides of eye pads (Fig. 2). For daily use of this equipment, these electrodes were designed to use as dry electrodes and no need to use electrode gel or paste.

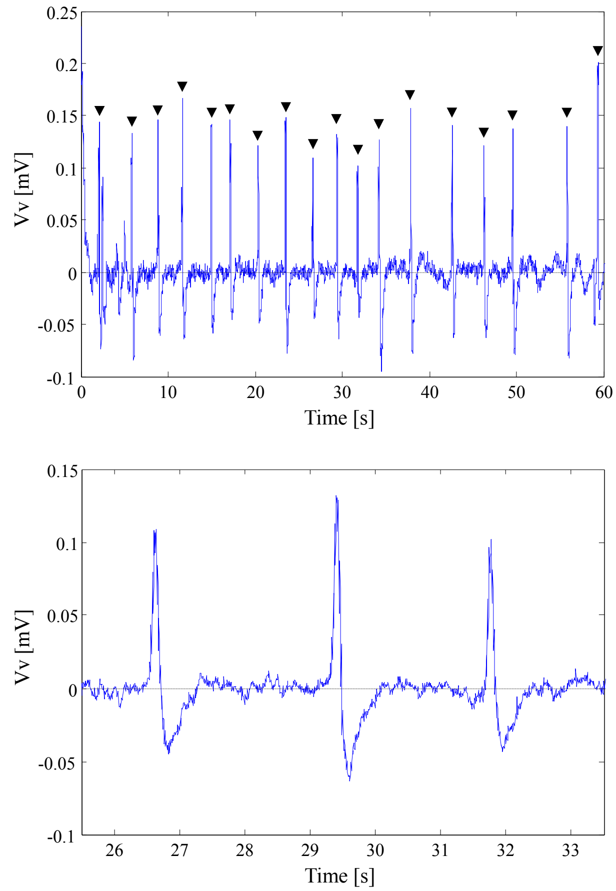

Figure 3. Measured vertical EOG (V_v) during eye blinks. Triangles detnote the timings of events of eye blinks detected from measured data (upper). Enlarged view of the measured signal (lower)

B. EOG amplifiers

After removing DC components, EOG was amplified by using operational amplifiers. The gain of the amplifier was set to 1000. The amplifier unit was in a small box located between the electrode C and bridge to shorten the lead wires from electrodes to amplifiers for minimizing the contamination of external noises.

The DC component of EOG has rich information to extract fixation points of the eyes [5]. On the other hand, frequent calibrations to remove observed DC drifts are needed to amplify small amplitude of DC signal. To realize stable amplification without calibrations, the AC mode EOG was adopted in this system. The AC mode EOG contains enough information to extract direction or distance of the eye gaze with high accuracy [6].

C. Six-axis motion sensors

To detect user's body movement, six-axis motion sensors (three-axis accelerometer and three-axis gyroscope) were mounted on this system. It can be used to detect various kinds of information on user's body movement, e.g. posture and move of center of gravity during locomotion or physical exercises.

Time [min]			Subject 1				Subject 2				Subject 3				Subject 4				Subject 5			
			TP	FP	FN	Rate [%]	TP	FP	FN	Rate [%]	TP	FP	FN	Rate [%]	TP	FP	FN	Rate [%]	TP	FP	FN	Rate [%]
0	-	1	18	0	0	100.0	6	5	0	54.5	9	0	0	100.0	11	0	0	100.0	14	4	0	77.8
1	-	2	15	0	0	100.0	7	1	0	87.5	5	0	0	100.0	15	0	2	88.2	14	0	2	87.5
2	-	3	18	0	0	100.0	6	0	1	85.7	6	0	0	100.0	6	0	1	85.7	12	0	3	80.0
3	-	4	17	0	0	100.0	9	0	0	100.0	6	0	0	100.0	10	0	2	83.3	12	1	0	92.3
4	-	5	19	0	0	100.0	20	1	1	90.9	5	0	0	100.0	14	0	2	87.5	9	0	0	100.0
5	-	6	18	0	0	100.0	11	0	0	100.0	8	0	0	100.0	13	0	2	86.7	12	1	1	85.7
6	-	7	15	0	0	100.0	15	0	0	100.0	6	0	0	100.0	20	0	3	87.0	13	0	0	100.0
7	-	8	18	1	0	94.7	21	0	0	100.0	9	0	0	100.0	30	0	0	100.0	12	1	0	92.3
8	-	9	17	0	0	100.0	21	0	1	95.5	5	0	0	100.0	33	0	4	89.2	10	1	0	90.9
9	-	10	13	0	0	100.0	24	0	1	96.0	6	0	0	100.0	22	0	3	88.0	13	0	0	100.0
Total			168	1	0	99.4	140	7	4	92.7	65	0	0	100.0	174	0	19	90.2	121	8	6	89.6

Table 1. Accuracy of eye blink detection by eyewear.
TP: true negative, FP: false positive, FN: false negative, Rate = TP/(TP+FP+FN)

D. Microcontroller

The microcontroller chip was mounted on this eyewear to control the whole system including AD converter and Bluetooth transmitter. I can also be used to analyze data in real time, e.g. the detection algorithm of eye blinks can be embedded to the microcontroller.

E. AD converter and transmitter

Analog-to-digital conversion was applied to the amplified EOG and the output of motion sensors. The sampling frequency was 133 Hz, and accuracy was 12 bits.

The acquired digital data can be transmitted to PC or smart phones by Bluetooth LE.

IV. EOG Generated by Eye Blinks

The EOG during eye blink was measured, and the events of eye blink were detected from the components V_h and V_v.

A. Measurement of EOG during eye blinks

Fig. 3 shows the typical measured EOG during eye blinks. The upper figure shows the time course of the vertical component of the EOG (V_v), and the lower figure is its enlarged view.

It is known that the eyeball moves upwards and suddenly moves back to the original position (Bell's phenomenon [7, 8]). By such a rapid movement of eyeball, a rectangle pulse is observed in the vertical DC EOG signal, and the horizontal signal is not changed. In case of the EOG measurement on AC mode, the rectangle pulse is observed as a pulse with a positive peak which is followed by the negative one (Fig. 3).

B. Detection of eye blinks from EOG

The timings of the eye blink were detected from the obtained components V_h and V_v.

Considering the applicability in daily use of the eyewear, the machine learning algorithm was not adopted. To detect the temporal changes of V_h and V_v, the value and latency of the peaks of the signal were evaluated, and the events of each eye blink were detected if the evaluated conditions met the certain criteria.

Five subjects with normal vision took part in the experiment. During experiment, each subject sit on a chair was requested to gaze to a fixation point and stay relaxed for 10 minutes. The EOG was measured by the eyewear and the video of the subject's face was taken simultaneously. From a video image, the actual timings of the eye blinks were obtained manually. This study was reviewed and approved by the Ethics Committee on Clinical Investigation, Shibaura Institute of Technology. All subjects provided written informed consent.

The triangles shown in the upper figure in Fig. 3 denote the events each of which was detected as an eye blink by the above algorithm and the eyes were actually blinked (i.e. true positives). From Fig. 3, it was shown that the detection algorithm worked well.

Table 1 shows the accuracies of eye blink detection by all subjects. The number of true positives (TPs), false positives (FPs) and false negatives (FNs) of each subject are shown for every one minute. From this table, the accuracies of eye blink detection were 89.6 to 100% and were enough for practical applications.

V. EOG Related to Eye Gaze

The EOG response to the movement of eye gaze was measured. Fig. 4 shows the EOG responses to the eye gaze movement to up, down, right and left. One of the EOG components is shown for each of the EOG responses (V_v for up and down, V_h for right and left).

This subject was requested to gaze to the fixation point in front of the face, move the eye gaze to each direction rapidly without moving his head and fix it for a short moment, and move back to the fixation point. The visual angle of the eye gaze movement was approximately 10°.

It was shown that the onset (move from fixation point) and offset (move back to fixation point) of the eye gaze movement

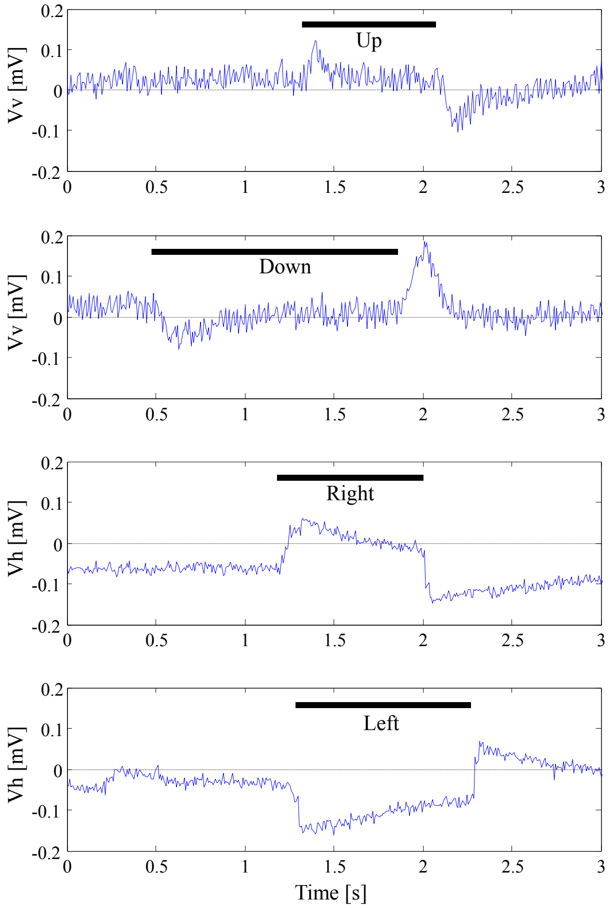

Figure 4. Measured vertical EOG (V_v) during eye blinks. Triangles detnote the timings of events of eye blinks detected from measured data. (upper). Enlarged view of the measured signal (lower)

resulted in the sudden changes of the EOG components of corresponding direction of the eye gaze.

VI. Discussion and Conclusion

In this paper, the eyewear being developed to measure and detect eye and body movement was reported. The eye movement was detected from EOG which could be measured by three dry electrodes, which can be placed on user's face just by wearing the eyewear. This system can also measure a body movement by six-axis motion sensor. (The detailed description of the motion sensor part will be presented elsewhere.)

To detect user's mental and physical states in daily living, it is necessary to measure signals without restricting the user's activities. And the rapid preparation to place the electrodes or sensors without using electrode gel or paste, or adhesive plaster is quite necessary. This system can be used just by wearing the eyewear, and it will open a new vista to measure user's mental and physical states.

It is expected that the present system can be used to detect user's mental and physical states in various scenes in the daily living. If the drowsiness, sleepiness and fatigue of car drivers or machine operators can be detected in advance, it can be used to reduce car accidents or serious injuries due to machine operations. It can also be used to reduce overworking of officers. It will contribute to increase the officer's concentration to their works, and improve the quality of office works.

Moreover, the eye gaze is reflected by the user's cognitive states, e.g. interest or mental concentration. Many systems have been developed to detect user's interests to object in real time. The proposed system might be used for the purpose of neuromarketing by easy-to-use and cheaper way.

EOG measurement is also expected to use in the medical and healthcare purposes. As many kinds of mental and physical diseases reflect in eye movements, real-time measurements and analysis of EOG can contribute to observe and diagnose such diseases.

The motion sensor can be applied to the real-time detections of movement, posture, or variation of the center of gravity of the body, calorie consumption due to practice. It can contribute to increase the performances of sports players or to improve the effects of rehabilitations of paralyzed patients. As on the present system, the motion sensor is located on the trunk of the body, more precise body movement can be measured than the sensor system placed on the feet or hands.

The improvement of signal measurement, and algorithms to detect eye blinks, gaze and various features of eye movements are further study. The developing system "JINS MEME" will be commercially available soon from JIN Co., Ltd. [9]

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