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Real-time Estimation System of Gaze Angle Based on Electrooculogram

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Abstract: This paper describes an online eye-tracking method based on electrooculogram (EOG) to estimate gaze angle. The objective is to use biomedical signal EOG as the input of human-machine interface for both disabled and healthy people. In this study, a quadratic function is applied to set the relation between EOG and gaze angle. The estimated gaze angle is decided by three EOG channels with maximum amplitude after compensating shift and smoothing. The results of real-time estimation showed high accuracy, which makes it possible in many application fields, such as assistance robot control, online word processor and so on.

Keywords: electrooculogram, gaze angle, tracking target, real-time estimation**.**

I. INTRODUCTION

In Japan, it is estimated that over 5% of the total population is disabled and the population aged over 65 years will have a ratio at nearly 1 person in 4 in 2020. With the rapid growth of life expectancy in recent years, a large part of elder people will experience functional problems in daily life, such as eating and moving. It is necessary to provide a new human machine interface to increase the quality of life for the elder or disabled people and allow them a more autonomous lifestyle.

In the past years, there has been a significant increase in using neuro-physiological signal such as electrooculogram (EOG) [1], electromyogram (EMG) [2] and electroencephalogram (EEG) [3] as assistive technology for disabled people. EOG is the recording of the steady corneal retinal potential which is proportional to vertical and horizontal movements of the eye [4]. It offers an objective way to quantify the direction of gaze, and is applied widely in assisted wheelchair [1], meal assistance orthosis [5], etc.

In this study, an online estimation system is established to track the gaze angle of user by EOG. The purpose is to use biomedical signal EOG as the input of human-machine interface for both disabled and healthy people. The relation between EOG amplitude and gaze angle is set by a quadratic function. One of the most important features is the use of compensation to improve the performance of estimation. After comparing the target angle and the estimated angle, the results show the quadratic function together with the method of compensation is effective in estimating the gaze angle of the user. The good performance and real-time response make it possible to provide a fast and reliable control input for home assistance robots, online word processor and other kinds of communication by use of eye movements.

II. METHODS

1. General structure of real-time estimation system

The general structure of eye tracking is illustrated in Fig. 1. During the experiment, a target point was moving around a circle at constant speed on the screen. The subject was asked to stare at the moving point. Ten

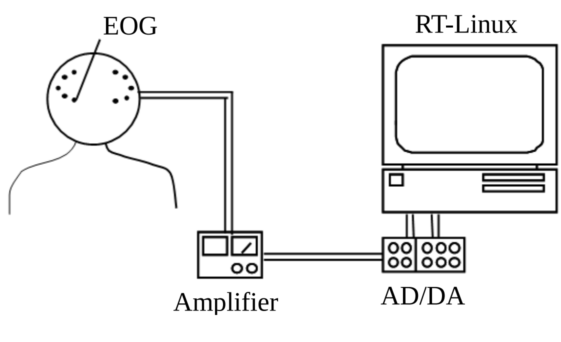

Fig. 1 General structure of estimation system

channels of EOG were acquired, amplified by EEG-1000 with sampling rate of 100Hz, and then sent to RT-Linux system for further processing after AD/DA conversion.

Eleven electrodes are placed on the face, each with an interval of 45 degree, as shown in Fig. 2. Cz is for reference. The mean value of F3 and F4, C3 and C4 is calculated to present the EOG on the vertical direction. So eight channels of EOG (A1, F7, F34, F8, A2, T4, C34, and T3) are used to estimate the gaze angle.

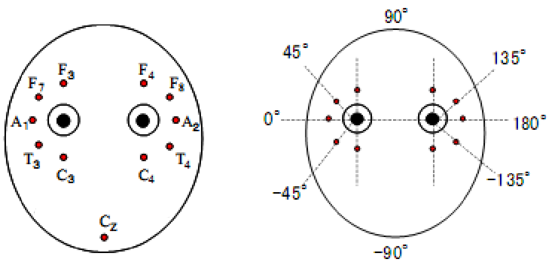

Fig. 2 Placement of electrodes

2. Pre-processing of EOG

A. Band pass filter

EOG is first passed by a Butterworth band pass filter with a cut frequency from 0.1Hz to 10Hz, to remove environment noise.

B. Bias elimination

Average of EOG signal is subtracted from the filtered EOG $A_i(t)$, to eliminate the bias deviation which is caused by the placement of electrodes as (1),

$$A_i^*(t) = A_i(t) - \overline{A_i} \tag{1}$$

where $A_i^*(t)$ is the signal after elimination of bias deviation, $\overline{A_i}$ is the average of EOG, and i is the channel number.

C. Normalization

Normalization is applied to minimize the difference among each channel as (2),

$$A_i^{'}(t) = A_i^*(t) / \left|\overline{A_i^*}\right| \tag{2}$$

where $A_i^{'}(t)$ is the signal after normalization.

3. Estimation of gaze angle by quadratic function

When the iris of eyeball is gazing at one direction, EOG around this direction is positive. EOG around the opposite direction is negative. In a word, EOG from the nearest electrode in the gaze direction has the maximum positive amplitude. The gaze angle is estimated based on such relationship between EOG amplitude and gaze angle.

In this study, a quadratic function is used to model EOG signal from each channel, as (3)

$$A_i^{'}(t) = a\theta_i^2 + b\theta_i + c \tag{3}$$

where θ_i is the angle of electrode. Three EOG channels, the one with maximum EOG amplitude, together with its two neighbor EOG channels are used to determine the acme of quadratic function ($-b/2a$, $c-b^2/4a$), which is the estimated gaze angle and corresponding amplitude.

4. Compensation of estimated gaze angle

As most of bio-potentials, EOG is sensitive to many factors, such as acquisition noise, skin conditions, head movements, processing delay and sudden saccade of eyeballs, so proper compensation is needed to improve the estimated results. Here, two steps of compensation are applied before the real-time estimation by use of training EOG data.

A. Compensation of angle shift

Processing delay may cause the shift of estimated angle. In order to compensate the shift of angle φ, least square method is applied according to the following cost function $J_1(\varphi)$ as (4),

$$J_1(\varphi) = \int [\alpha(t) - \theta(t+\varphi)]^2 dt \tag{4}$$

where $\alpha(t)$ is the target angle, $\theta(t)$ is the estimated angle, φ ranges from -50 to 250. The φ_0 which has the minimum $J_1(\varphi_0)$ is used to compensate the shift.

B. Smoothing

Smoothing is also applied to impair the influence of sudden saccade of eyeballs according to (5),

$$\theta^*(t) = (1-\lambda) \times \theta^*(t-\Delta t) + \lambda \times \frac{\theta(t+\varphi) + \theta(t+\varphi-\Delta t)}{2} \tag{5}$$

where $\theta^*(t)$ is the estimated angle after smoothing. The coefficient λ is decided by least square method according to (6),

$$J_2(\lambda) = \int \left[\alpha(t) - \theta^*(\lambda, t)\right]^2 dt \tag{6}$$

where λ ranges from 0.01 to 0.99 with an interval of 0.01. The λ_0 which has the minimum $J_2(\lambda_0)$ is used to smooth the estimated angle.

After applying the selected coefficients (φ_0, λ_0) into the compensation of delay and smoothing for the testing data, $\theta^*(t)$ is got as the final estimated gaze angle.

III. RESULTS

1. Estimated gaze angle without compensation

In the experiment, the red target point was moving round a circle with radius of 10cm at the speed of 10 cm/s. The estimated result was illustrated in a green point, tracking the red target on the screen. The target angle and the estimated angle after pre-processing are illustrated in Fig. 3. There was obvious shift between the target and the estimated one.

2. Estimated gaze angle with compensation

A. Compensation of shift

Different values of delay φ were applied to calculate the cost function $J_1(\varphi)$, as shown in Fig. 4. φ was ranging from -50 to 250, and $J_1(\varphi)$ reached its minimum when φ was 151.

B. Smoothing

Different values of λ were applied to calculated the cost function $J_2(\lambda)$, as shown in Fig. 5. λ was ranging from 0.01 to 0.99 with an interval of 0.01, and $J_2(\lambda)$ reached its minimum when λ was 0.09.

After applying the proper coefficients (φ, λ) of compensation, the estimated gaze angle was improved and was able to chase the target angle as shown in Fig. 6.

IV. DISCUSSION

1. Necessity of compensation

Due to the processing delay, there always exists a shift of angle between the estimated one and the target one, as shown in Fig. 3. We can also find the estimated

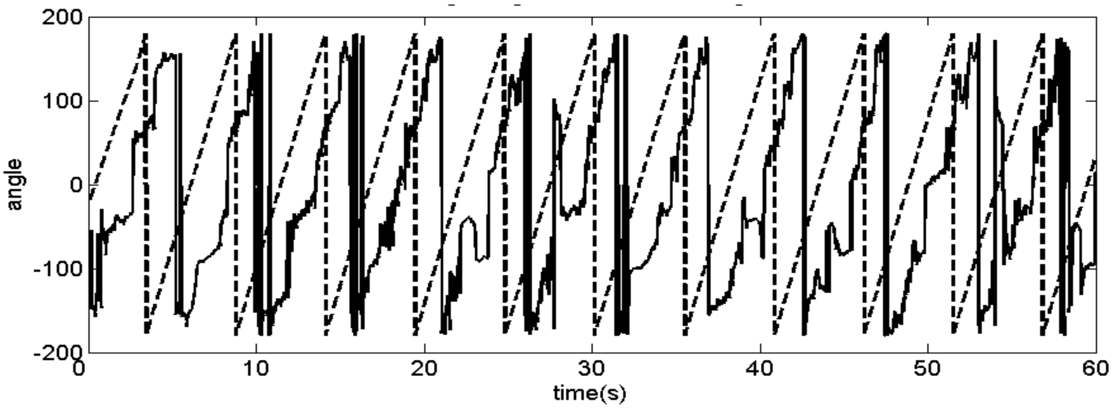

Fig. 3 Target angle and estimated angle without compensation. Dash: target; solid: estimated angle

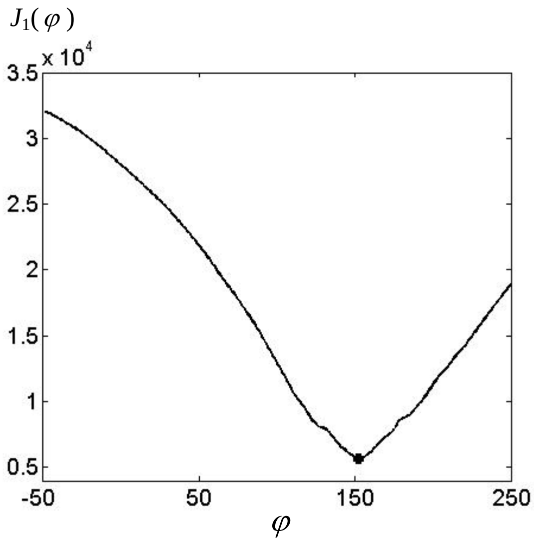

Fig. 4 Cost function of $J_1(\varphi)$. Cost function reached the minimum when φ is equal to 151.

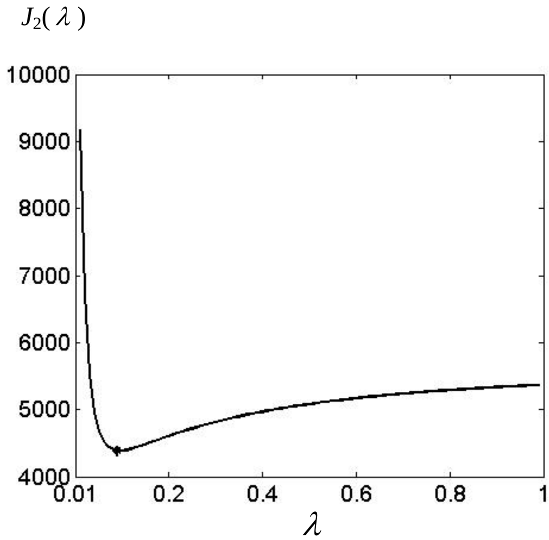

Fig. 5 Cost function of $J_2(\lambda)$. Cost function reached the minimum when λ is equal to 0.09.

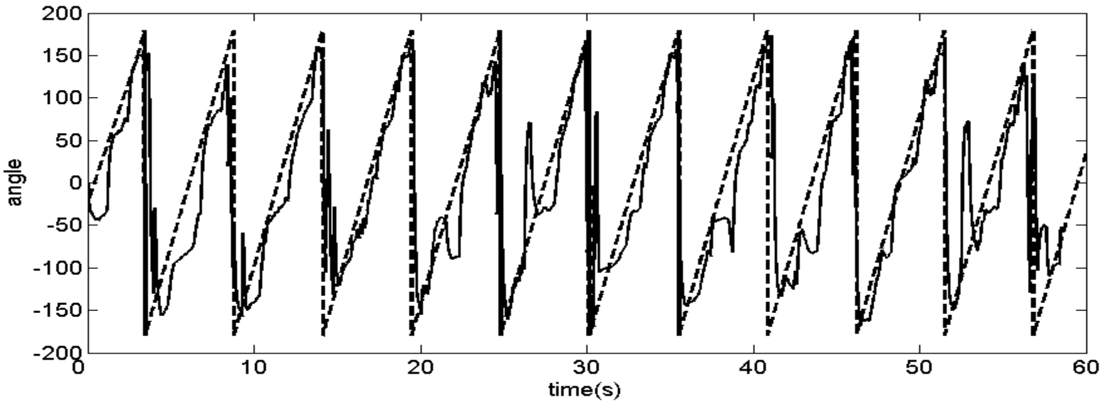

Fig. 6 Target angle and estimated angle with compensation. Dash: target; solid: estimated angle

angle contains many fluctuations. This is probably because EOG is easily influenced by environment noise, such as head movements or blinks. It is essential to use some methods to compensate these deficiencies. Instead of choosing coefficients by experimental experience, here we used cost function $J_1(\varphi)$ and $J_2(\lambda)$ to find proper coefficients by least square method. The whole segment of EOG signals were used as training data to find the coefficients that had the minimum cost functions. The selected coefficients were then applied to estimate the gaze angle of testing data. The effective of this method was illustrated in Fig. 6, in which the estimated angle was quite smooth and was able to track the target angle.

2. Future work

Our future goal is to realize an EOG-based tracking system with more freedom. The target can move at variable speed and in different radius. We would like to investigate the best way to track eye movements by EOG in 2D space.

Another work line is the application part. We would like to develop an EOG based meal assistance robot that serves the disables for eating, or online word processor. Moreover, this kind of achievement can be used for healthy people as novel input of communication and video games.

V. CONCLUSION

In this study, a relationship between EOG amplitude and gaze angle is established by a quadratic function, to estimate the exact gaze angle of eye movements. Compensation of shift and smoothing is applied to improve the performance of estimation by least square method. The real-time estimation system is realized by RT-Linux. The results show the proposed method is quite accurate to estimate the gaze angle. Its high performance in accuracy and response time guarantee the perspective in many fields, such as real-time control of assistance robot, novel input of telephone, word processor for the disables, and video games for healthy people as well.

VI. ACKNOWLEDGMENT

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