Realization of FIR System Characterizing Eye Movement based on Electrooculogram

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Abstract— **The Electrooculogram (EOG) is one of important biosignals. The EOG is useful for many applications such as some disease analysis or assistive application for some type of disability persons. This paper proposes a new method identifying two eye movements, which are clockwise and counter-clockwise eye rotation movements using impulse response of the Finite Impulse Response (FIR) system characterizing EOGs between two channels. The proposed method consists of the three main processes: 1) EOG signal acquisition, 2) Fourier series approximation of EOG waveform, 3) the feature extraction using impulse response of FIR system characterizing EOGs between two channels. The experimental results show that the proposed method is useful for identifying two eye movements (clockwise and counter-clockwise).**

Keywords—EOG classification, EOG recognition, FIR system

I. Introduction

Electrooculogram (EOG) is one of biosignals that can be measured and monitored in living beings. The EOG is obtained from muscle during eye movement which is measured by six electrodes for horizontal and vertical directional eye movement [1]. In addition to, EOG has been developed in several researches such as the application for controlling some devices with EOG signal [2-4], or diseases assessment that is about eye movement or body's balance [5-6]. S. Sai Surya Teja and *et. al* [2] designed a wearable EOG mask for assistive system for typing English alphabet on the virtual keyboard. In 2016, moreover, EOG was applied in the real-time eye-writing recognition by Kwang-Ryeol Lee *and et. al* [3]. Furthermore, the EOG can be applied to the assessment of some diseases, the vertigo, dizziness and disequilibrium. Mina Ranjbaran and Henrientta L. Galiana [5] proposed an identification of Vestibulo-Occular Reflextion (VOR) to diagnose various disorders. The EOG is useful in many applications.

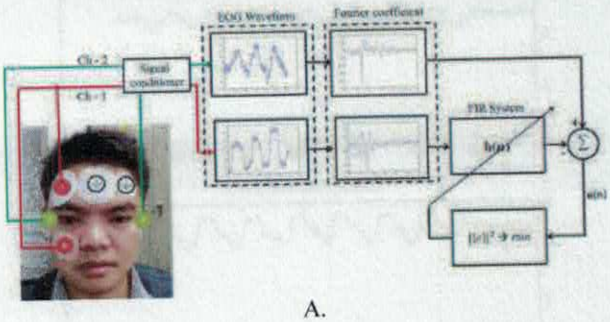
This research emphasizes to classify the two eye movements from two channels of EOG signal that consist of Clockwise and Counter Clockwise movements. Although, there are various methods recently for recognizing the eye movement such as VDO camera for eye tracking movement by image processing whereas it is uncomfortable and expensive for user. Moreover, some research use a thresholding technique [4] for EOG classification but it is complicate for Clockwise and Counter Clockwise eye movements. Therefore, this research proposes a new simple algorithm of signal processing for classifying these eye movements.

II. Proposed Method

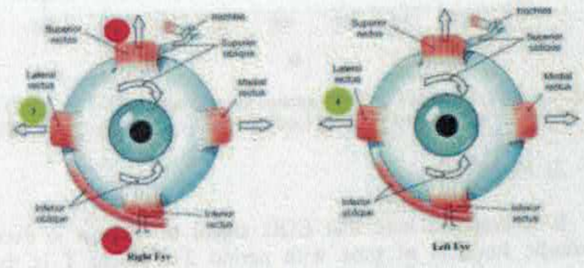
The proposed method consists of the three major processes: 1) EOG signal acquisition, 2) Fourier series calculation for approximation of EOG waveform, 3) FIR system representation of Eye Movements based on EOG signals from two channels, as shown in the figure 1. This section describes the implementation processes of the proposed method.

1) Electrooculogram Acquisition

Electrooculogram is the signal obtained from muscle around the eye during eye movement. The EOG can be measured with six electrodes which can detect movements in the horizontal and vertical directions. In this paper, EOG of eye movement is detected in the clockwise and counter clockwise rotations from two channels. Fig. 1. shows the position of electrode around subject's eye.



A.



B.

Fig. 1. A. Block diagram of proposed method. B. Position of eye muscles that relate with the Fig.1 A. [7]

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In Fig. 1., Ch1 shows EOG between superior rectus and inferior rectus, while Ch2 shows EOG between lateral rectus and medial rectus. Then, these signals are sent to analog to digital (A/D) port of the microcontroller (STM32f4 model) in order to convert the EOG analog signal to digital signal. Figure 2 shows the normal waveform of EOG signal for clockwise and counter-clockwise rotation movements.

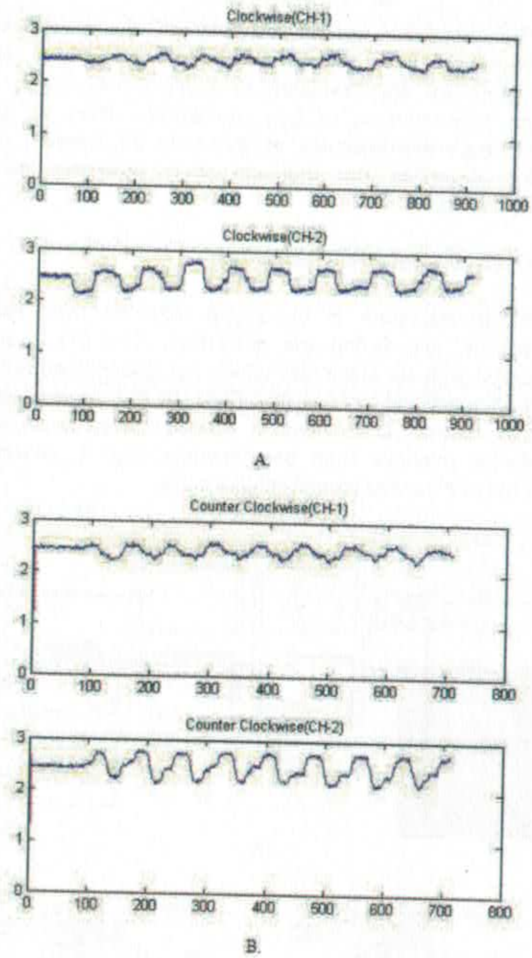

Fig. 2. A.Waveform of Clockwise rotation eye movement (Ch-1 and Ch-2) B. Waveform of Counter-Clockwise rotation eye movement (Ch-1 and Ch-2)

2) Fourier Series

It is assumed here that EOG signal of interest is even periodic function of time with period 2T, where T is the measurement duration time. Under above assumption, EOG signal can be_expressed by the Fourier series:

$$f^{(j)}(t) = a_0^{(j)} + \sum_{k=1}^{\infty} a_k^{(j)} \cos[k\omega_0 t] \tag{1}$$

where $\omega_0 = \frac{\pi}{T}$, the superscript (j) means the j^{th} channel and $a_0^{(j)}$ and $a_k^{(j)}$ are computed numerically and given by

$$a_0^{(j)} = \frac{1}{N}\sum_{i=0}^{N} f^{(j)}(i\tau) \tag{2}$$

$$a_k^{(j)} = \frac{2}{N}\sum_{i=0}^{N} f^{(j)}(i\tau)\cos[\frac{ki}{N\tau}\pi] \quad ; k\neq 0 \tag{3}$$

where $\tau = \frac{T}{N}$ and N is the number of data

3) FIR system representing Eye Movement based on two EOG signals

We consider an FIR system having the Fourier coefficients $a_k^{(j)}$, (j=1,2) obtained above as the input and output respectively. The FIR system is given by

$$\hat{a}_k^{(2)} = \sum_{i=0}^{M} h_{k-i} a_i^{(1)} \tag{4}$$

where M is the order of the FIR system and h_k is the impulse response. In this case the impulse response h_k is determined such that

$$J = \sum_{k=0}^{N} (a_k^{(2)} - \hat{a}_k^{(2)})^2 \rightarrow \min. \tag{5}$$

That is, the optimal impulse response can be obtained as

$$\vec{h} = (h_0, \cdots, h_M)' = (F'F)^{-1} F' \vec{y} \tag{6}$$

where $(\cdots)'$ is the_transposition_of $(\cdots)$ and

$$\vec{y} = (a_0^{(2)}, \cdots, a_M^{(2)})',$$

$$F = \begin{bmatrix} a_0^{(1)} & 0 & \cdots & 0 \\ a_1^{(1)} & a_0^{(1)} & \cdots & 0 \\ \cdots & \cdots & \cdots & \cdots \\ a_N^{(1)} & a_{N-1}^{(1)} & \cdots & a_{N-M+1}^{(1)} \end{bmatrix}$$

The impulse response vector $\vec{h}$ obtained above is used here as inherent feature of eye movement.

4) The Identification of eye movement

It is assumed here that $\vec{h}_1^{ref}$ and $\vec{h}_2^{ref}$ are the reference feature (impulse response) vectors representing clockwise rotation and counter clockwise rotation movements, respectively which these are obtain from the training data set process and calculation as shown in Equation 6.

In the case, eye movement can be identified as

clockwise rotation if $\eta_1 < \eta_2$,

counter clockwise rotation if $\eta_1 > \eta_2$,

where

$$\eta_k = \left\| \vec{h}_k^{\,ref} - \vec{h}^{\,unknown} \right\|, \text{ (k=1,2)}$$

$\|\bullet\|$ is the Euclidean norm.

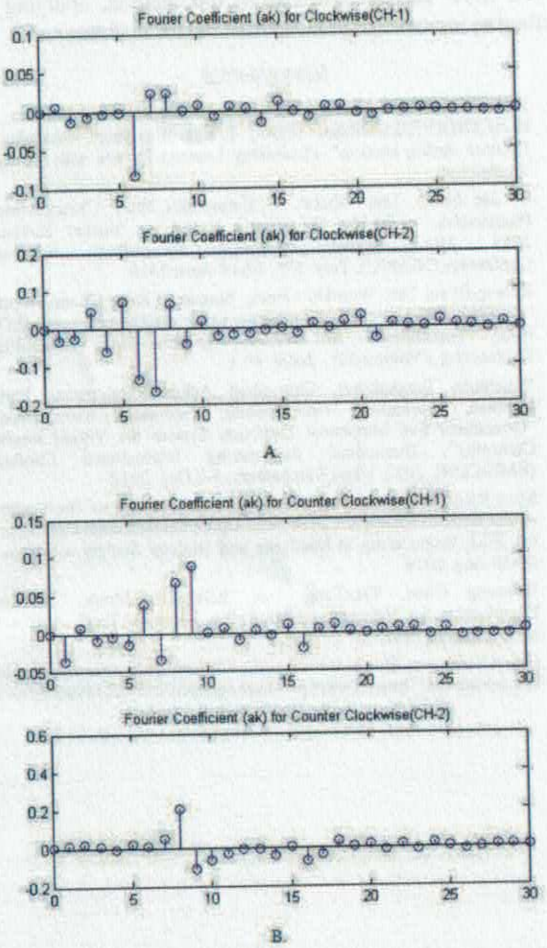

Fig. 3. A. Fourier Coefficeints of Clockwise rotation eye movement (Ch-1 and Ch-2) B. Fourier Coefficeints of Counter-Clockwise rotation eye movement (Ch-1 and Ch-2)

III. EXPERIMENTAL RESULT AND DISCUSSION

We will try to identify two eye movements, clockwise and counter-clockwise rotations, using impulse response of FIR system characterizing the two eye movements.

It is assumed here that the reference impulse responses, $\vec{h}_1^{ref}$, $\vec{h}_2^{ref}$, of the FIR system have been obtained beforehand by cut and try method.

In our experiment, we selected the number of Fourier coefficients, N=30, and the order of FIR system, M=10 .

Fig.3 shows the Fourier coefficients of EOG for clockwise and counter-clockwise. Furthermore, Fig. 4 shows the impulse responses of the FIR systems having the above Fourier coefficients as the input and output, respectively. We use these impulse responses as the references for the clockwise and counter-clockwise rotation eye movements, respectively.

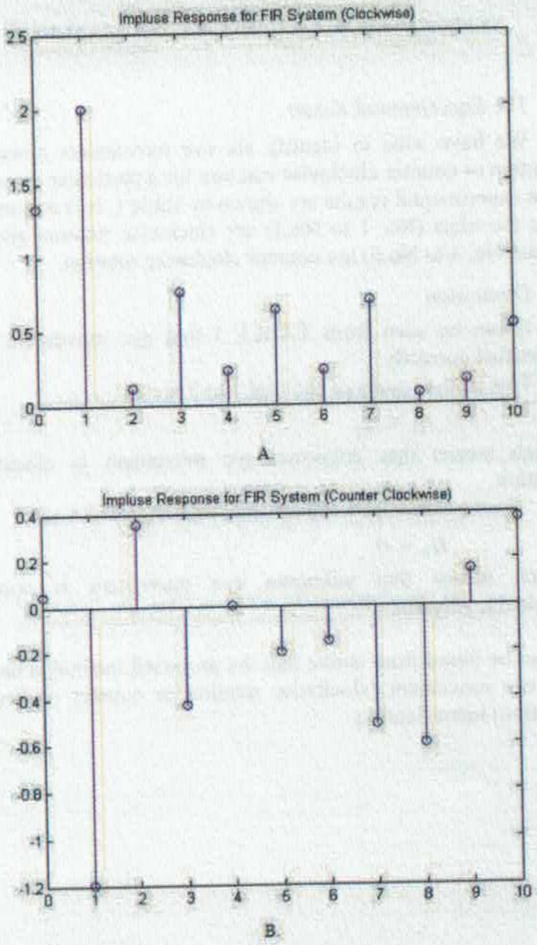

Fig. 4. A. Impulse response of Clockwise rotation eye movement B. Impulse response of Counter-Clockwise rotation eye movement

TABLE I. EXPERIMENTAL RESULTS

No.	η_1	η_2	Rotation
1.	2.71	6.22	Clockwise
2.	3.36	5.86	Clockwise
3.	2.78	6.13	Clockwise
4.	8.42	0.50	Counter Clockwise
5.	8.40	0.52	Counter Clockwise
6.	10.86	1.93	Counter Clockwise

A. The Experimental Result

We have tried to identify six eye movements clockwise rotation or counter clockwise rotation for a particular person. The experimental results are shown in Table I. It is assumed that the trials (No. 1 to No.3) are clockwise rotation and the trials (No. 4 to No.6) are counter clockwise rotation.

B. Discussion

It can be seen from TABLE I that eye movement was identified correctly.

That is, the results of the trial 1 to 3 are

$$\eta_1 < \eta_2$$

which means that unknown eye movement is clockwise rotation.

On the other hand, the results of the trial 4 to 6 are

$$\eta_2 < \eta_1$$

which means that unknown eye movement is counter clockwise rotation.

It can be found from above that the proposed method is useful for eye movement (clockwise rotation or counter clockwise rotation) identification.

IV. CONCLUSION

This paper presented a method identifying two different eye movements based on EOG signals using impulse response of FIR system characterizing EOG signals between two channels. It was found from our experimental results that the proposed method is useful for the identification of eye movements (clockwise and counter-clockwise rotation).

To show the effectiveness of our method, applying this method to various eye movements remains as future work.

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