
EOG-BASED SIGNAL DETECTION AND VERIFICATION FOR HCI

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Abstract:
In this paper, we proposed an eye-movement tracking system. Based on Electro-Oculography (E.O.G) technology we detected the signal with different directions in eye-movements and then analyzed to understand what they represented about (e.g. horizontal direction or vertical direction). We converted the analog signal to digital signal and then used as the control signals for Human Computer Interface (HCI). In order to make the system “robust”, several applications with EOG-based HCI had been designed. Our preliminary results revealed more than 90% accuracy rate for examining the eye-movement that may become a new useful human-machine user interface in the near future.

Keywords:
Electro-Oculography (E.O.G), Motor Neuron Disease, Eye-Movement, Amyotrophic Lateral Sclerosis, Human-Machine/Computer Interface (HMI/HCI)

1. Introduction

Jean-Dominique Bauby was a famous journalist and editor of the fashion magazine ELLE. In 1995, Bauby suffered a massive stroke. His condition is called Locked-in Syndrome; he could only blink his left eyelid. In spite of his hard condition, Bauby blink his eye when the correct letter was reached by his interlocutor reciting the alphabet and finally accomplished the book "The Diving Bell and the Butterfly" in 1997 [9]. In Taiwan, Mr. Chen suffered Motor Neuron Disease, (M.N.D) or Lou Gehrig's disease. Impressively, Mr. Chen accomplished 5 books that contain 190,185 words from 1999 to 2005 (the most words written by blinking in the Guinness World Records) [6]. For thousands of people, Amyotrophic Lateral Sclerosis (ALS) deprives them from using their limbs or even speech. They leave the brain and eyes activity unimpaired. The only way for communication is to detect the Eye-movement correctness. EOG-based signal processes provided the detection of the Eye-movement resulting from looking-up, down, left and right. [13] have developed a new method for automatic estimation of vigilance level by using electroencephalogram (EEG), electromyogram (EMG) and eye movement (EOG). [3,4] diagnosis of subnormal eye through the analysis of EOG signals and then to assist the physician to make the final decision without hesitation. So the eye-movement HCI can be taken as an input device for communication [8,11,16,18].

Figure 1. Eye-movement HCI platform architecture.
In this paper, we constructed an eye-movement HCI platform for several applications. Figure 1 illustrated the Eye-movement HCI platform architecture. The eye-movement coils are the electromagnetic fields that received signal between 50 to 3500uV with a frequency range of about dc-100 Hz. Eye-movement signals needs to be adjusted/normalized by signal amplifier, adders and filters. The filters eliminate the effects due to other bio-potentials, such as saccadic/blink over to the EOG signal. After that, the EOG signal is then converted to
digital signal and then transmitted to the computer. The application control component will deal with the eye-movement and then interact with the desired application. Therefore, our proposed platform can serve various services.

The paper is organized as follows. Section 2 introduces the related works with Eye-movement detection. Some classical eye-movement measurement techniques for recording the electrical activity of eye-movement will be described in details in this section. The proposed EOG-based Eye-movement HCI platform is given in section 3. Some propose prototype applications for Eye-movement are shown in section 4. The diverse guidance tests and experimental results are given in section 5. Finally, section 6 draws the conclusion and future work.

2. Eye-movement Measurement Techniques

Some electrodes measurement for bio-potential recordings and suitable applications are discussed in this section. These related eye-movement measurement techniques and applications contains: Eye-Mouse (EM) [8,14], Eye-writing System and emulation of Oral Speaking, Eye-Tracking System for powered wheelchair [17], and EOG-based application for Hospital Alarm System [16].

a. Infrared Video System, IRVS

Infrared Video System (IRVS) consists of a charge-coupled device (CCD) camera, an image capture card, and an LCD projector [7,19]. These methods are suitable for real-time extraction of the position of the pupil in the eye image. Since the eye gaze tracking may represent a person’s focus of attention, it has potential applications in Human Computer Interaction (HCI), Virtual Reality, Eye-Disease Diagnosis, and Human Behavior Studies. In addition, some of these systems required the user’s head to be motionless during eye tracking. They must often be calibrated repeatedly for each individual, and they also showed low tolerance for head movements and required the user to keep their heads still.

b. Infrared Oculography, IROG

In the infrared Oculography (IROG), the infrared light reflected through Sclera, is converted into current to detect the movement of eyes [12]. It is cheaper and can be easily applied. However, the harm caused by infrared light to eyes is unknown.

c. Search Coil (SC)

Search Coil (SC) [15], which was inducted by magnetic field, possessed benefits as high precision and fixed magnetic field. But it couldn’t use too long due to the influence of excretions from eyes.

d. Optical-type Eye Tracking System

Optical-type Eye Tracking System was composed of headset displayer, mini-CCD, light source, image-fetching card, and image processing unit. The method fetches the images of eyes with a mini-CCD and then figures out the central position of pupil with a specific program [1,17]. Its benefit included noncontact, and could be used after putting on the headset. But the weight of the headset and bright light source would make users uncomfortable.

e. Purkinje Dual-Purkinje-Image (DPI)

Purkinje DPI is to analysis four Purkinje images reflected from the incoming light on the boundaries of the lens and cornea. Tracking the direction of gaze by the pupil tracking technique is similar to limbus tracking, but only the smaller boundary between the pupil and the iris is used here [2]. DPI method provided a more tracking accuracy because it avoids the shelter issues from the eyelid. Anyway, the related set of system is more expensive.

f. Electro-Oculography (EOG)

Electro-Oculography (EOG) detects the eye movement by recording the corneal-retinal potential difference from hyper-polarizations and de-polarizations existing between the cornea and the retina. The potential difference can be taken as the electrical dipole with a negative pole at the fundus and positive pole at the cornea. By measuring the voltage induced across a set of electrode coils pasted around the eyes as, we can measure the electric signal of the eye’s dipole as the eye-movement changes [8,11,16,18]. EOG is the most widely used technique in measuring the bio-potential.

3. Eye-movement HCI System

a. System Architecture

We designed the hardware circuits, and according to the literature [14], the eye-movement coils produces between 50 to 3500uV with a frequency ranging from dc-100 Hz. So we must design the amplified circuits. The flow chart of detecting signals is shown in Fig.2. The EOG signal —is input to the instrumentation amplifier, in which the signals are amplified by about 50 times. The circuit uses an adder to balance the signals, 0.05 Hz high pass filter and another amplifier with a gain of 10 to adjust the signals to 1.5V. The flow chart of EOG signal recordings is illustrated in figure 2.
Figure 2. Flow chart of the EOG signal recording.

A.1 Bio-potential Recording
The EOG was attached on to the surrounding area of eyes with the help of others, and then turned on to detect the corneal-retinal potential difference. We chose pragmatic reliable low-cost electrodes for long-term use in EOG signal recordings.

A.2 Bio-potential Amplifier
The amplifier IC (INA128, Texas Instruments, TI) as shown in figure 3, which was composed of 3 Difference amplifiers was used. We have to modify the RG resistance to change its gain [17]. Here we adapted RG as 1K to get a voltage gain of about 50 times.

\[ V_o = \frac{R_2}{R_1} V_o(1+\frac{2R_2}{R_G}(V^+ - V^-)) \]

Figure 3. INA128 [17]

A.3 Balance
Signals differentially amplified by INA128 may not be balanced, so we adapted an adder to balance the signal.

A.4 Filtering
According to literature, the signal band-width of eye-movement was located in the range of 0.1Hz~20Hz, so signals more than 20Hz would be regarded as noise which should be deleted using noise filters. Here we designed a band-pass filter [14] ranging from 00.5 to 23 Hz to isolate the disturbance from grid electricity of 60Hz. However, we realized that just a one-class low-pass filter couldn’t effectively avoid the noise, so we added another low-pass filter of 19Hz, and the output was better with much better stability.

\[ \frac{1}{\sqrt{2}} \left( \frac{R_1}{R_2} \right) C_1 C_2 \]

\[ \frac{1}{2\pi \left( 3 \times 10^{-1} \times 10^{-4} \right)} \]

\[ \frac{1}{6.28 \times 3} \]

\[ = 18.84 \approx 0.053 \text{ Hz} \]

Figure 4. High pass filter.

The high pass filter is shown in figure 4, in which the signal frequency below than 0.05 Hz would be isolated. In figure 5, the first-class low-pass filter is used to isolate signals of frequency higher than 23.417Hz. In Fig 6, the second-class low-pass filter would deal with the signals passing through the first-class filter to get a higher Q value of signals.

\[ \frac{1}{\sqrt{2}} \left( \frac{R_9}{R_{10}} \right) C_3 C_4 \]

\[ \frac{1}{2\pi \left( 68 \times 10^{-9} \times 0.1 \times 10^{-4} \right)} \]

\[ \frac{1}{6.28 \times 6.8 \times 10^{-7}} \]

\[ = 42.704 \times 10^{-1} \approx 23.417 \text{ Hz} \]

Figure 5. First-class low-pass filter

\[ \frac{1}{\sqrt{2}} \left( \frac{R_{13}}{R_{14}} \right) C_5 C_6 \]

\[ \frac{1}{2\pi \left( 82 \times 10^{-10} \times 0.1 \times 10^{-4} \right)} \]

\[ \frac{1}{6.28 \times 8.2 \times 10^{-7}} \]

\[ = 51.496 \times 10^{-1} \approx 19.418 \text{ Hz} \]

Figure 6. Second-class low-pass filter.

A.5 Horizontal Movement
Since the voltage range of AD converter in our microprocessor was from 0 to 3.3V, we needed to design an
adjusting circuit to let the detected voltage available.

A.6 Input into microprocessor

The reason why we selected SPCE061A as our core microprocessor was due to its advantages like re-programming capability, real-time debugging, low cost, and simple interface. After AD converting, the signals are sent to the microprocessor through an RS-232 interface [10].

B. Preliminary Experimental Results

The following paragraph will illustrate the EOG analog signal for bio-potential changes when the eye moves up, down, left, and right.

B.1 EOG Analog Signal

Figure 7 show the fuzzy set values for the EOG analog signal waves recorded by the Oscillograph. The related fuzzy distinction rules are shown in Table 1. More testing results are shown in Appendix I.

Table 1: Fuzzy Distinction Rule

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>Rule</th>
</tr>
</thead>
<tbody>
<tr>
<td>high</td>
<td>high</td>
<td>Up</td>
</tr>
<tr>
<td>mid</td>
<td>mid</td>
<td>Right</td>
</tr>
<tr>
<td>mid</td>
<td>mid</td>
<td>Stop</td>
</tr>
<tr>
<td>mid</td>
<td>low</td>
<td>Down</td>
</tr>
<tr>
<td>low</td>
<td>mid</td>
<td>Left</td>
</tr>
</tbody>
</table>

Where A is Left-Right signal and B is Up-Down signal.

B.2 EOG Digital Signal Detection

The signals after A/D conversion are sent to a computer through the RS232 interface. The signal detection flow chart is shown in Figure 8.

4. Detection of Eye-Movement

After designing three kinds of detecting the interface of eye-movement, the system could be applied into the system of controlling TV, DIY eye-sight level checking, and eye-controlling game.

Application selection user interface is shown in Figure 9.

```c
if (rs232.isStart==true) {
    if (Program.rs.direction==direction) {
        textBox3.Text=direction;
        switch (Up Dn Lf Rt signal) {
            case 1:
                break;
            case 2:
                break;
            case 3:
                break;
            default:
                MessageBox.Show("Invalid direction.");
                break;
        }
        if (direction count >= 3) {
            direction count = 0;
            timer1.Enabled = false;
            rs232.timerFlag = false;
            break;
        }
        direction count++;
        waitFlag = true;
    }
    else direction count = 0;
}
```
B. The adjusting system of eye-movement

As shown in figure 10, whenever the users open the system, the system would execute the adjusting system automatically.

The design could meet with the eye-movement ranges of different users.

The system could record and figure out the different movement ranges of users to judge the real action of eyes.

After the adjustment of the system, the precision of the whole system could get up to 90%.

need help with others.

button1_Click
if (timer1.Enabled)
    timer1.Enabled = false;
else
    timer1.Enabled = true;

button8_Click
if (!File.Exists("record.txt"))
    Sw = File.CreateText("record.txt");
else
    sw = File.AppendText("record.txt");
}

C. EOG based remote-control System for TV

Turn on the TV with Electro-Oculography interface as shown in Fig.11. Its function is to shift the channels and to adjust the volume.

timer1.Enabled = true;
plInfo.UseShellExecute = true;
if (rs232.isStart == true)
    if (P.r.d == direction)
        TextBox1.Text = “direction”;
    if (UpDnLfrtsignal == direction)
        rs232.count = 0;
        SendKeys.Flush();
}

D. Eye-sight Level Checking System

Upon starting the system, it would give out the test items, and users could answer the test items with Electro-Oculography interface and test out the eyesight level as shown in Fig.12.

After comparing with the level tested by the hospital, a precision of up to 95% could be obtained.

It worked without any help from others.

if (rs232.isStart == true)
    label2.Text
    if (Up Dn Lf Rt signal == direction)
        if (UpDnLfRtsignal == direction)
            r++;
        else
            w++;
            nextPic();
            count = 0;
    }
if (end == true && final == true && r == 2)
    end = false;
5. Experimental Discussion

A. Distortion of EOG Signals

In the experimental processes, we found that there would be 30 to 90 minutes of best signal stability for every user with different physical conditions and environment, and over the time period, the signals would shift. We tried to explain this situation as resulting from long time attachment of EOG and sweating of skin. If we wash the EOG with alcohol, the situation would be improved.

A.2 Movement of Eyes

Since the range of horizontal movement of eyes was wider than the vertical movement, the detected signals became significant and larger and did not easily cause error.

A.3 Face muscle and eyes movement

If the users are nervous, blink eyes, or make much exaggerated gestures and speech, all of such actions would cause irregular movement of face muscle and eyes to decrease the precision of detecting eye-movement.

6. Conclusions

In this paper, we proposed a multi-purposes eye-movement tracking system. Integrating Electro-Oculography (E.O.G) installations we detected the signal with different directions in eye-movements and then analyzed to understand what they represented about (e.g. horizontal direction or vertical direction). We converted the analog signal to digital signal and then used as the control signals for Human Computer Interface (HCI). We finally accomplished the multi-purposes eye-movement HCI platform, and this system cost was much lower than other methods. The system adapted the direction-sensor interface design, and the system would be active according to the indicated direction. Users could easily use this system and the precision of the system after adjustment could get more than 90%.

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References


