DEVELOPMENT OF AN EOG BASED ROBOT MANIPULATOR AND END POINT DIRECTION CONTROL SYSTEM

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Electro-oculograph (EOG) is one of the biosignal that can be used to improve life quality in human machine interface area. EOG occurring as the eye activities changes the magnitude of potential between cornea and retina. This signal was used to control robot manipulator in four directions (up, down, left and right). To record this phenomenon we used NF Instrument with head box to amplify the signal and processor box to process digital filters. Combination of 3 digital filters, 1.6 Hz High Pass Filter, 60 Hz Low Pass Filter and 60 Hz Ham Filter and finalized by 6 Hz Low Pass Filter gave neat signal until the difference among the eye movements could be distinguished. This is a real time system since it could detect when a signal comes and send it to the robot manipulator system through Arduino microcontroller. The determination of the signal emersion was successfully calculated by the combination of wavelet transform with scale = 1 and translation = 0.31 and garbor filter with $\sigma = 1$. Since the average accuracy of the system is more than 90% so we can use this method for some extend applications later.

Keywords: EOG signal, robot manipulator, NF Instrument, eye movement, real time system.

1. Introduction

Nowadays, the discussion about how technology improves the life quality of disable people becomes an important issue combining engineering people and medical practitioners. Carlos G Pinhero et al [1] proved that biosignal is could be the alternative way to build a communication that can help people who had severe motor disabilities. Choi Kyung Ho et al [2] had an idea to recognize the condition of an operator in front of a virtual web screen who had confusion with a missed question based on electrooculogram (EOG) signal by using neural network.

EOG is one of the biosignals currently undergoing close scrutiny by a great many scientists for possible applications in daily life. The EOG signal derived from eye activities such as gaze motion and blink eye can be used to control devices through a man-machine interface. In 2002, EOG signals were used to control a wheelchair [3, 4]. This topic was followed by Alex Dev et al [5] and gave the comparison among some techniques to control wheelchair such as manually controlled, voice controlled and brain controlled before deciding to use EOG signal. EOG was also developed to other applications such as controlling computer functions [6, 7, 8, 9], gadget functions [10] and mobile robot [11]. Another study gave a brief experiment in horizontal and vertical eye movement for normal volunteers. Then, the combination of biosignals from eye, head, mouth and hand was introduced to build a vision-based human-computer interaction system [12].

EOG signal was also used to choose some letters as objective in the display and this signal was represented by cursor motion. Experiments to allow disabled people to communicate using a virtual keyboard were also performed in 2009[13].

Recently, a robot has gained fame with its ability to grab and move an object in a human-like manner. Biosignals derived from eye blinks have been used to control this robot [14].

In this paper, EOG signal in four basics directions (right, left, up and down) has been selected to control robot manipulator. In order to build a real time system, wavelet transform and gabor filter are used in case of detecting a movement. The EOG system and robot manipulator have been connected with Arduino microcontroller by serial communication.

2. EOG

EOG is recorded as a weak electric potential existing around the eye. This signal comes from eyes activities making the difference potential between cornea and retina. Cornea has more positive polarity than retina [15]. EOG signal can be obtained by placing electrode in appropriate position around the eyes. International Society for Clinical Electrophysiology of vision always searches the best design of EOG equipment but it is still limited to some extents. Fig.1 illustrates the retina and cornea polarity and positions of four electrodes (Ch1, Ch2, minus (-), and ground).

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3. Experiment Design

This study combines biosignal and control system to move flexible robot manipulator by using gaze motion. So, in simply the input of the system is biosignal and the output is end-effector movement. These input and output are connected by arduino microcontroller (Fig. 2). There are four inputs that would be recognized by this system which are right, left, up and down.

3.1 NF Instrument

NF Instrument had two boxes, a processor box and a head box (Fig. 3). Head box had an amplifier signal to send the data from operators to processor box. Processor box provided some specifications of filters that could be selected as combinations to this experiment. These were available features provided by this machine:

a. High Pass Filter (HPF) : 1.6, 5, 16 Hz
b. High Pass Filter (HPF) : 60, 30, 15 Hz
c. Ham Filter : 50, 60 Hz
d. Frequency sampling : 400, 200, 100 Hz

3.2 Robot Manipulator

This is a 2 degree of freedoms robot manipulator. Fig. 4 shows the appearance of flexible manipulator which was used in this study. Except the based part that was iron, it was made by lighter aluminum to make it had good balance. The joints were built using DC servo motors. It had embedded encoder so it is possible to with encoder as the output pulse is 1000 pulse/rotation. To handle the stability of the motor, harmonic drive was present between the output shaft and the motor with 1:100 reduction ratio.

The program was created on the desktop PC then it sent the signal using the D/A board to the motor via servo amplifier. Angle of rotation of the DC motor was detected by encoder and used as the feedback to DSP board manufactured by DSpace. Matlab was used to design the control system with 1 msec sampling period.

This is a planar robot with 2 links and 2 joints (Fig. 5). The length of link 1 is $l_1$ and link 2 is $l_2$. The homogeneous matrices for these 2 joints are (1) and (2). The end effector position based on the robot coordinate are expressed in (3) and (4). From these matrixes we can get the kinematic relationship between based and end-effector, as shown in (5).
Fig. 5. Joint and link coordinates.

\[
\begin{align*}
\mathbf{^0T_i} &= \begin{bmatrix} 
\cos \theta_i & \sin \theta_i & 0 & 0 \\
-\sin \theta_i & \cos \theta_i & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 
\end{bmatrix} \\
\mathbf{^1T_2} &= \begin{bmatrix} 
\cos \theta_2 & \sin \theta_2 & 0 & 0 \\
-\sin \theta_2 & \cos \theta_2 & 0 & l_2 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 
\end{bmatrix} \\
\mathbf{^2P_n} &= [0 \ l_2 \ 0 \ 1]^T \\
\mathbf{^0P_n} &= [x_n \ y_n \ 0 \ 1] 
\end{align*}
\]

So the homogeneous matrix for the end-effector to the based is:

\[
\mathbf{^0P_n} = \mathbf{^0T_i} \mathbf{^1T_2} \mathbf{^2P_n} 
\]

\[
\begin{align*}
\begin{bmatrix} l_1 \sin(\theta_i + \theta_2) + l_2 \sin \theta_i \\
l_1 \cos(\theta_i + \theta_2) + l_2 \cos \theta_i \\
0 \\
1 
\end{bmatrix}
\end{align*}
\]

Determination of robot manipulator inverse kinematic was used on this study. It was needed to find the rotation of joints since the end-effector position was found. Table 1 gives us the physical composition of the robot. So, we can find the \( \theta_1 \) and \( \theta_2 \) as shown in (6) and (7) where \( d \) is formulated by (8).

\[
\theta_1 = \text{atan}2(x_n, y_n) - \text{atan}2(\pm \sqrt{x_n^2 + y_n^2 - d^2}, d) \tag{6}
\]

\[
\theta_2 = \text{atan}2(x_n - l_1 S_1, y_n - l_1 C_1) - \theta_1 \tag{7}
\]

\[
d = \frac{x_n^2 + y_n^2 + l_1^2 - l_2^2}{2l_1} \tag{8}
\]

4. Eye Potential Analysis

EOG signal is very sensitive to many factors and sometimes difficult to distinguish it with noise. Fig. 6 gives the information about the signal after it was attached this following signal processing: 60 Hz Low pass filter (LPF), 1.6 Hz High pass filter (HPF), 60 Hz Ham filter and 100 ms sampling time. The vertical axis is the potential of EOG signal in \( \mu \text{V} \). The blue line is Ch1 to detect vertical eye movement and the red line is Ch2 to detect horizontal eye movement.

Table 1 Specification of Robot Manipulator.

<table>
<thead>
<tr>
<th>Motor 1</th>
<th>rated output</th>
<th>500</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>rated torque</td>
<td>1.65</td>
<td>Nm</td>
</tr>
<tr>
<td></td>
<td>rated speed</td>
<td>2500</td>
<td>Rpm</td>
</tr>
<tr>
<td></td>
<td>peak torque</td>
<td>4.214</td>
<td>Nm</td>
</tr>
<tr>
<td>Motor 2</td>
<td>rated output</td>
<td>105</td>
<td>W</td>
</tr>
<tr>
<td></td>
<td>rated torque</td>
<td>0.326</td>
<td>Nm</td>
</tr>
<tr>
<td></td>
<td>rated speed</td>
<td>3000</td>
<td>Rpm</td>
</tr>
<tr>
<td></td>
<td>peak torque</td>
<td>0.784</td>
<td>Nm</td>
</tr>
<tr>
<td>Motor 3</td>
<td>rated output</td>
<td>39</td>
<td>W</td>
</tr>
<tr>
<td></td>
<td>rated torque</td>
<td>0.11</td>
<td>Nm</td>
</tr>
<tr>
<td></td>
<td>rated speed</td>
<td>3000</td>
<td>Rpm</td>
</tr>
<tr>
<td></td>
<td>peak torque</td>
<td>0.323</td>
<td>Nm</td>
</tr>
<tr>
<td>Link 1</td>
<td>Length</td>
<td>440</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>Diameter</td>
<td>5</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>Material</td>
<td>stainless</td>
<td></td>
</tr>
<tr>
<td>Link 2</td>
<td>Length</td>
<td>440</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>Diameter</td>
<td>4</td>
<td>mm</td>
</tr>
<tr>
<td></td>
<td>Material</td>
<td>aluminium</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 6. EOG signal.
This signal had regular superimposed noise frequency 50 Hz or 60 Hz. Using low pass filter transfer function as in (9) with cut off frequency was 6 Hz, we could improve the signal performance shown in Fig. 7. In a glance, the pattern of EOG signal was looked pretty well to be recognized. This was the final signal form that could be used to control robot manipulator for the further experiment.

\[ H(s) = \frac{4\pi^2 f^2}{s^2 + 4\pi f \cos \frac{\pi}{4} s + 4\pi^2 f^2} \]  

Fig. 7. EOG signal after 6 Hz LPF.

After the processing signal, we studied the signal for up, down, right and left eye movement. There was a target display on the monitor (Fig. 8). The black line helped operator to track the red point as the target in horizontal and vertical line.

Fig. 8. Target display on the monitor.

This stage of experiment was not yet included the flexible robot manipulator part, because the goal in this section was only to study the characteristics of each signal (Fig. 9). The response of the signal, represented by the signal gradients, are available in table 2. The gradient combinations from two channels (Ch1 and Ch2) evidently represented four eye movement directions. In up and down eye movement, Ch1 and Ch2 give the same potential polarity but in case right and left eye movement, the polarities are different.

<table>
<thead>
<tr>
<th></th>
<th>Up</th>
<th>Down</th>
<th>Right</th>
<th>Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ch1</td>
<td>(-)</td>
<td>(+)</td>
<td>(-)</td>
<td>(+)</td>
</tr>
<tr>
<td>Ch2</td>
<td>(-)</td>
<td>(+)</td>
<td>(+)</td>
<td>(-)</td>
</tr>
</tbody>
</table>

5. Gaze Motion Recognition

As mentioned before, we had already succeed to secure EOG signal from NF Instrument, and we also made four combinations of the signal from Ch1 and Ch2 that meet the requirement for four eye movement directions. The next problem was how to detect when the eyes move. Since Elisa Magoso et al [17] showed that wavelet transform was successfully define the eye movement in sleep phase and Al-Amin Bhuiyan et al [18] described how gabor filter worked well on face recognition, we combined wavelet transform (19) and gabor filter (20). Wavelet transform played role to change time domain signal only to frequency, amplitude and time then gabor filter function was to detect when a movement appear.

\[ WT(a, b) = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{\infty} f(t) \psi(t - b/a) dt \]  

With \( t \) is time, \( a \) is scale and \( b \) is translation, we tried to find the pairs of them. We decided to set \( b \) value is 1 and \( 1/a = 0.31 \) because it could give appropriate time when a signal arise. Some signals with the variations of \( 1/a \text{ (oct)} \) are available in Fig. 10. There is a trend that the bigger \( a \) so the smoother signal, but we must keep the gap between two wave at a distance that
still can be separated well. Gabor filter used $\sigma=1$ and $\text{oct}=-\log_2 a$ it could define clearly when a signal arise.

$$\psi(t) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{t^2}{2\sigma^2}} e^{j\omega t}$$  \quad (11)

6. Experimental Results

This experiment was able to control the robot manipulator to go to the direction of gaze motion. Although there were some conditions when the unexpected movement appeared, the robot could be well hands-free operated with four general instructions: up, down, left and right. It can also realize the flexibility of the system operation. In this experiment, there was no depth study about the distance of end-effector motion, but it pure concerned on the fitting of manipulator movement and gaze motion. The problem on this system was the necessity of the operator to have good experience handling the tools, so it took time for operator training. The stability of the input and the correctness of the

Fig. 10. EOG signal after wavelet transform with scale $= 1$ and (a) translation $= 0.5$, (b) translation $= 0.25$, (c) translation $= 0.0125$, and (d) translation $= 0.031$.  

(223)
output depended on operator knowledge and experiment about this system. It was also sensitive to some events such as head movement, positions of electrodes, and face muscle. However, the signal from blink eye is also important to recognize if this system is developed for other applications. As long as the blink signal is not too big, we can still handle it well, but it can affect the operation if it is strong and reduce system accuracy because the blink signal is very similar to up signal from Ch1. As shown by Fig. 11, the signal from a blink is very similar to one from an upward gaze. More efforts are needed to differentiate these signals with more certainty [18]. Despite of the stability of the input and the correctness of the output depend on operator experience. Minimizing this requirement would make the system more useful.

The accuracy of gaze detection was also investigated. This is summarized in Table 3, where each rows lists the results from 100 trials of each gaze. The rightward gaze was the most accurately detected at 96%, while the most error prone was the leftward gaze at 87%. Errors were few, but when errors do occur, 72% of them showed up as false up or down indications, whereas the rest of them indicated the false left or right directions.

<table>
<thead>
<tr>
<th>Output Motion</th>
<th>U</th>
<th>D</th>
<th>L</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>U</td>
<td>92</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>4</td>
<td>90</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>L</td>
<td>8</td>
<td>3</td>
<td>87</td>
<td>2</td>
</tr>
<tr>
<td>R</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>96</td>
</tr>
</tbody>
</table>

7. Conclusion

In this study we focused on the potentials that existed around the orbit of eye to operate the end effector of robot manipulator. First, this signal was measured by placing the electrodes around the eye. Then, Those were analyzed to discover the diversity of the signal for right, left, up and down gaze motion. To detect the eye movement event, wavelet transform with gabor function was succeed with a good level of satisfaction. The combination of the electrode, Ch1 and Ch2, could be simply used to discriminate the directions of eye movements. This technique has the average probability success ratio more than 90% in up, down, right and left eye movement.

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References