Implementation of Fuzzy Logic System for Motor Motion Generation Based on Electrooculogram

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ABSTRACT

Electrooculography (EOG) is a technique that sensed eye movement based on recording of the standing cornea-retinal potential that existing between the cornea and retina. This electrooculography signal is known as electrooculogram that can be used to control the human machine interface (HMI) such as a wheelchair motion. The aim of this project was to control the motor by using EOG signals. The signals of eye movements were acquired using the EOG circuit. These data were passed to the fuzzy logic controller that was developed using MATLAB. As a result, the two DC motors were able to operate according to the rules set of fuzzy logic using the eye signals as inputs. The limitation of this project was the fuzzy logic controller rules and the membership functions were developed using MATLAB and then converted into Arduino coding. The Arduino Mega 2560 acts as the interface between the EOG circuit and DC motors. Then, the fuzzy logic controller was integrated into Arduino Mega 2560 in order to control the motion of motor. Besides, there were four (4) subjects, two males and two female, selected for the EOG data acquisition.

Keywords: *Electrooculography, wheelchair, DC motor, Fuzzy Logic Controller (FLC), rehabilitation purpose.*

Introduction

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Wheelchair is used by disabled person to help moving from one place to another place. Most of electric wheelchairs operate using joystick, keyboard and touch screen. These control require hands to operate, so it is not suitable for the handicapped and paralyzed person to use it. Thus introducing rehabilitation aid will allow them to become independent in doing several activities. The latest rehabilitation aid techniques are Human Machine Interface (HMI) and Human Computer Interface (HCI). The concept of HMI is converting signal produced by the human body gestures to control the electromechanical devices, while HCI uses signal from the human body to control the cursor movements [1]. There are two medium of controls for HCI and HMI: non-biosignal and biosignal. The examples of non-biosignal are tongue control and head movement tracking. Electrooculography and electromyography are the examples of biosignal. There are many applications developed to help people with several disabilities such as videooculography systems or infrared oculography based on the eye position using a camera [2].

There are several applications using eye movement such as controlling the electronic devices and rehabilitation aids. Besides, it also can guide and control the mobile robots using the signals that have been developed. One of them is a video-based tracking system. This system has a high accuracy, so it can be used as a communication tool between human and machine [3], [4]. However, this system is an expensive device, so the alternative for the eye-tracking system is based on the electrooculography. Basically, an EOG circuit is a low cost device , only used the common electrical components. Hopefully, this technology will expand and have lots of application in the future where only a gaze or blink of eye is used for controlling any machine especially in rehabilatation purpose.

This paper consisted of seven topics include the electrooculography (EOG) and data acquisition of EOG. The experimental setup and fuzzy logic controller (FLC) also discusses. Then followed by results and discussion. The last topic is a conclusion.

Electrooculography (EOG)

Electrooculography is a technique that sensed eye movement based on recording the standing cornea-retinal potential existing between the cornea and retina [5]. The EOG values ranges from 0.05 mV to 3.5 mV in human and linearly proportional to eye displacement [6], [7]. It has the range of frequency about 100Hz in direct current (DC) and changes approximately 0.02 mV for each degree of eye movement [10]. The EOG technique is inexpensive, easy to use, reliable and relatively unobtrusive compared with head-worn cameras that used in video-based mobile robots such as VOG [8]. The electrooculogram is acquired using five (5) electrodes that placed on the face as shown in Figure 1. The reference is an important to create safety electrical path off and also to protect the amplifier [9]. The horizontal position consists of left and right electrodes whereas vertical position consists of up and down electrodes [10], [11]. Table 1 shows the eye signal reflected for vertical and horizontal positions. Since the EOG signal is smaller, it needs to be amplified using operational amplifier such as AD620 [12]. This signal then needs to be converted using analog to digital converter such as Arduino Uno microcontroller and AT90USBKEY based on the ATMEL 8-bit AT90USB1287 microcontroller [13]. Most the converted signal is processed using MATLAB. The signal can be used to control the wheelchair motion by using microcontroller such as PIC 16F877 and LPC1788 [14].

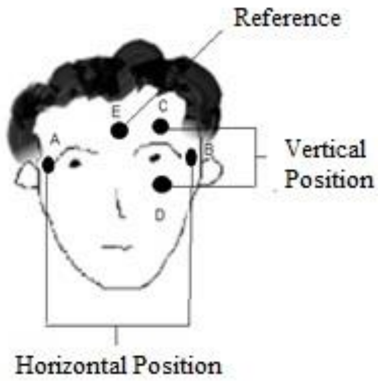

Figure 1: Electrode placement

Table 1: The eye signal reflected

Electrode Position	Signal Reflected
A	Left
B	Right
C	Up
D	Down

Experiment setup

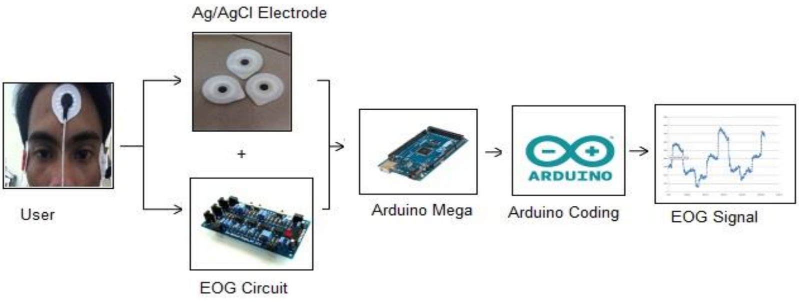

Figure 2: Experiment setup for acquaring EOG signal

In this experiment, the EOG data acquisition was acquired using Ag/AgCl electrodes. Figure 2 shows the experiment setup for EOG data acquisition. The EOG circuit was interfaced with Arduino Mega 2560 that acted as analog to digital converter. There were four (4) subjects, two males and two females, who were selected in order to get the data acquisition. The system was connected with the real motor in order to obeserve the effectiveness of the proposed control algorithm.

EOG Data Acquisition

The EOG circuit is made from Bio Medical Simple Kit series EOG (JUH CO., Ltd.) as shown in Figure 3. The gain in this instrumentation amplifier was 50. The high pass filter was 0.01 Hz with first amplifier with gain of 4. The notch filter was 60 Hz whereas the band pass filter for low pass filter and high pass filter were 40 Hz and 0.01 Hz. The gain for second amplifier are 20. The function of the first and second amplifier in this circuit was to increase the signal amplitude as EOG signal is too small. The total amplifier or gain in this EOG circuit is 4000. The function of high pass filter and low pass filter was to reject the noise that amplified by INA126. The function of notch filter was to cut off frequency of 60 Hz noise.

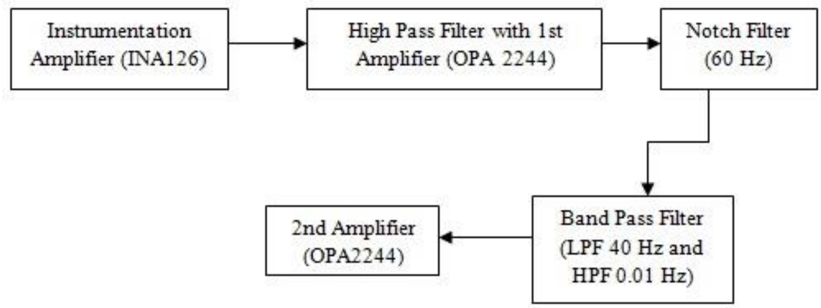

Figure 3: Block diagram of EOG circuit

Meanwhile, Figure 4 shows the EOG horizontal signal acquired using EOG circuit. It consisted of right and left EOG signals.

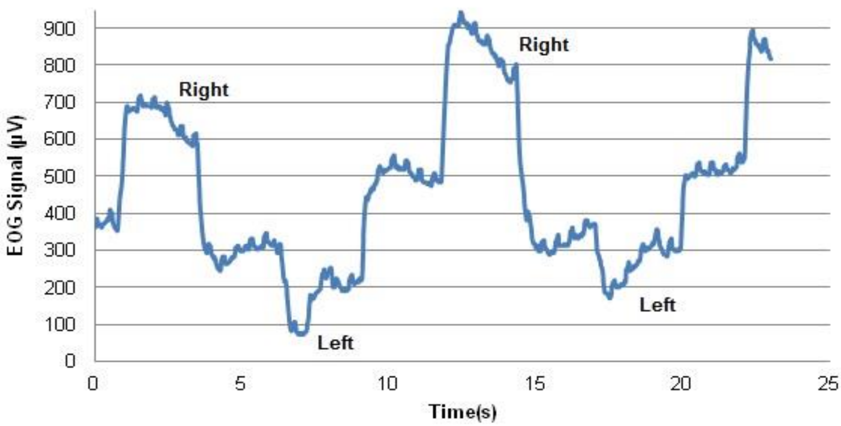

Figure 4: EOG Horizontal Signal

The averaged value of EOG horizontal signals were shown in Table 2 and Table 3 for right and left movement of eyes. These readings were taken from the four subjects calculated from Equation (1). Subject 1 and Subject 2 are males meanwhile Subject 3 and Subject 4 are females. There are five (5) readings were taken for every subject. In this project, the signal value from bit number (in digital) was converted into micro-voltage (µV) (in analog) using Equation (2).

$$\text{Average} = \frac{(1\text{st} + 2\text{nd} + 3\text{rd} + 4\text{th} + 5\text{th}) \text{ of readings}}{5} \quad (1)$$

$$\text{Voltage} = \frac{\frac{\text{Signal Value}}{255} \text{ x } 5\text{ V}}{4000} \quad (2)$$

Table 2: Averaged value of EOG horizontal signals for right movement

Subject	**Reading (μV)**					**Average (μV)**
	1st	**2nd**	**3rd**	**4th**	**5th**	
1	581.91	398.80	189.28	21.51	39.53	246.21
2	133.71	63.59	307.33	428.51	143.25	215.28
3	149.69	83.21	52.49	212.58	33.84	106.36
4	283.07	341.62	335.12	371.03	401.43	346.39

Table 3: Averaged value of EOG horizontal signals for left movement

Subject	**Reading (μV)**					**Average (μV)**
	1st	**2nd**	**3rd**	**4th**	**5th**	
1	657.53	802.86	844.59	871.89	881.96	811.77
2	849.92	896.02	710.26	926.47	994.26	875.39
3	629.18	726.39	622.76	625.24	828.29	686.37
4	735.37	678.33	594.92	573.38	577.91	631.98

From Table 2 and Table 3, the minimum and maximum voltage for the left eye movement was 106.36 μV and 346.39 μV. While the minimum and maximum voltage for the right eye movement was 631.98 μV and 875.39 μV. Based on these reading, it say to every person has their own reading of eye muscles, so that, the algorithm can generate using the minimum and maximum value. However, in this project, these analog values of EOG signal were converted into digital value, so that it could be used as the inputs for the fuzzy logic system using Equation (3).

$$\text{Digital Value} = \frac{\text{Voltage}}{5\text{V}} \text{ x } 255 \text{ x } 4000 \quad (3)$$

Algorithm for Motor Motion

Figure 5 shows the algorithm for the motor motion system. The user can chose the condition either to move in linear direction or angular direction.

This condition was displayed on the liquid crystal display (LCD). If the user chooses to move in linear motion, the eye's user should look to the left and then the linear condition will be displayed on LCD. However, in linear motion, the user has two conditions, either to move forward (FWD) or reverse (REV). The user was allowed to select any condition within 15 seconds before it looping back to the main menu. The user would move forward when he/she looking on the right and moving backward when he/she looking on the left. This condition was same for the angular motion. The user has 15 second before it looping back to the main menu. The user would move to the left when he/she looking to the left and to the right when he/she looking to the right

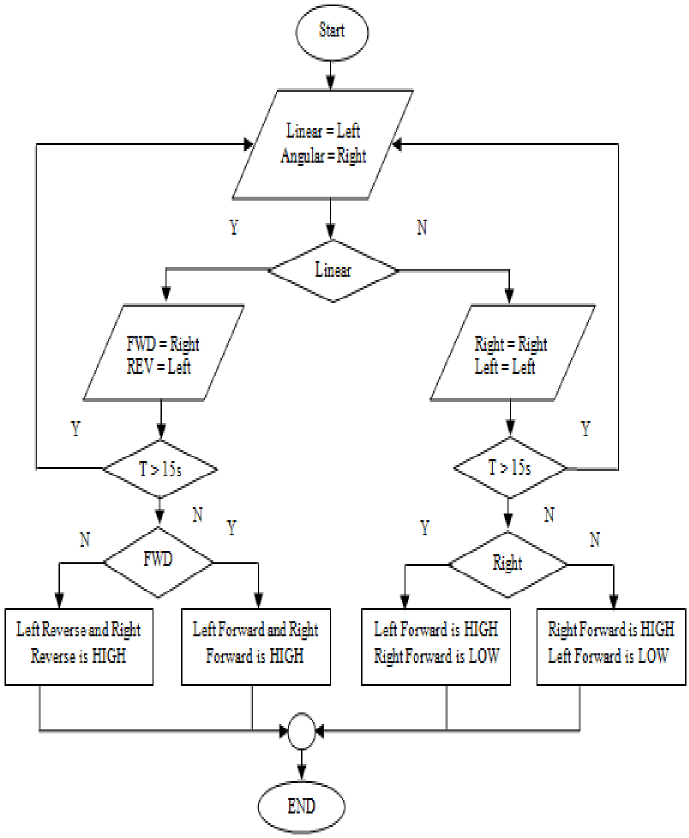

Figure 5: Algorithm of EOG wheelchair controller

Fuzzy Logic Controller (FLC)

The Sugeno fuzzy inference was used in this project because of constant output membership function compared with Mamdani fuzzy inference that have variable of output membership function such as triangular or singleton. The purpose of this fuzzy logic controller was to fuzzified the EOG signals into fuzzy variables. This fuzzy input would be deffuzified using weighted average method into crisp value. The rules was defined from EOG inputs based on the principle as shown in Table 4.

Table 4: Working principle

Eye movement	Preference
If eye is moving	Preference is depend on eye movement direction. The input from Ag/AgCl sensor will control the motor motion.

The triangular membership function was used for both input variables which is Signal1 and Signal2 as shown in Figure 6 and Figure 7. This membership function is simple, only required three points to forming a triangle. It consists of three membership functions which were Left, DN (Do Nothing) and Right. The range input for Left and Right for both input membership functions were 21 to 71 and 129 to 179 whereas for DN was 71 to 129.

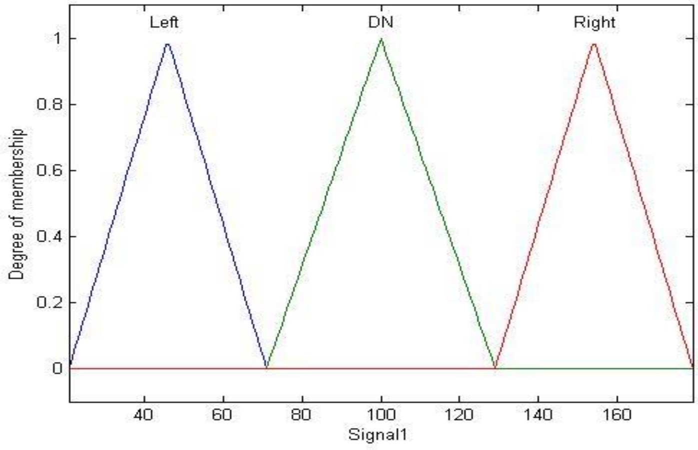

Figure 6: Input membership function for Signal1

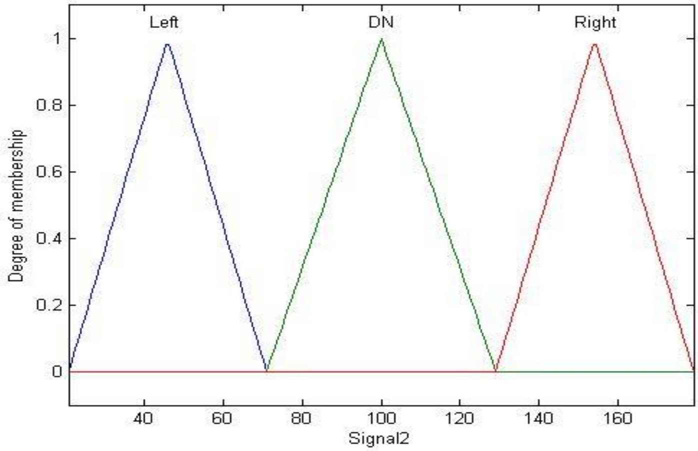

Figure 7: Input membership function for Signal2

The rules for the motor motion were defined as shown in Table 5. It consisted of nine (9) rules where the motor motion is depending on the Signal1 and Signal2. These rules were used to control the motor motion for wheelchair movement based on the EOG horizontal signals. The wheelchair was moving forward based on rules number 9 whereas it was reversing based on rules number 7. It will turning to the right direction based on rules 5 and to the left based on rules number 2. It was stop moving based on rules number 1, 3, 4, 6 and 8.

Table 5: Wheelchair based EOG control system rules

Rules	Input Variable		Output Variable (Motor Motion)				Wheelchair Motion
	S1	S2	LF	LR	RF	RR	
1	L	L	LOW	LOW	LOW	LOW	STOP
2	L	DN	LOW	LOW	HIGH	LOW	LEFT
3	L	R	LOW	LOW	LOW	LOW	STOP
4	R	L	LOW	LOW	LOW	LOW	STOP
5	R	DN	HIGH	LOW	LOW	LOW	RIGHT
6	R	R	LOW	LOW	LOW	LOW	STOP
7	DN	L	LOW	HIGH	LOW	HIGH	REVERSE
8	DN	DN	LOW	LOW	LOW	LOW	STOP
9	DN	R	HIGH	LOW	HIGH	LOW	FORWARD

*S1 = Signal1, S2 = Signal2, LF = Left Forward, LR = Left Reverse, RF = Right Forward, RR = Right Reverse, L = Left, R = Right, DN = Do Nothing

Results and Discussions

In this project, the signal from horizontal position: leftward and rightward direction were used as an input. The minimum and maximum value for the left and right eye movement were converted from the voltage (μV) into the digital value as shown in Table 6.

Table 6: Digital value for eye movement

Eye Movement	Minimum (bit)	Maximum (bit)
Left	21	71
Right	129	179

The purpose of this value was converted into the digital value due to use in the fuzzy logic controller. The fuzzy logic controller was developed and tested using MATLAB/SIMULINK. Figure 8 shows the block diagram of the fuzzy logic controller. The block diagram consisted of two inputs which are Signal1 and Signal2. It was also consisted of four (4) outputs which were LeftForward (LF), LeftReverse (LF), RightForward (RF) and RightReverse (RR).

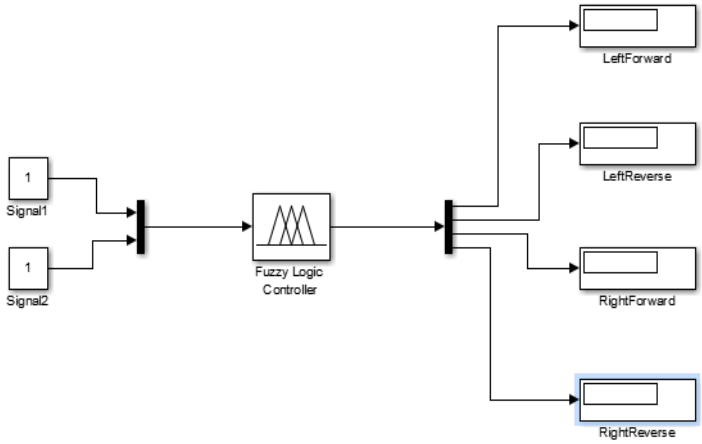

Figure 8: Block Diagram of Fuzzy Logic Controller

In this project, there were two conditions for the motor motion either linear motion or angular motion. Table 7 shows the conditions for both linear and angular motion.

Table 7: Linear and angular condition

No	Conditions	Signal Value(bit)
1	The main menu display condition to the user either to move in linear or angular direction.	Linear : 21 to 71 Angular : 129 to 179
2	The sub menu for linear direction is display when the user moves the eye to the left direction.	Forward : 129 < Signal2 < 179 and 71 < Signal1 < 129 Reverse: 21 < Signal2 < 71 and 71 < Signal1 < 129
3	The sub menu for angular direction is display when the user moves the eye to the right direction.	Right: 129 < Signal1 < 179 and 71 < Signal2 < 129 Left: 21 < Signal1 < 71 and 71 < Signal2 < 129

The main result for this projects, focused on the motion of motor. There were two motors used in this experiment which were attached on the wheels. Based on the algorithm and fuzzy logic controller, the motors were moved based on the rules. For example, if S1 was L (Left) and S2 was DN (Do Nothing), both motors wouls turn leftward. The summary of the motion of motor can be seen in Table 8.

Table 8: The wheelchair motion based on eye condition

Eye Signal		State				Result (Motion)
S1	S2	LF	LR	RF	RR	
L	DN	0	0	1	0	LEFT
R	DN	1	0	0	0	RIGHT
DN	L	0	1	0	1	REVERSE
DN	R	1	0	1	0	FORWARD
DN	DN	0	0	0	0	STOP

*S1 = Signal1, S2 = Signal2, LF = Left Forward, LR = Left Reverse, RF = Right Forward, RR = Right Reverse, L = Left, R = Right, DN = Do Nothing

Conclusion

In conclusion, the objective to control the DC motor motion by using EOG signals was achieved. The motion of DC motor was depended on the option selected by the user. Then the fuzzy logic controller can be implemented as a controller for this system. It is recommended in the EOG data acquisition, the lead wires should be twisted and not shake as possible to minimize the effects of external noise. Therefore, the eye signals can be used as a communication tools such as wheelchair, prosthetic limb and human machine interface.

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