Recognition of horizontal gaze motion based on electrooculography using tsugeno fuzzy logic

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Abstract. Electrooculography is a biosignal activity generated from the human’s eyes activity. In this research, the eyes movements (left and right) were recognized by processing the EOG signal. The eyes movements in the horizontal movement were identified from the direction and the magnitude of the gaze angle. The direction of the eyes movements was detected using the polarity of the signal whereas the magnitude of gaze angle was computed using Tsugeno fuzzy method with two approaches, namely area of signal and peak of the signal. The system was able to detect the direction of gaze motion with the accuracy of 100%. The accuracy of the EOG signal in calculating the magnitude of the gaze angle was 93.46% for the right and 89.88% for the left. The number was higher compared to the performance of the peak point with the accuracy of 88.06% for the right and 84.79% for the left. The result in this paper showed that the system was able to detect the direction of eyes movements very well. However, the calculation of the magnitude of eyes movements is still a challenge to be improved in the future.

1. Introduction
Electrooculography (EOG) is a biosignal from eyes activity. EOG occurs because of difference polarity between cornea and retina [1]. Eyes activities such as gaze motion and blink can be distinguished by EOG signal [2]. EOG has a linear relationship with the magnitude of eye gaze angle. This linear condition of EOG happens at ± 45° for horizontal movement and between -38.7° and +30.7° in the vertical [3].

The threshold method has been developing as the basis for the EOG signal recognition process. EOG signal polarity is defined by using the threshold value. Positive polarity is the condition when EOG signal passes the positive threshold value, and negative polarity is the condition when EOG signal passes the negative threshold value [4]. Based on the polarity, EOG signal can distinguish the direction of eyes movement such as up, down, left and right. The polarity of EOG signal can be utilized as a robot motion controller, with four motion directions [5], as well as a controller for object tracking robot in 2D [4] and 3D [6].

The ability of EOG to distinguish eyes activity has contributed not only in the medical field where the eyes movements were used as eye-writing recognition system for stroke patients [7] but also in the control function of tools to help human’s tasks. EOG signal is used to operate the warning system at the hospital. Hospital alarm works by using blink movements in patients as an alarm, which sequence and duration of blink movements differ from the gaze movements [8].
In the research [9], the computer was operated by recognizing eyes movements to replace mouse to play a serious game. EOG signal was processed by recognizing the movement signal using wavelet transform and for signal reconstruction using DWT and SWT methods. The accuracy rate of the system in the first test, the average error reached 2.6, but the error decreased to 0.3 for women and 0.4 for men after the fifth test.

Wheelchairs control for a start and stop switch can be processed using EOG signal from eye blinks, with a waveform detection algorithm that distinguishes the intended and unintended blinks based on synchronization between the blink and the switch button. The average accuracy of this system was 99.5%, response time (RT) reached 1.35 for switch command in the control state, and the average of False Positive Rate (FPR) reached 0.10/min in the idle state [10].

EOG features used to process the EOG signal are an area of the signal [6] and the peak of the signal [4]. These features display the pattern of the EOG signal in every eyes movement. Fuzzy logic as an intelligent system that can map the information of eyes movements from EOG signal [11].

This research aims to detect the direction and the magnitude of human eyes movements in horizontal gaze motion. Two features of the EOG signals that studied were an area of signal and peak of the signal. The performance of the system in recognizing eyes activity was compared to using the two features. The system used the Fuzzy Logic algorithm in processing data input.

2. Method
2.1. System architecture

Based on Figure 1, the system begins by detecting and recording the eyes signal using a transducer, one type of surface electrode. Four electrodes were used; two for Channels (CH1 and CH2), one for Ground (G) and one for reference (R). Channel electrode was positioned on the muscles around the eyes [5].

The signal detected by the electrode (from now on is called EOG signal) was passed to the circuit of Amplifiers and Filters to be processed. The amplifier circuit is a circuit that functions to strengthen the voltage and current inputs. The amplifier circuit consists of three amplifiers namely IC AD320 with a gain of 495 times, and IC LM324 for the second and the third amplifier with a gain of 1.25 times and 13.6 times. The filter circuit is an electrical circuit designed to pass or hold signals on a specific frequency area. The filter used was BPF (Band Pass Filter) with frequency cutoff of 1.33 Hz-10.61 Hz.

The processed EOG signal was received by National Instruments (NI) USB-6008 via Analog pins to gain acquisition data which later was sent to the computer and displayed through the GUI in Visual Studio 2010 equipped with NI MAX library. Then, the EOG signal was recorded and saved in a .csv file. A Fuzzy Logic system was constructed using MATLAB software for signal recognition from the recorded data.
2.2. **EOG features**

Four EOG features used in this system were positive threshold value, negative threshold value, area of signal and peak of the signal. The threshold value is the limit values that distinguish noise with the EOG signal. The threshold value used was 0.2 mV for a positive threshold and -0.2 mV for a negative threshold. Area of the signal in this research is the area under the curve of the EOG signal. The system begins to calculate the EOG value when EOG signal passes over the threshold. This calculation ends when EOG signal value is zero. The threshold value is also used to set the peak of the EOG signal. The peak of the EOG signal is shaped like a half-wave. The peak value is obtained by comparing the current EOG signal with the previous EOG signal. The largest EOG signal is selected as the peak of the EOG signal. The four EOG features can be seen as in Figure 2.

![Figure 2. Area signal of EOG and peak signal of EOG](image)

2.3. **The polarity of signal to detect direction**

This research was focused on the detection of horizontal gaze motion (left and right). The polarity of the EOG signal on the eye movements to the right and left is shown in Figure 3 and 4. EOG signal which the peak value is above the positive threshold marked as EOG signal with positive polarity is shown on blue signal (CH1) in Figure 3 and the red signal (CH2) in Figure 4. Whereas EOG signal which the peak value is below the negative threshold is named as EOG signal with negative polarity, shown on the red signal (CH2) in Figure 3 and the blue signal (CH1) in Figure 4. The polarity pair of each channel for the left and right movements is depicted in Table 1 as follows.

![Figure 3. The polarity of EOG Signal of Right Gaze](image)  
![Figure 4. The polarity of EOG Signal of Left Gaze](image)
Table 1. Relationship of CH1-CH2 against eye motion

| Movement | Right | Left | No Movement |
|----------|-------|------|-------------|
| CH1      | +     | –    | -0.2 < x < 0.2 |
| CH2      | –     | +    | -0.2 < x < 0.2 |

2.4. Fuzzy logic to detect gaze angle
When the direction of movements was established using the signal polarity, fuzzy logic worked to calculate the angle of eyes movements. The input of fuzzy logic is the EOG signal of CH1 and CH2.

The method used in the fuzzy logic system was Tsugeno method, with the implication of intersection. The implication phase to intersect the membership degree value of CH1 and CH2 was generating a value for predicate which later is processed in defuzzification. Furthermore, the defuzzification used Weight Average (WA) method. WA method as the defuzzifier generated angular value. The output of the defuzzification process was the angular value of the eyes movements. The fuzzy process of the system can be seen as in Figure 5.

2.5. Experimental design
The objects of the experiment were four points of each gaze direction as seen in Figure 6 (object points). The distance of object points from the central point was 8 cm, 16 cm, 32 cm, and 24 cm. The angle of the eye movements was calculated from the central point to the object points. With the eyes distance to the central point was 40 cm; the angle of eye movements was operated by Pythagoras theorem. EOG signal was recorded on point 1, point 2, point 3 and point 4 for each gaze direction. Each point represented the magnitude of object distance from the user’s eyes; small, rather small, rather big and big.

Figure 6. The eye position at gazing on object point to the right and the left
2.5.1. *Experiment to design membership function*

Two data were obtained from the EOG signal, namely data of the area of the signal and the peak of the signal. Two fuzzy systems were constructed based on these two data.

Four fuzzy sets were assigned based on the distance size of the object point for each system. Then a membership function for each set was formed. The membership function is a curve that shows the mapping of the input data points into the membership value or membership degrees (\( \mu [x] \)).

Membership value was obtained with the function approach. Function approach used was the representation of the triangular curve. The triangular curve along with the domain of membership function is depicted in Figure 7.

![Membership function](image)

**Figure 7.** Triangle curve

Domain Max (c), Min (a) and Mean (b) was required to build membership function. Max (c) is the highest value from area/peak data, Min (a) is the lowest value from area/peak data and Mean (b) is the average value from area/peak data, \( x \) is the input of the fuzzy system to obtain the membership degree value from \( x (\mu [x]) \).

2.5.2. *Experiment to evaluate the fuzzy system*

Once the membership function was formed for every set; Small (S), Rather Small (RS), Rather Big (RB) and Big (B), Rule-Base System was established. The fuzzy rule was used as a reference in determining the fuzzy output. There are four conditions for decision-making; Near (N), Rather Near (RN), Rather Far (RF) and Far (F).

**Table 2.** Tables of the fuzzy rule, based on Area of Signal; (a) Right gaze, (b) Left gaze, and based on Peak of Signal; (c) Right gaze and (d) Left gaze

| CH1 | S  | RS | RB | B  |
|-----|----|----|----|----|
| S   | N  | N  | N  | N  |
| RS  | N  | RN | RF | RF |
| RB  | N  | RN | RF | F  |
| B   | N  | RF | RF | F  |  
| (a) |    |    |    |    |

| CH1 | S  | RS | RB | B  |
|-----|----|----|----|----|
| S   | N  | N  | N  | N  |
| RS  | N  | RN | RF | RF |
| RB  | N  | RN | RF | F  |
| B   | N  | RF | RF | F  |  
| (b) |    |    |    |    |

| CH1 | S  | RS | RB | B  |
|-----|----|----|----|----|
| S   | N  | N  | N  | N  |
| RS  | N  | RN | RF | RF |
| RB  | N  | RN | RF | F  |
| B   | N  | RN | RF | F  |  
| (c) |    |    |    |    |

| CH1 | S  | RS | RB | B  |
|-----|----|----|----|----|
| S   | N  | N  | N  | N  |
| RS  | N  | N  | RF | F  |
| RB  | N  | RN | RF | F  |
| B   | N  | RN | RF | F  |  
| (d) |    |    |    |    |
3. Result and discussion

3.1. Membership function

Five experiments from five respondents were performed resulting in 25 data: the area and the peak of EOG Signal as the input of the fuzzy system. The value of Max, Min and Mean were taken from the 25 data as the domain of membership function.

**Area of Signal**

Table 3 shows the domain value of the membership function for the fuzzy system of the area of the signal. Based on the area of the signal, membership function obtained from the right gaze; for CH1 presented on the formula (3), (4), (5), (6) and CH2 in the formula (7), (8), (9), (10). For the left gaze; CH presented on the formula (11), (12), (13), (14) and CH2 in the formula (15), (16), (17), (18).

| Points | Max (c) | Min (a) | Mean (b) |
|--------|---------|---------|----------|
|        | CH1 R L | CH1 R L | CH1 R L |
|        | CH2 R L | CH2 R L | CH2 R L |
| 8 cm   | 18.581  | 13.15   | 10.582  |
|        | 36.49   | 40.15   | 17.484  |
|        | 24.34   | 23.43   | 21.93   |
|        | 13.25   | 8.809   | 25.8    |
|        | 31.615  |         |         |
| 16 cm  | 27.557  | 18.48   | 18.387  |
|        | 62.48   | 66.49   | 34.044  |
|        | 20.558  | 11.48   | 21.93   |
|        | 53.002  | 58.21   | 45.7    |
|        | 4.723   | 52.723  |         |
| 24 cm  | 32.457  | 25.85   | 20.558  |
|        | 74.62   | 78.23   | 26.41   |
|        | 11.48   | 58.21   | 68.3    |
|        | 58.21   | 68.3    | 68.912  |
| 32 cm  | 40.666  | 28.37   | 22.506  |
|        | 102     | 107.5   | 68.79   |
|        | 582.10  | 87.6    | 84.494  |

Table 3 shows the domain value of the membership function for the fuzzy system of the area of the signal. Based on the area of the signal, membership function obtained from the right gaze; for CH1 presented on the formula (3), (4), (5), (6) and CH2 in the formula (7), (8), (9), (10). For the left gaze; CH presented on the formula (11), (12), (13), (14) and CH2 in the formula (15), (16), (17), (18).

\[
\hat{\mu}_{Small}[x] = \begin{cases} 
0, & x < 10.582 \\
10.582 - x, & 10.582 \leq x < 13.25 \\
13.25, & x \geq 13.25
\end{cases} 
\]

\( x \leq 10.582 \text{ or } x \geq 18.5813 \)

\( 10.582 \leq x \leq 13.25 \)

\( 13.25 \leq x \leq 18.5813 \)  \( (3) \)

\[
\hat{\mu}_{RatherSmall}[x] = \begin{cases} 
0, & x < 18.3867 \\
18.3867 - x, & 18.3867 \leq x < 21.437 \\
21.437, & x \geq 21.437
\end{cases} 
\]

\( x \leq 18.3867 \text{ or } x \geq 25.5573 \)

\( 18.3867 \leq x \leq 21.437 \)

\( 21.437 \leq x \leq 25.5573 \)  \( (4) \)

\[
\hat{\mu}_{RatherBig}[x] = \begin{cases} 
0, & x < 20.5584 \\
20.5584 - x, & 20.5584 \leq x < 26.5117 \\
26.5117, & x \geq 26.5117
\end{cases} 
\]

\( x \leq 20.5584 \text{ or } x \geq 32.4567 \)

\( 20.5584 \leq x \leq 26.5117 \)

\( 26.5117 \leq x \leq 32.4567 \)  \( (5) \)

\[
\hat{\mu}_{Big}[x] = \begin{cases} 
0, & x < 22.506 \\
22.506 - x, & 22.506 \leq x < 29.54 \\
29.54, & x \geq 29.54
\end{cases} 
\]

\( x \leq 22.506 \text{ or } x \geq 40.666 \)

\( 22.506 \leq x \leq 29.54 \)

\( 29.54 \leq x \leq 40.666 \)  \( (6) \)
\[
\mu_{\text{Small}}[x] = \begin{cases} 
0, & x \leq 14.784 \\
\frac{x - 14.784}{25.8 - x}, & 14.784 \leq x \\
\frac{25.8 - 14.784}{25.8 - x}, & 25.8 \leq x \\
36.49 - 25.8, & x \geq 36.49
\end{cases}
\]
\]
\[
x \leq 17.484 \text{ or } x \geq 36.49
\]

\[
\mu_{\text{RatherSmall}}[x] = \begin{cases} 
0, & x \leq 34.044 \\
\frac{x - 34.044}{45.7 - x}, & 34.044 \leq x \\
\frac{45.7 - 34.044}{45.7 - x}, & 45.7 \leq x \\
62.48 - 45.7, & x \geq 62.48
\end{cases}
\]
\]
\[
x \leq 34.044 \text{ or } x \geq 62.48
\]

\[
\mu_{\text{RatherBig}}[x] = \begin{cases} 
0, & x \leq 53.002 \\
\frac{x - 53.002}{68.3 - x}, & 53.002 \leq x \\
\frac{68.3 - 53.002}{68.3 - x}, & 68.3 \leq x \\
74.62 - 68.3, & x \geq 74.62
\end{cases}
\]
\]
\[
x \leq 53.002 \text{ or } x \geq 74.62
\]

\[
\mu_{\text{Big}}[x] = \begin{cases} 
0, & x \leq 68 \\
\frac{x - 68}{87.6 - 68}, & 68 \leq x \\
\frac{87.6 - x}{87.6 - 102}, & 87.6 \leq x \\
102 - 87.6, & x \geq 102
\end{cases}
\]
\]
\[
x \leq 68 \text{ or } x \geq 102
\]

\[
\mu_{\text{Small}}[x] = \begin{cases} 
0, & x \leq 3.692 \\
\frac{x - 3.692}{8.809 - x}, & 3.692 \leq x \\
\frac{8.809 - x}{13.15 - 8.809}, & 8.809 \leq x \\
13.15 - 8.809, & x \geq 13.15
\end{cases}
\]
\]
\[
x \leq 3.692 \text{ or } x \geq 13.15
\]

\[
\mu_{\text{RatherSmall}}[x] = \begin{cases} 
0, & x \leq 10.28 \\
\frac{x - 10.28}{14.7 - x}, & 10.28 \leq x \\
\frac{14.7 - x}{18.48 - 14.7}, & 14.7 \leq x \\
18.48 - 14.7, & x \geq 18.48
\end{cases}
\]
\]
\[
x \leq 10.28 \text{ or } x \geq 18.48
\]

\[
\mu_{\text{RatherBig}}[x] = \begin{cases} 
0, & x \leq 11.48 \\
\frac{x - 11.48}{19.22 - x}, & 11.48 \leq x \\
\frac{19.22 - x}{25.85 - 19.22}, & 19.22 \leq x \\
25.85 - 19.22, & x \geq 25.85
\end{cases}
\]
\]
\[
x \leq 11.48 \text{ or } x \geq 25.85
\]

\[
\mu_{\text{Big}}[x] = \begin{cases} 
0, & x \leq 14.63 \\
\frac{x - 14.63}{21.41 - x}, & 14.63 \leq x \\
\frac{21.41 - x}{28.37 - 21.41}, & 28.37 \leq x \\
28.37 - 21.41, & x \geq 28.37
\end{cases}
\]
\]
\[
x \leq 14.63 \text{ or } x \geq 28.37
\]
\[ \mu_{\text{Small}}[x] = \begin{cases} 
0, & x \leq 23.43 \\
\frac{x - 23.43}{31.615 - 23.43}, & 23.43 \leq x \leq 31.615 \\
\frac{31.615 - x}{40.15 - 31.615}, & 31.615 \leq x \leq 40.15 
\end{cases} \] (15)

\[ \mu_{\text{Rather Small}}[x] = \begin{cases} 
0, & x \leq 40.65 \\
\frac{x - 40.65}{52.723 - 40.65}, & 40.65 \leq x \leq 52.723 \\
\frac{52.723 - x}{66.49 - 52.723}, & 52.723 \leq x \leq 66.49 
\end{cases} \] (16)

\[ \mu_{\text{Rather Big}}[x] = \begin{cases} 
0, & x \leq 58.21 \\
\frac{x - 58.21}{68.921 - 58.21}, & 58.21 \leq x \leq 68.921 \\
\frac{68.921 - x}{78.23 - 68.921}, & 68.921 \leq x \leq 78.23 
\end{cases} \] (17)

\[ \mu_{\text{Big}}[x] = \begin{cases} 
0, & x \leq 67.79 \\
\frac{x - 67.79}{84.494 - 67.79}, & 67.79 \leq x \leq 84.494 \\
\frac{84.494 - x}{107.5 - 84.494}, & 84.494 \leq x \leq 107.5 
\end{cases} \] (18)

**Peak of Signal**

| Points | Max (c) | Min (a) | Mean (b) |
|--------|---------|---------|----------|
|        | CH1 | CH2 | CH1 | CH2 | CH1 | CH2 |
| Gaze   | R | L | R | L | R | L | R | L | R | L |
| 8 cm   | 0.293 | -0.065 | -0.52 | 0.641 | 0.119 | -0.26 | -0.628 | 0.4361 | 0.201 | -0.176 | -0.573 | 0.529 |
| 16 cm  | 0.487 | -0.208 | -0.83 | 1.091 | 0.201 | -0.382 | -1.129 | 0.8043 | 0.308 | -0.298 | -0.940 | 0.916 |
| 24 cm  | 0.528 | -0.208 | -0.94 | 1.418 | 0.201 | -0.464 | -1.2 | 1.1828 | 0.372 | -0.318 | -1.08 | 1.282 |
| 32 cm  | 0.559 | -0.208 | -1.02 | 1.582 | 0.222 | -0.546 | -1.292 | 1.2135 | 0.373 | -0.312 | -1.139 | 1.4246 |

Table 4 shows the domain value of membership function for the fuzzy system of the peak of the signal. Based on the peak of the signal, membership function obtained from the right gaze; for CH1 is presented on the formula (19), (20), (21), (22) and CH2 in the formula (23), (24), (25), (26). For the left gaze; CH1 presented on the formula (27), (28), (29), (30) and CH2 in the formula (31), (32), (33), (34).

\[ \mu_{\text{Small}}[x] = \begin{cases} 
0, & x \leq 0.119 \\
\frac{x - 0.119}{0.201 - 0.119}, & 0.119 \leq x \leq 0.201 \\
\frac{0.201 - x}{0.293 - 0.201}, & 0.201 \leq x \leq 0.293 
\end{cases} \] (19)
\[ \mu_{\text{RatherSmall}}[x] = \begin{cases} 0, & x > 0.201 \lor x \geq 0.487 \\ \frac{0.308 - x}{0.308 - 0.201}, & 0.201 \leq x \leq 0.308 \\ \frac{0.487 - x}{0.487 - 0.308}, & 0.308 \leq x \leq 0.487 \end{cases} \]

(20)

\[ \mu_{\text{RatherBig}}[x] = \begin{cases} 0, & x > 0.201 \lor x \geq 0.528 \\ \frac{0.372 - x}{0.372 - 0.201}, & 0.201 \leq x \leq 0.372 \\ \frac{0.528 - x}{0.528 - 0.372}, & 0.372 \leq x \leq 0.528 \end{cases} \]

(21)

\[ \mu_{\text{Big}}[x] = \begin{cases} 0, & x > 0.222 \lor x \geq 0.559 \\ \frac{0.373 - x}{0.373 - 0.222}, & 0.222 \leq x \leq 0.373 \\ \frac{0.559 - x}{0.559 - 0.373}, & 0.373 \leq x \leq 0.559 \end{cases} \]

(22)

\[ \mu_{\text{Small}}[x] = \begin{cases} 0, & x > -0.628 \lor x \geq -0.52 \\ \frac{-0.573 - x}{-0.573 - (-0.628)}, & -0.628 \leq x \leq -0.573 \\ \frac{-0.52 - x}{-0.52 - (-0.573)}, & -0.573 \leq x \leq -0.52 \end{cases} \]

(23)

\[ \mu_{\text{RatherSmall}}[x] = \begin{cases} 0, & x > -1.129 \lor x \geq -0.83 \\ \frac{-1.29 - x}{-1.29 - (-1.129)}, & -1.29 \leq x \leq -0.940 \\ \frac{-0.940 - x}{-0.940 - (-1.08)}, & -0.940 \leq x \leq -0.83 \end{cases} \]

(24)

\[ \mu_{\text{RatherBig}}[x] = \begin{cases} 0, & x > -1.2 \lor x \geq -1.02 \\ \frac{-1.08 - x}{-1.08 - (-1.2)}, & -1.2 \leq x \leq -1.08 \\ \frac{-0.94 - x}{-0.94 - (-1.08)}, & -1.08 \leq x \leq -0.94 \end{cases} \]

(25)

\[ \mu_{\text{Big}}[x] = \begin{cases} 0, & x > -1.292 \lor x \geq -1.02 \\ \frac{-1.139 - x}{-1.139 - (-1.292)}, & -1.292 \leq x \leq -1.139 \\ \frac{-1.139 - x}{-1.139 - (-1.02)}, & -1.139 \leq x \leq -1.02 \end{cases} \]

(26)

\[ \mu_{\text{Small}}[x] = \begin{cases} 0, & x > -0.26 \lor x \geq -0.065 \\ \frac{-0.176 - x}{-0.176 - (-0.26)}, & -0.26 \leq x \leq -0.176 \\ \frac{-0.065 - x}{-0.065 - (-0.176)}, & -0.176 \leq x \leq -0.065 \end{cases} \]

(27)

\[ \mu_{\text{RatherSmall}}[x] = \begin{cases} 0, & x > -0.382 \lor x \geq -0.208 \\ \frac{-0.298 - x}{-0.298 - (-0.382)}, & -0.382 \leq x \leq -0.298 \\ \frac{-0.298 - x}{-0.298 - (-0.298)}, & -0.298 \leq x \leq -0.208 \end{cases} \]

(28)
$\mu_{\text{RatherBig}}[x] = \begin{cases} 0, & x \leq (-0.464) \lor x \geq (-0.208) \\ (-0.318) \leq x \leq (-0.318) \\ (-0.208) \leq x \\ \end{cases}$

$\mu_{\text{Big}}[x] = \begin{cases} 0, & x \leq (-0.546) \lor x \geq (-0.208) \\ (-0.312) \leq x \leq (-0.312) \\ (-0.208) \leq x \\ \end{cases}$

$\mu_{\text{Small}}[x] = \begin{cases} 0, & x \leq 0.4361 \lor x \geq 0.641 \\ 0.529 \leq x \leq 0.529 \\ 0.641 \leq x \\ \end{cases}$

$\mu_{\text{RatherSmall}}[x] = \begin{cases} 0, & x \leq 0.8043 \lor x \geq 0.916 \\ 0.916 \leq x \leq 0.916 \\ \end{cases}$

$\mu_{\text{RatherBig}}[x] = \begin{cases} 0, & x \leq 1.1828 \lor x \geq 1.418 \\ 1.282 \leq x \leq 1.282 \\ \end{cases}$

$\mu_{\text{Big}}[x] = \begin{cases} 0, & x \leq 1.2135 \lor x \geq 1.582 \\ 1.4246 \leq x \leq 1.4246 \\ \end{cases}$

### 3.1.2. Fuzzy system accuracy

Accuracy system test was conducted after the system of fuzzy recognition was constructed. The test was conducted by giving four target points for each left and right side (eight points in the horizontal gaze) to be seen by the subject. The test was conducted by five subjects with five times of experiments for each point (200 test data). Accuracy was obtained by comparing the results of eyes movement recognition in the angular domain between the output of the constructed fuzzy system and the theoretical result. As shown from Table 5, the accuracy of two fuzzy systems was obtained; area of signal 91.67% and the peak of signal 86.43%.

| Gaze Angle | Area of Signal | Peak of Signal |
|------------|----------------|----------------|
|            | Accuracy (%)    |                |
| Right      | Left            | Right          | Left          |
| 11.3°      | 96.65           | 99.91          | 99.13         | 83.3          |
| 21.8°      | 98.4            | 91.17          | 84.05         | 90.25         |
| 30.9°      | 96.41           | 90.2           | 91.5          | 80.81         |
| 38.66°     | 82.48           | 78.27          | 77.6          | 84.83         |
|            | 93.5            | 89.9           | 88.06         | 84.8          |
|            | 91.67           | 86.43          |               |               |
4. **Conclusion**

The system was able to identify the direction of eyes movements using signal polarity and calculate the magnitude of gaze direction using the fuzzy method. The fuzzy system successfully recognized the EOG signal for the horizontal gaze motion by constructing membership function. Membership function was constructed with the data from the area of the signal and the peak of the signal. The accuracy of a fuzzy system based on the area of the signal was better than a fuzzy system based on the peak of the signal. Nevertheless, both have the average accuracy that exceeded 85%.

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