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FUZZY-BASED CLASSIFIER DESIGN FOR DETERMINING THE EYE MOVEMENT DATA AS AN INPUT REFERENCE IN WHEELCHAIR MOTION CONTROL

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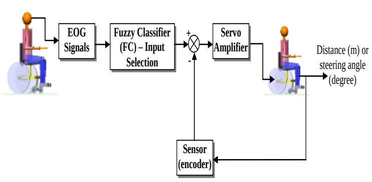
Graphical abstract



Abstract

Fuzzy logic is widely used in many complex and nonlinear systems for control, system identification and pattern recognition problems. The fuzzy logic controller provides an alternative to the PID controller which is a good tool for control of systems that are difficult to model. In this paper, the fuzzy-based classifiers were designed in order to determine the eye movement data. These data were used as an input reference in wheelchair motion control. Then, a set of an appropriate fuzzy classification (FC) was designed based on the numerical data from eye movement data acquisitions that obtained from the electrooculogram (EOG) technique. Each fuzzy rule (FR) for this system is based on the form of IF-THEN rule. Since membership functions (MFs) are generated automatically, the proposed fuzzy learning algorithm can be viewed as a knowledge acquisition tool for classification problems. The experimental results on eye movement data were presented to demonstrate the contribution of the proposed approach for generating MFs using MATLAB simulink for linear motion in forward direction.

Keywords: Fuzzy logic, wheelchair, bio-potential, eye movement, Electrooculogram (EOG)

1.0 INTRODUCTION

Fuzzy logic controller (FLC) is viewed as an artificial decision maker that operates in a closed-loop system in real time. It gathers the plant output data, compares it with the reference input, and then decides what the plant input should be acting to ensure the performance objectives are met based on the rules. Therefore, to design a fuzzy controller, the control engineer must gather information on how the artificial decision maker should act in the closed-loop. This information can come from the understanding of the plant's dynamics and write down the rules on how to control the system. These 'rules' basically say, if the plant output and reference input are behaving in a certain manner, then the plant input should be some value [1-2].

Fuzzy logic systems (FLS) are rule-based systems in which the input is first *fuzzified* (i.e., converted from a crisp number to a fuzzy set) and subsequently processed by the inference engine that retrieves knowledge in the form of fuzzy rule-based. The fuzzy sets computed by the fuzzy inference as the output of each rule are then composed and *defuzzified* (i.e., converted from a fuzzy set to a crisp number). The fuzzy sets is an adequate theory to develop classification tools for modeling cognitive human processes that related to the aspects of recognition [3-5]. Therefore, the fuzzy logic system is a nonlinear mapping from the input to the output space [6-8]. The fuzzy logic (FL) is based on the fuzzy sets theory, provides a natural way for constructing fuzzy IF-THEN rules that are closer to human decision making process by using linguistic interpretations in a mathematical framework [9-10]. These fuzzy classifications are used in determining the input reference based on the eye movement for controlling the wheelchair motion. This paper presents the membership functions (MFs) and the rules for the input reference for each movement of the wheelchair. In addition, a set of an appropriate FCs are discovered from the eye movement data acquisition. Since MFs are generated automatically, the proposed fuzzy learning algorithm can be viewed as a knowledge acquisition tool for classification problems.

The rest of this paper is organized as follows: Section 2 briefly describes the data acquisitions that are getting from the eye movement. Then followed by Section 3, describes the related works about generating MFs for input reference. Section 4 describes the computational results of the proposed approach and finally, the conclusion is discussed in Section 5.

2.0 EYE MOVEMENT DATA ACQUISITION

In order to generate the membership functions (MFs) for fuzzy classification, the data acquisitions from the eye movement signal are collected using the Ag/AgCl electrodes, which these electrodes were attached near to the eye according to the motion of wheelchair. These data were collected using the g.USBamp amplifier that is easily configured via MATLAB/SIMULINK environment (MATLAB version 7.0.1 (R14SP1)). Figure 1 shows the overall block diagram of data acquisition set up for EOG-based wheelchair motion control. This wheelchair model was developed using MSC. Visual Nastran 4D.

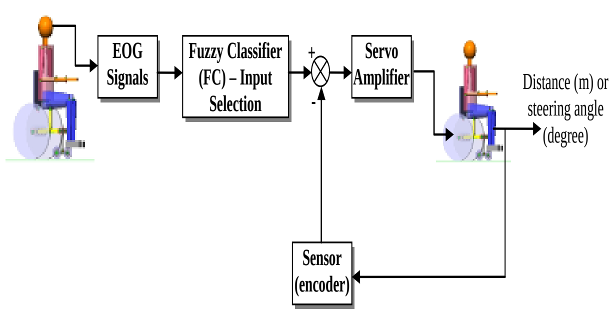


Figure 1 EOG-based wheelchair motion control

Based on [11], the different strengths of eye movement will give the different value of eye movement for different people. In this experiment, the goggle is used to differentiate the different levels for eye movement, where the three positions with the distance is 7 mm between levels to other level were marked for each eye movement. The objective of this step is to know the effect of eye movement signals on the different levels of eye movement strength. The data for each eye movement of each strength level were collected and then the averaged. There are five readings were taken for each level of eye movement in 20 s. The result for each eye movement and distance can be seen in Table 1 for straight motion in forward direction.

3.0 FUZZY-RULE-BASED CLASSIFICATION

The purpose of this FC is to generate the condition for selecting the respective distance input based on the eye movement data. There are four types of eye input signals; (inputeye_down), (inputeye_up), (inputeye_left) and (inputeye_right). The output parameters are distance (m). The FC is designed for selection of the different corresponding input distance based on the strength of the eye movement. In this case, only focus on eye movement in forward direction. Since it is known that wheelchair user in tetraplegic category might have different ability or strength to move their eye, thus this will affect the corresponding distance input signal set point for wheelchair motion. Therefore, FC here is used to select the proper distance input based on the strength of the eye movement signal.

For eye movement in upward direction, the domain of input parameter was divided into four subsets: Positive High (PH), Positive Medium (PM), Positive Low (PL) and Zero (Z) as shown in Figure 2 based on the positive signal values for upward direction. The mix of trapezoidal, triangular and singleton type MF have been used representing (inputeye_up). The range of the fuzzy input depends on the range of the input of eye signal which is 0 – 2 x 10^{-4} V. Meanwhile, the domain of output parameter was divided into four subsets: Long Distance (LD), Medium Distance (MD), Short Distance (SD), and Zero (Z) as shown in Figure 3. The range for the output distance is between 0 to - 1 m.

Table 1 Eye inputs of upward eye movement with the output distance in forward direction

Eye movement	Eye inputs	Output distance
up_1	0.8 x 10^{-4} V	0.27 m
up_2	1.1 x 10^{-4} V	0.48 m
up_3	1.7x 10^{-4} V	0.75 m

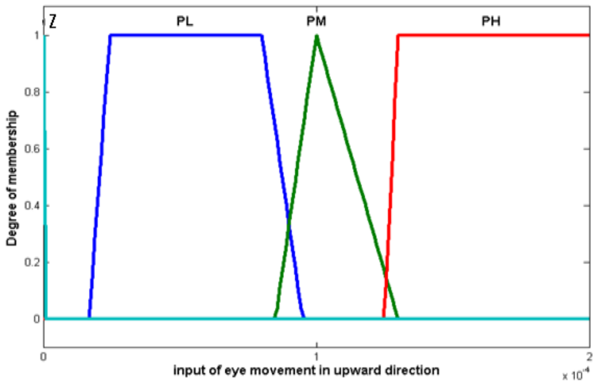


Figure 2 Fuzzy set for (Inputeye_Up)

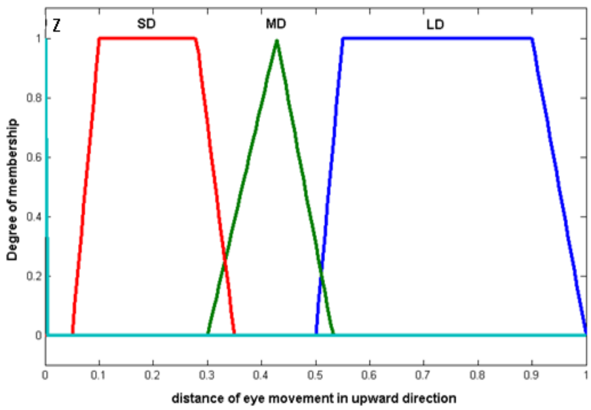


Figure 3 Fuzzy set for output distance

Fuzzy rule is the second element in identification the first FLC system designed. In this proposed system, there are four rules designed which are derived to give the selection condition for the input position or rotation that depends on the eye movement input signal.

The fuzzy rules for eye movement in upward direction are:-

IF inputeye_up is PH, THEN the position is LD
IF inputeye_up is PM, THEN the position is MD
IF inputeye_up is PL, THEN the position is SD
IF inputeye_up is zero, THEN the position is Z

4.0 FUZZY-RULE-BASED CONTROL MOTION

For linear motion control, the fuzzy controller is required to control the wheelchair motion to reach the desired distance based on the input of eye signals. This requirement is considered by expecting the controller to direct the wheelchair to reach the desired distance. Fuzzy rules are designed based on the following set of equations.

$$E_0 = Y_0 - Ref \qquad \text{(Eq. 1)}$$

$$E_1 = Y_1 - Ref \qquad \text{(Eq. 2)}$$

$$\Delta E = E_1 - E_0 = Y_1 - Y_0 \qquad \text{(Eq. 3)}$$

Then, the fuzzy rules are based on the condition below:

Case A - Error (*e*) is positive, the change of error (*Δe*) is negative and thus the voltage (U_1) is zero. This happens because the error is moving toward the target reference.

Case B - Error (*e*) is positive, the change of error (*Δe*) is positive and thus the voltage (U_1) is negative, in order to bring the error back to the target reference.

Case C - Error (*e*) is negative, the change of error (*Δe*) is negative and thus the voltage (U_1) is positive, in order to bring back the error to the target reference.

Case D - Error (*e*) is negative, the change of error (*Δe*) is positive and thus the voltage (U_1) is zero. This happens because the error is already moving toward the target reference.

Therefore, the fuzzy rules can be summarized as in Table 2, Table 3 and Table 4 for sum error (ΔE).

Table 2 Fuzzy rules table for straight linear motion control (Sum of error, (∑e) = P)

		Change of error, (Δe)				
		NB	**NS**	**Z**	**PS**	**PB**
Error, (e)	**NB**	PB	PB	PB	PS	Z
		PB	*PB*	*PB*	*PS*	*Z*
	NS	PB	PB	PS	Z	NS
		PB	*PB*	*PS*	*Z*	*NS*
	Z	PB	PS	Z	NS	NB
		PB	*PS*	*Z*	*NS*	*NB*
	PS	PS	Z	NS	NB	NB
		PS	*Z*	*NS*	*NB*	*NB*
	PB	Z	NS	NB	NB	NB
		Z	*NS*	*NB*	*NB*	*NB*

Table 3 Fuzzy rules table for straight linear motion control (Sum of error (∑e) = N)

		Change of error, (Δe)				
		NB	**NS**	**Z**	**PS**	**PB**
Error, (e)	**NB**	PB	PB	PB	PS	Z
		PB	*PB*	*PB*	*PS*	*Z*
	NS	PB	PB	PS	Z	NS
		PB	*PB*	*PS*	*Z*	*NS*
	Z	PB	PS	Z	NS	NB
		PB	*PS*	*Z*	*NS*	*NB*
	PS	PS	Z	NS	NB	NB
		PS	*Z*	*NS*	*NB*	*NB*
	PB	Z	NS	NB	NB	NB
		Z	*NS*	*NB*	*NB*	*NB*

Table 4 Fuzzy rules table for straight linear motion control (Sum of error, (∑e) = Z)

		Change of error, (ë)				
		NB	**NS**	**Z**	**PS**	**PB**
Error, (e)	**NB**	PB	PB	PB	PS	Z
		PB	*PB*	*PB*	*PS*	*Z*
	NS	PB	PB	PS	Z	NS
		PB	*PB*	*PS*	*Z*	*NS*
	Z	PB	PS	Z	NS	NB
		PB	*PS*	*Z*	*NS*	*NB*
	PS	PS	Z	NS	NB	NB
		PS	*Z*	*NS*	*NB*	*NB*
	PB	Z	NS	NB	NB	NB
		Z	*NS*	*NB*	*NB*	*NB*

5.0 SIMULATION RESULTS

Using MATLAB simulation, the PID-type FC was designed and implemented. The model of wheelchair which was developed using MSC.Visual Nastran 4D and was used in this simulation as a plant of the system. The eye movement input data was used to represent the distance of the wheelchair motion accordingly. The eye movement input data was only considered after 6 seconds when the eye signal reaches a stable state. In running this simulation, the eye signal was selected at its maximum or minimum peak point based on the eye movement. Therefore, the maximum peak data condition was used for the upward movement direction. The eye signal is very small which about 2.0 μV to 2.0 μV is. The FC for input selection was designed and implemented to determine how far the wheelchair will have to move. The saturation was used to give the limitation between [-1 1] in the simulation since the MF in FLC had been normalized. The result for linear motion can be seen in Figure 4 to Figure 6.

The output distance is shown in Table 5. Then, the results show that the highest eye movement input data will give the highest distance for the wheelchair to move in forward direction.

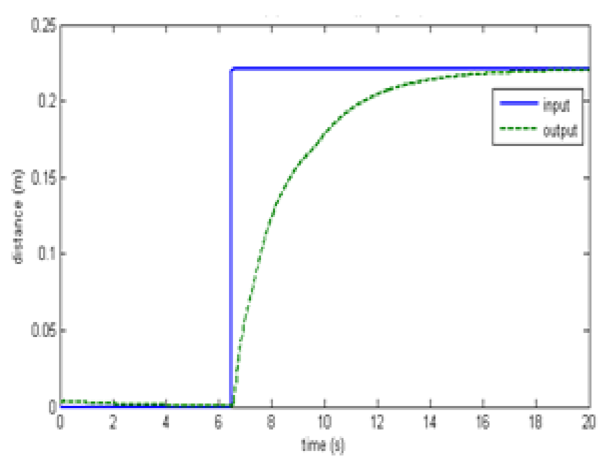


Figure 4 The distance for eye movement upward (up_1)

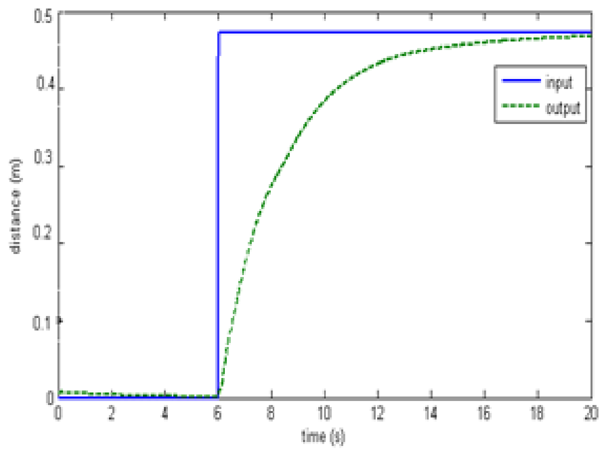


Figure 5 The distance for eye movement upward (up_2)

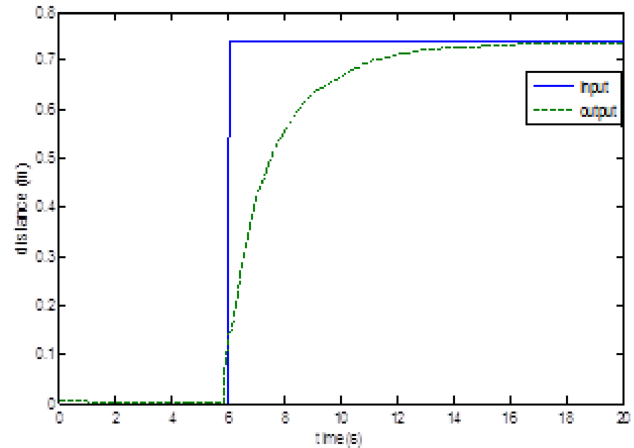


Figure 6 The distance for eye movement upward (up_3)

Table 5 Input-output distance for eye movement in upward direction

Eye movement input data	Input distance	Output distance
Eye_up1	0.27 m	0.27 m
Eye_up2	0.48 m	0.48 m
Eye_up3	0.75 m	0.75 m

6.0 CONCLUSION

This paper discussed the design of FC for giving the distance for linear motion of wheelchair based on the input of eye movement data acquisition. The fuzzy logic rules have been formulated based on the expert knowledge gain from experiences and also some published works. The proposed FC has been developed and simulated for variations eye movement input data. The simulation results showed that the designed FC was able to control the linear motion using eye movement input signal which is very significant tool among tetraplegic.

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