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FUZZY LOGIC BASED VEHICLE SPEED CONTROL PERFORMANCE CONSIDERING DIFFERENT MEMBERSHIP TYPES

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ABSTRACT

Vehicle dynamics like acceleration, braking, and other factors can be controlled based on its speed. This paper design and analyse a fuzzy logic controller to control the speed of a vehicle to achieve the optimum control characteristics. Different number of fuzzy sets and fuzzy membership types known as triangular, trapezoid and Gaussian are configured to obtain the best solution for the problem. The vehicle speed as the inputs for the system is varied to simulate different cases of vehicle movement to determine the effectiveness of the system. The vehicle acceleration as the output is then being tuned to match and decide the vehicle motion appropriately with smooth movement. The effectiveness and the validity of the controller will be verified by some simulations and are assessed based on time consumption. Result has shown that Gaussian membership type has better results for less than four fuzzy sets.

Keywords: fuzzy logic, vehicle speed control, membership function.

INTRODUCTION

Vehicle has been used for centuries to mobilize people around the world. Since 1900's, the vehicle technology has rapidly been developed from petrol based vehicle to hybrid and finally to the electric vehicle [1]. Along with these fascinating inventions, a lot of issues have been identified in each of the stages consisting of fuel consumption, battery management, vibrations, mechanical structures, and disturbance and as well as environmental issues.

In the aspect of fuel consumption, vehicle speed plays an important role to define the effectiveness of fuel usage of an automobile. Most of automobiles depend on its speed to move and the speed differs for each manual or automatic transmission. The speed can also affects the fuel consumptions, the car vibration, and can majorly causing dangerous impact to both passengers and driver if involved in any accidents. Besides, the vehicle speed also describes the motion of a vehicle whether it is smoothly moving to make the vehicle better and comfortable. For example, slowing down a vehicle can be realized by deacceleration or a braking system. A sudden brake may injure the passenger. Therefore, a system is required to decrease the sudden changes of speed for better movement.

Fuzzy Logic is an approach that mimics the human decision system based on experience or experimental data obtained in specific conditions. Fuzzy logic has been used in automobile [2] for various application such as braking system [3], cruise control [4], travel distance[5] and electric vehicle[6-8]. Each works are analyzing the performance based on a single membership type which is either the triangular, trapezoid or Gaussian memberships. Generally the triangular or the trapezoid consumes less computational time compared to the Gaussian approach [9]. Hence, if a system need faster decision, then the triangular or trapezoid are more preferable. Even though Gaussian membership has more computational time for it to process the information, the result is more accurate. Therefore, designer must take into account these factors to select the suitable membership types for the system. Control strategy based speed control was also studied by V. Sezer *et al.* [10]. They claim that the fuzzy based control with defined model surpassed the conventional model especially when aggressive steering is considered. This lead to a hypothesis that Fuzzy logic based system is more robust in various situations.

This paper focuses on the vehicle speed control analysis based on various membership types' performance. The system configuration is shown in Figure-1 explaining about the whole architecture of the vehicle. The research attempts to adjust the speed with proper value to achieve smooth acceleration with different membership types. Previous work by K. Mahmud *et al.* [11] demonstrates that the Fuzzy Logic offers better performance compared to the conventional PID controller especially when rise and the settling time are considered. The study however lacking of the comparison between the system without Fuzzy Logic controller and with Fuzzy Logic as it defines whether the proposed system has improve the current technologies. Their study addressed only a single membership function i.e. triangular membership performance analysis compared to the PID controller. The process could perform faster by using the triangular membership, but the question still remains whether the triangular membership has the best performance compared to other membership types. Moreover, the effects of number of fuzzy sets for each membership are not discussed as it will define the effectiveness of the proposed system.

This paper is organized as follow. Next section describes the system overview for the Fuzzy Logic controller as the speed regulator. It is followed by the result and analysis of each of the membership types with comparison to the original system. Finally, the paper is summarized in the final section regarding the performance of the proposed controller.

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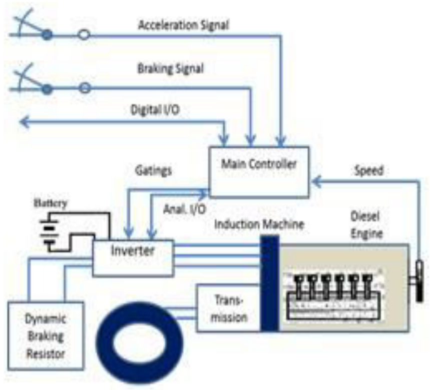

Figure-1. Vehicle architecture [11].

PROBLEM FORMULATION

The dynamic equation of the vehicle is as follows:

$$\dot{v}(t) = \frac{1}{m}[-A_p v^2(t) - d + f(t)]$$

$$\dot{f}(t) = \frac{1}{\tau}[-f(t) + u(t)]$$

where u represents as control input, m=1300kg represents the vehicle mass, A_p=0.3Ns²/m² defines the aerodynamic drag, d=100N is the friction force in constant, f is the driving and braking force, and τ=0.2(s).

Fuzzy Logic normally constructed by three main stages; fuzzification, rule evaluations and defuzzification. The first process of developing the fuzzy system i.e. the fuzzification is by defining the linguistic variables for each input and output. In this case, the linguistic variables are the speed error, the change in error and the speed. Both speed error and the change in error are the input while the speed is the output. The rules are also defined based on the expected performance and from experiences. Mainly the rules are developed based on the preceding works [11]. Next is to determine the fuzzy sets. Fuzzy sets have a variety of shapes, such that in this project, the shapes of triangle, trapezoid and Gaussian are used as these shapes often provided an adequate representation of the expert knowledge and significantly simplify the process of computation. The designed rules bases are presented in Table-1 for 3 memberships and Table-2 for 7 memberships. The following are the abbreviations in the rules. Remark that, most of the rules constructed are based on the preceding works by K. Mahmud *et al.* [11].

Table-1. Rules for 3 memberships. S define small, M defines medium and L is for large.

Error(E) / Change of error, ΔE	S	M	L
S	S	S	M
M	S	M	L
L	L	L	L

Table-2. Rules for 7 memberships.

E / ΔE	NL	NM	NS	ZE	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NM	NM	NS	ZE	PS
NS	NL	NM	NS	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PS	PM	PL
PM	NS	ZE	PS	PS	PM	PL	PL
PL	ZE	PS	PM	PL	PL	PL	PL

For symbol in Table 2, the following is the definitions.

NL – Negative Large
NM – Negative Medium
NS – Negative Small
ZE – Zero
PS – Positive Small
PM – Positive Medium
PL – Positive Large

Rules evaluation is then used to determine the best output for each condition. The result of rule evaluations is defuzzified to obtain the output. To carry these processes in MATLAB, the fuzzy set must be encoded, as well as the fuzzy rules and its evaluations to perform fuzzy inference system. The project mainly uses MATLAB software with fuzzy logic inference toolbox. Different number of fuzzy sets and fuzzy membership types are discussed later to determine the best solution for the control system. Some of the system settings consisting of the input and output configurations are shown in Figure-2 and Figure-3.

The last step evaluates and tunes the processes of the proposed system. This is to generate the best vehicle speed with a good response of rise time and settling time.

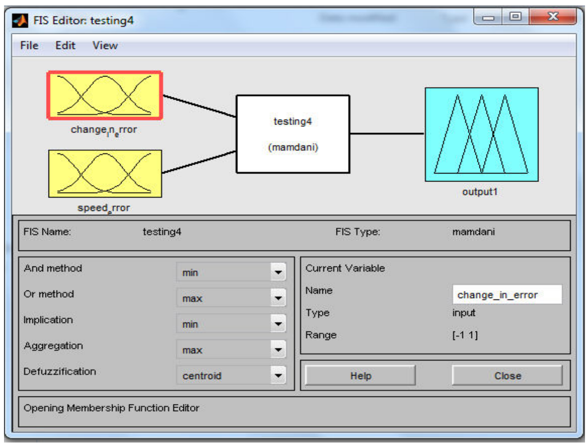

Figure-2. The input and output of the proposed system.

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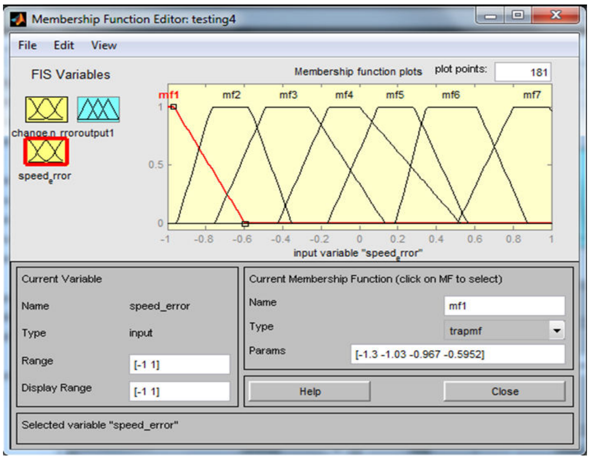
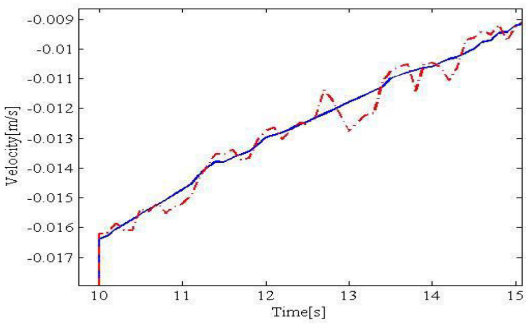


Figure-3. The fuzzy sets design in a trapezoidal membership function.

RESULTS AND ANALYSIS

The analysis is carried based on three different input conditions. Case 1 defines a situation where the input is specific which controlled the vehicle to move in a constant motion. Case 2 moves the vehicles in a random motion. Then Case 3 navigates the vehicle to move in a dynamic condition where both the vehicle can move in a specific and in random input. The results are tabulated after several tuning processes to gain consistency and reliability of the proposed technique.

Based on Figures-4-7, it can be observed that the normal system has faster rise time compared to the fuzzy logic technique. However, fuzzy logic is able to smooth the vehicle speed for both 3 memberships and 7 memberships regardless of whatever types of membership. There are no big differences between all of the membership type's performance. No overshoot were also shown during simulation. To look in details the performance, the error between the normal and any of the membership types is squared and is depicted in Figure-8. From the Figure, it can be concluded that the Gaussian membership has the lowest error and perform better accuracy than the other two types. This should be a reference to decide which membership function is better. Gaussian membership offer better accuracy and smoothness of velocity during the whole movement.



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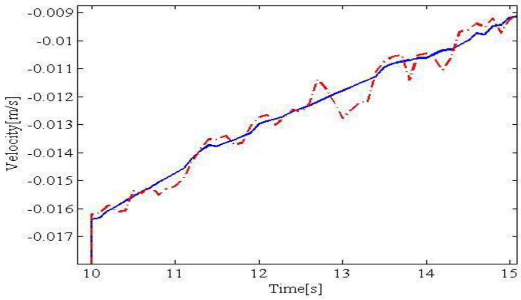

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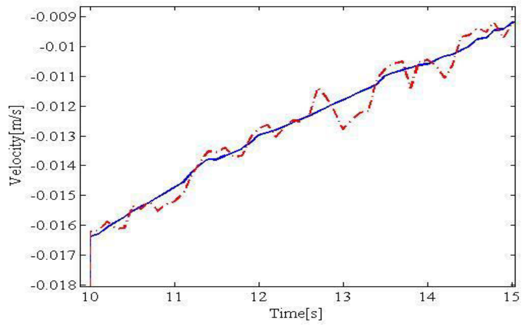
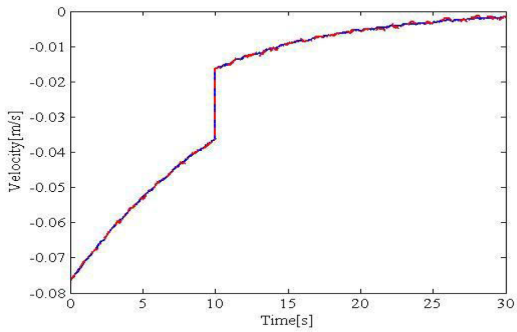


(c)

Figure-4. The vehicle speed characteristics for case 3 with 3 memberships. Red line is the normal condition without fuzzy logic. Blue line defines the fuzzy logic performance of speed characteristics for each membership type (a) The Gaussian membership (b) The Trapezoid membership (c) The Triangular membership.



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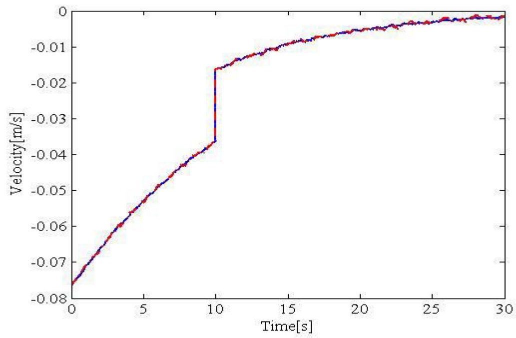

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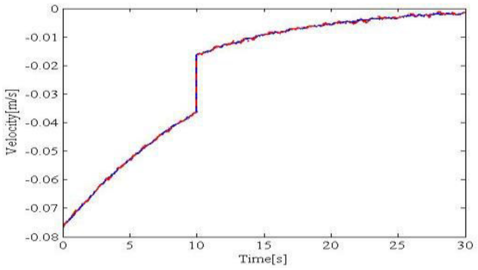
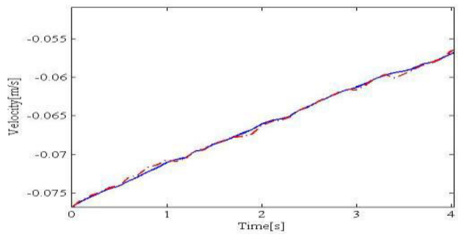


(c)

Figure-5. The vehicle speed characteristics for case 3 with 7 memberships. Red line is the normal condition without fuzzy logic. Blue line defines the fuzzy logic performance of speed characteristics for each membership type (a) The Gaussian membership (b) The Trapezoid membership (c) The Triangular membership.



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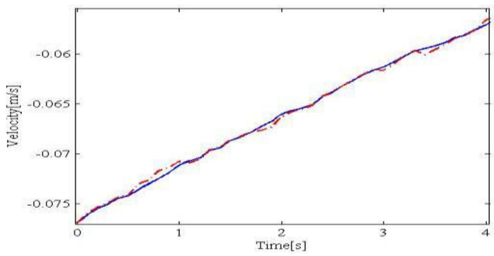

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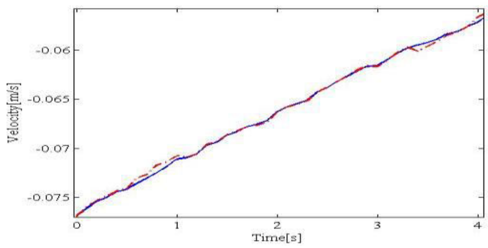
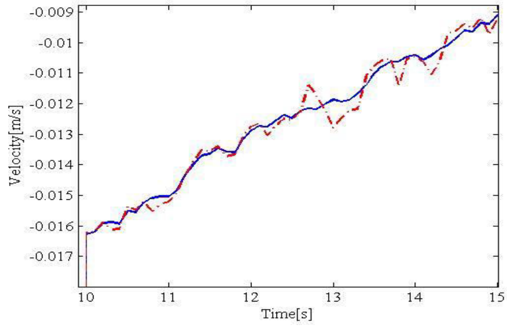


(c)

Figure-6. The vehicle speed characteristics for case 3 about rise time performance 7 memberships. Red line is the normal condition without fuzzy logic. Blue line defines the fuzzy logic performance of speed characteristics for each membership type (a) The Gaussian membership (b) The Trapezoid membership (c) The Triangular membership.



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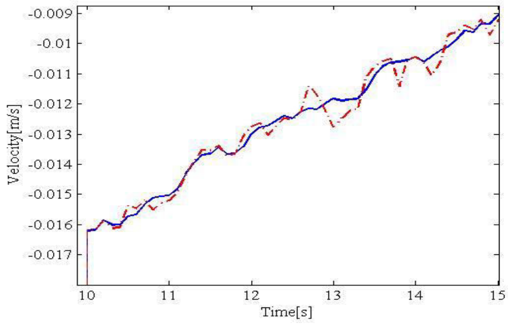

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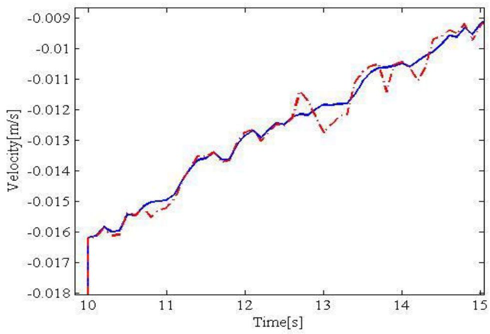

(c)

Figure-7. The vehicle speed characteristics for case 3 about smoothness of movement 7 memberships. Red line is the normal condition without fuzzy logic. Blue line defines the fuzzy logic performance of speed characteristics for each membership type (a) The Gaussian membership (b) The Trapezoid membership (c) The Triangular membership.

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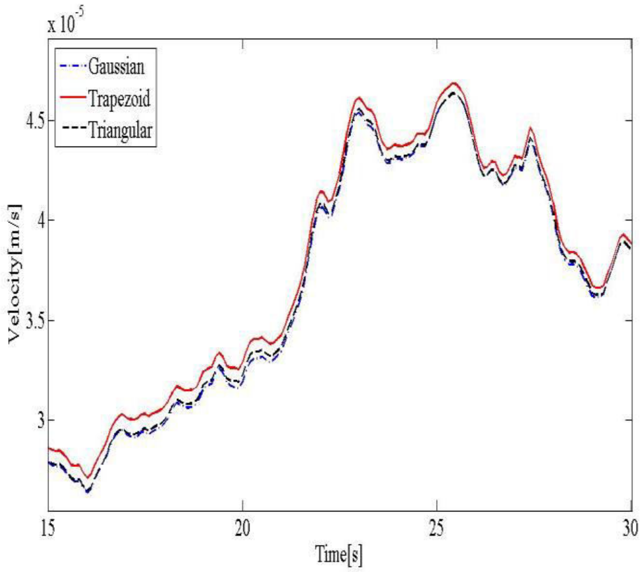

Figure-8. Gaussian membership function shows lower error compared to the other two memberships performance

Table-3 presents the results of 3 memberships performance between triangular, trapezoid and Gaussian memberships. It can be observed that the nonfuzzy controller shows the best rise time of 0.01621[s] and 0.01634[s] for different cases of input. This result is not reported by K. Mahmud *et al* [11] which explains that by applying the fuzzy logic into the system, the performance has a trade-off about the rise time. This is due to the processing time needed to calculate the desired speed as designed by the rules. The fastest time consumed is the triangular membership as can be calculated by average based on Table-4. Interestingly for the 7 memberships analysis, the Gaussian has better performance even though for the case 2, the result is second to the triangular membership. Despite of these outcomes, both fuzzy and nonfuzzy shows a smooth transient behavior as can be seen on Figures 4-7.

The analysis has also taken into account time consumption for each of the membership types. Based on ten runs of simulations, the results have shown that the triangular membership has the lowest computation time. This result also agrees with the current trends and findings for various kind of application that discuss different membership performance [6]. It shows about 0.0004614[s] to process the information. This is then followed by the trapezoidal membership where it needs about 0.0005970[s] to process. Lastly, the Gaussian membership require 0.0005976[s], which is 0.0000006[s] more than the trapezoidal membership.

In practical and normal driving condition, the Gaussian memberships shows the best performance as it has the highest accuracy as even though the error is higher than the other two types, it is still very small and the technique is still able to provide faster response to the changing condition.

CONCLUSIONS

This paper discussed and analyzed the different performance of three membership types; triangular, trapezoid and Gaussian memberships for vehicle speed control. The result defines that by fuzzy logic, the rise time is slower than the normal system without fuzzy logic. Nevertheless, the results suggest two important findings. The first one is the smoothness of movement if the fuzzy logic approach is applied. The second aspect is that the Gaussian membership has the higher accuracy compared to other membership types if the time consumed for operation is not considered.

Table-3. Fuzzy logic performance with 3 memberships with comparison to the normal system.

Membership	Input	Type MF	Fuzzy/ Nonfuzzy	Rise Time (sec)	Transient Behaviour (smoothness)	Time consumed (sec)
3 memberships	Step	Trapezoid	Fuzzy	-0.01627	Smooth	0.000300
			Nonfuzzy	-0.01621	Smooth	
		Triangle	Fuzzy	-0.01627	Smooth	0.000297
			Nonfuzzy	-0.01621	Smooth	
		Gaussian	Fuzzy	-0.01629	Smooth	0.000251
			Nonfuzzy	-0.01621	Smooth	
	Random	Trapezoid	Fuzzy	-0.01638	More smooth	0.000265
			Nonfuzzy	-0.01621	Less smooth	
		Triangle	Fuzzy	-0.01641	More smooth	0.000251
			Nonfuzzy	-0.01621	Less smooth	
		Gaussian	Fuzzy	-0.01638	More smooth	0.000253
			Nonfuzzy	-0.01621	Less smooth	
	Step+ Random number	Trapezoid	Fuzzy	-0.01634	More smooth	0.000307
			Nonfuzzy	-0.01642	Less smooth	
		Triangle	Fuzzy	-0.01635	More smooth	0.000262
			Nonfuzzy	-0.01642	Less smooth	
		Gaussian	Fuzzy	-0.01636	More smooth	0.000254
			Nonfuzzy	-0.01642	Less smooth	

Table-4. Fuzzy logic performance with 7 memberships with comparison to the normal system.

Membership	Input(s)	Type MF	Fuzzy/ Nonfuzzy	Rise Time (sec)	Transient Behaviour (smoothness)	Time consumed (sec)
7 memberships	Case 1: Specific input	Trapezoid	Fuzzy	-0.01626	Smooth	0.000269
			Nonfuzzy	-0.01621	Smooth	
		Triangle	Fuzzy	-0.01625	Smooth	0.000254
			Nonfuzzy	-0.01621	Smooth	
		Gaussian	Fuzzy	-0.01625	Smooth	0.000262
			Nonfuzzy	-0.01621	Smooth	
	Case 2: Random input	Trapezoid	Fuzzy	-0.01621	More smooth	0.000268
			Nonfuzzy	-0.01621	Less smooth	
		Triangle	Fuzzy	-0.01621	More smooth	0.000257
			Nonfuzzy	-0.01621	Less smooth	
		Gaussian	Fuzzy	-0.01626	More smooth	0.000266
			Nonfuzzy	-0.01621	Less smooth	
	Case 3: Dynamic input	Trapezoid	Fuzzy	-0.01622	More smooth	0.000257
			Nonfuzzy	-0.01642	Less smooth	
		Triangle	Fuzzy	-0.01621	More smooth	0.000256
			Nonfuzzy	-0.01642	Less smooth	
		Gaussian	Fuzzy	-0.01622	More smooth	0.000281
			Nonfuzzy	-0.01642	Less smooth	

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