Comparative Analysis on the Effect of Triangular and Gaussian Membership Functions on Fuzzy Controlled Vehicle Platoon

*[1]Ajayi Ore-Ofe, [1]Nafisa S. Usman, [2]Abdullahi Abubakar, [3]Aminu Y. Zubairu, [1]Riskikat F. Adebiyi, [1]Abdulfatai D. Adekale and [1]Umar Abubakar

[1]Department of Computer Engineering, Ahmadu Bello University, Zaria, Nigeria
[2] Department of Electrical Engineering, Ahmadu Bello University, Zaria, Nigeria
[3] Department of Mechanical Engineering, Ahmadu Bello University, Zaria, Nigeria
ajayi.oreofe17@gmail.com

Received: 06-JUL-2023; Reviewed: 05-SEP-2023; Accepted: 29-SEP-2023
http://doi.org/10.46792/fuoyejet.v8i3.1070

ORIGINAL RESEARCH

Abstract- Fuzzy controlled vehicle platoon system provides a simplified yet robust approach to achieving platoon string stability and uniform inter-vehicular gap keeping in autonomous vehicle platoon. Most truck platoon is affected by delay of platoons which causes trucks not to maintain a constant inter-vehicular gap and speed, unknown uncertainties which may result in crash or accident. However, the fuzzification and defuzzification method adopted affects the final platoon characteristics of the platoon to a large extent, while also determining velocity stability timing, although researcher select a fuzzification/defuzzification method based on comfort, familiarity or simplicity. This paper proposes to compare the effect of fuzzification and defuzzification method on vehicle platoon, to provide evidence on the selection criteria and how it affects the controlled system. Simulation was done in MATLAB environment, and the fuzzy control approach was applied to a 3-vehicle autonomous platoon, which was a combination of triangular/centroid, triangular/bisector, triangular/mean with Gaussian/centroid, Gaussian/bisector and Gaussian/mean of maxima under the same platoon scenario. It was found that the best performing combination is the triangular/centroid with 4.44 secs velocity stability for vehicle V3, and 1.91 secs distance stability for follower vehicle, when compared to Gaussian/MoM with 79.88 secs velocity stability V3, and 85.89 secs for follower vehicle which is the worst performing combination.

Keywords- Fuzzy, Gaussian, Membership Function, Platoon, Triangular

1 Introduction

Autonomous vehicles are also referred to as Connected and Automated Vehicles (CAVs), or driverless vehicles (Elliott *et al.*, 2019). Autonomous car assumed to be able to communicate with other vehicles and road infrastructure, relying on onboard sensors for information gathering and decision making. The communication technology adopted for autonomous vehicles for sharing information is in the form of V2X, a paradigm that covers several communications such as Vehicle-to-Infrastructure (V2I), Vehicle-to-Vehicle (V2V), Vehicle-to-Pedestrian (V2P) (Shrivastava, 2019). V2X is enabled by two communication technologies based on the Vehicular Ad Hoc Network (VANET) which are Dedicated Short Range Communication (DSRC) based on IEEE 802.11p (Shukla *et al.*, 2020) and Long-Term Evolution (LTE) cellular, sometimes referred to as Cellular-V2X (Abou-Zeid *et al.*, 2019).

Vehicle platooning system is the arrangement of multiple vehicles in motion, such that they aim to maintain the same velocity and keep equal distance between adjacent vehicles (Horowitz & Varaiya, 2000). One of the earliest platooning system is path program in California (Li *et al.*, 2017), earlier platoon system relied only on Radar-based sensor for data acquisition (Ajayi *et al.*, 2022).

The benefit of vehicle platooning includes fuel consumption (Nowakowski *et al.*, 2015), improved traffic efficiency, increased road throughput, road and vehicle safety (Axelsson, 2016). Some of the performance measures of platoon are obtained from amount of fuel saved, road throughput with platoon compared to without platoon, string stability, the distance between vehicles and velocity of individual vehicles (Ajayi *et al.*, 2023).

Conventional vehicular platoon control strategies require good knowledge of the entire system for an efficient model to be developed, where controllers such as proportional-integral-derivative (PID) are used (Abdulnabi, 2017; Fiengo *et al.*, 2019; Xavier & Pan, 2009), robustness and adaptive control capabilities are usually lacking due to the non-linearity and time-varying nature of the entire system (Ziebinski *et al.*, 2017). The use of fuzzy logic control systems (FLC) provides a robust control methodology (Singh & Lone, 2020), using a simplified fuzzy rule based on the understanding of vehicular operation and limitation, while also considering dynamic non-linear nature of entire system.

FLC system is an intelligent process control system that adapts to human un-precise concept and knowledge directly to control a process. The generalized block diagram of fuzzy control system is shown in Figure 1. Fuzzy Logic was first introduced by Lotfi A. Zadeh, of the University of California at Berkeley in a 1965 paper (Zadeh, 1965). FLC system has been used earlier on in vehicle related research areas (Nishida & Sugeno, 1985; Pappis & Mamdani, 1977; Sugeno *et al.*, 1989).

*Corresponding Author

Section B- ELECTRICAL/COMPUTER ENGINEERING & RELATED SCIENCES
Can be cited as:
Ore-Ofe A., Usman N. S., Abubakar A., Zubairu A. Y., Adebiyi R. F., Adekale A. D., Abubakar U. (2023). Comparative Analysis on the Effect of Triangular and Gaussian Membership Functions on Fuzzy Controlled Vehicle Platoon, FUOYE Journal of Engineering and Technology (FUOYEJET), 8(3), 307-313. **http://doi.org/10.46792/fuoyejet.v8i3.1070**

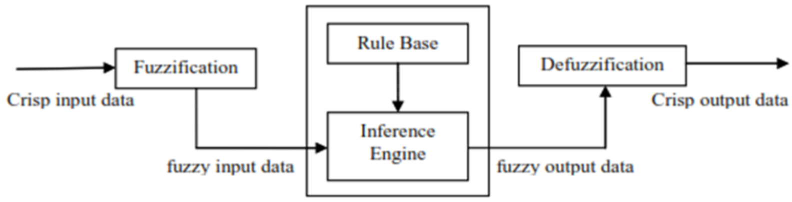

Fig. 1: Generalized Fuzzy Logic Control System

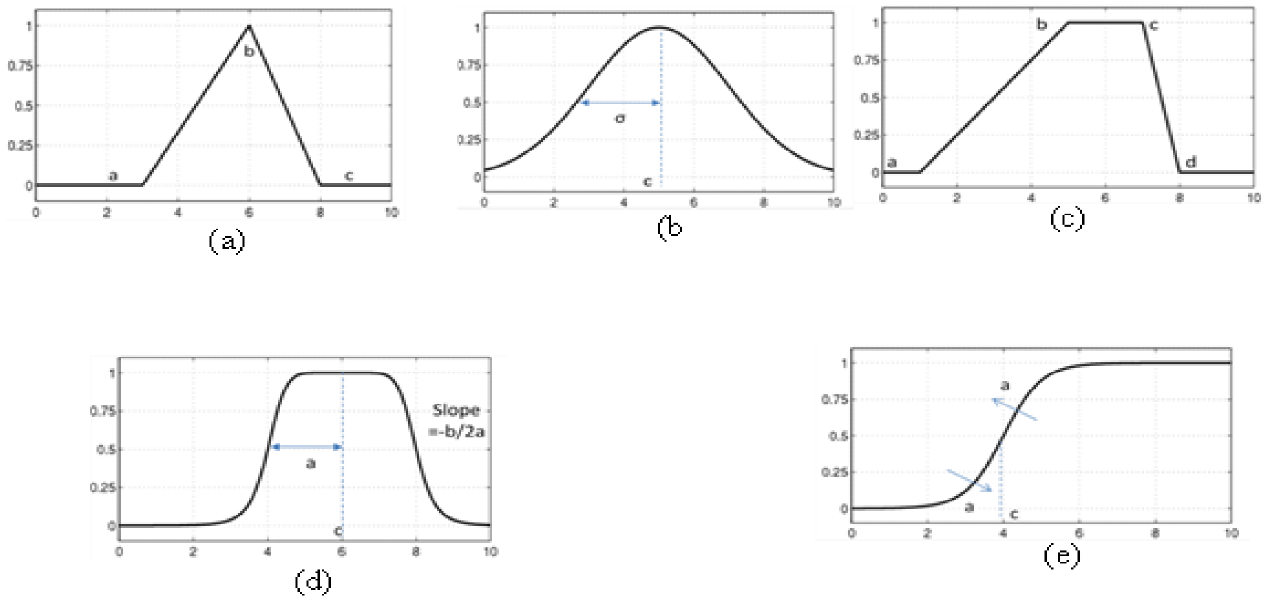

Fig. 2: Fuzzy Membership Function Types (a) Triangular (b) Gaussian (c) Trapezoidal (d) Generalized Bell Sigmoidal (Yen, 1999)

Fuzzy Logic control system can provide a simplified approach for platoon implementation in unmanned ground vehicles to take advantages of platooning and intelligent control methodology, however, the selectionof the best fit fuzzification/defuzzification technique will increase overall robustness and assist in simplifying implementation based on evidence. Fuzzification process converts crisp value (real world) classical data into fuzzy data referred to as membership function. There a several types of membership function applied in fuzzy control system, the most common is the Triangular, Gaussian, Trapezoidal, generalized bell and sigmoidal membership function, which is depicted in Figure 2 (a-e).

Defuzzification process is where an inferred fuzzy knowledge from the inference engine is converted into crisp value for driving the actuator. This is performed according to the output membership function (Chakraverty *et al.*, 2019). Some of the defuzzification methods in use are; Centroid of Gravity (CoG), Weighted Average, Bisector of Area (BOA) and Maxima methods which includes; First of Maxima (FOM), Last of Maxima (LOM) and Mean of Maxima (MOM). Literatures report that the COG is the most frequently used defuzzification method, due mainly to physical appeal (Nguyen *et al.*, 2019). This paper therefore attempts to provide empirical evidence of the effect of fuzzification/defuzzification combination on a platoon system control by investigating a triangular, Gaussian, centroid, mean of maxima ad bisector combinations.

Some of the work carried out in the field of vehicle platooning that relates to fuzzy control system details the adoption of particular fuzzification and defuzzification methodology often without justification or comparison to other selectable combinations. Some these research work includes; Ma *et al.* (2018) in their work, Hierarchical Fuzzy Logic Based variable structure control applied to Platoon of Vehicles was proposed. A two-layer fuzzy controller is developed to for robustness in uncertain operations triangular membership function was adopted. In He and Peng (2020), the authors proposed a Gaussian learning-based fuzzy predictive cruise control platooning system, applied for improvement in safety of connected vehicles. Also the work presented by Li *et al.* (2018) developed a Fuzzy Logic Control System for Vehicle Platooning dependent on V2V communication. The authors used a combination of PID and fuzzy logic control technique to maintain variable time-gap within vehicles in platoon, and implemented a mean-of-maxima defuzzification method without stated justification.

The rest of the paper is structured as follows. Section one introduces the fuzzy controlled vehicle platoon system, while section two discusses the modelling of the vehicle platoon system. Fuzzy logic membership functions are given in section three, while the vehicle platoon simulation scenario is given in section four. Results and discussions are given in section five, and finally section six gives the conclusion.

2 Modelling of the Platoon System

The platoon system model was achieved by considering a Platoon of 3 vehicles, all homogenous and having the same model representing the BMW Series 5 Sedan, some of the important parameters are the desired velocity the vehicle in platoon are expected to travel, the desired distance between all the cars in the platoon, the initial velocity of the cars in the platoon and also the acceleration/deceleration capabilities of the vehicles. Assumptions were made to enable the implementation of the platoon. These assumptions are as follows:

The cars were assumed to be capable of accelerating up to $50ms^{-2}$ and deceleration of $-40ms^{-2}$. A distance keeping range of between $0-20m$ is implemented, the distance between vehicles is adjustable as required before simulation is carried out. An illustration of the platoon layout is presented in Figure 3.

Vehicle parameters are presented in Table 1, showing the manufacturer technical specifications. As illustrated from Figure 3, the distance between vehicles in the platoon is computed and used to determine the platoon stability. The distance travelled by vehicle number 3 (V3) at time *t* is zero, distance travelled by vehicle number 2 (V2) is $D_{tv}(V2)$, while that travelled by vehicle (V1) is $D_{tv}(V1)$. Likewise, the distance between each of the cars in the platoon is computed, with distance between vehicle (V1) and (V2) is $Db(12)$ while the distance between vehicle (V2) and (V3) is $Db(23)$, the dynamic distance model of each vehicle in the platoon is obtained by equation (1).

$$D(t+\delta t) = D(t) + v(t)\delta t + \frac{1}{2}a(\delta t)^2 \quad (1)$$

The velocity of each vehicle in the platoon is determined by equation (2), where initial velocity can be determined at the start of the simulation.

$$V_f = V_i + a(\delta t) \quad (2)$$

The acceleration or retardation of the vehicle is assumed between $50ms^{-2}$ to $-40ms^{-2}$.

3 Fuzzy Logic Membership Function

The membership functions used for this research are:

3.1 Triangular Membership Function

Triangular membership functions are functions such that each value can be dynamically adjusted. The ranges of the functions are defined as:

$$\mu_A(v) = \begin{cases} 1 - \frac{|v-P_V|}{w} & , for\ |v-P_V| \le w \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

The equation describing the membership is given as (Trabia *et al.*, 2006):

$$trimf(x; a, b, c) = \begin{Bmatrix} 0 & x \le a \\ \frac{x-a}{b-a} & a \le x \le b \\ \frac{c-x}{c-b} & b \le x \le b \\ 0 & c \le x \end{Bmatrix} \quad (4)$$

Where $trimf$ denotes triangular membership function, x is the universal discourse, a, the lower limit, c the upper limit, and a value b.

$$\mu_A(v) = \begin{cases} 1 - \frac{|v-P_V|}{w} & , for |v-P_V| \le w \\ 0\ otherwise \end{cases} \quad (5)$$

Where w is the width of the triangular curve, when v is equal to P_V. This ensures that the membership function is 1, when the vehicle velocity reaches the desired set platoon velocity.

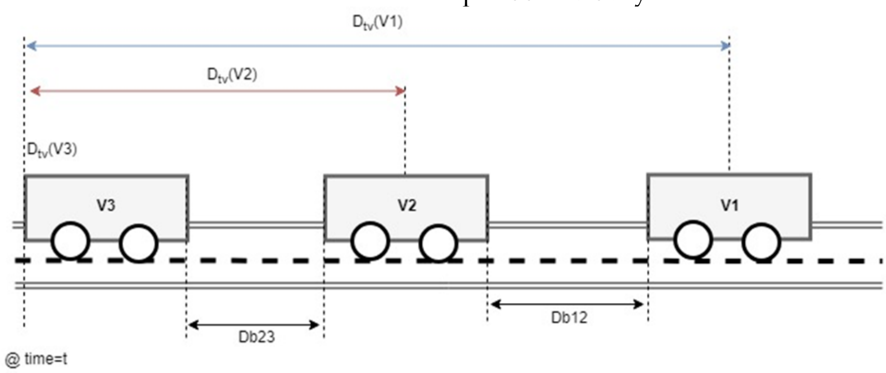

Fig. 3: Three Vehicle Platoon Arrangement

Table 1. Technical specification for BMW 520d model (Group, 2020)

Parameter	Wheelbase	Dimension	Drag Coeff.	Rolling Friction Coeff.	Air Resistance (ϱ)	Wheel radius	Max torque	Speed
Value	2975mm	4936/1868/1467mm	0.42	0.0120	0.22X2.35		400Nm	235km/h

3.2 Gaussian Membership Function

The Gaussian membership function make use of the linguistic variables and annotation. The membership functions are defined as:

$$\mu_A(x) = e^{-\frac{(x-m)^2}{zk^2}} \quad (6)$$

The Gaussian membership function is described by a central value c, and a standard deviation $\sigma > 0$. Gaussian is characterized by the smaller the value of σ, the narrower the bell shape. In this paper, the Mamdani inference engine provided in MATLAB® is used.

http://doi.org/10.46792/fuoyejet.v8i3.1070 journal.engineering.fuoye.edu.ng/

3.3 Defuzzification: Centroid of Gravity

For this paper, three defuzzification methods are employed; centroid, bisector and mean of maxima method. Equation (7) describes centroid of gravity.

$$x^* = \frac{\sum_{i=1}^{n} x_i \mu(x_i)}{\sum_{i=1}^{n} \mu(x_i)} \quad (7)$$

Equation (6) was applied to discrete membership function, where the defuzzifier value denoted by x^*, x_i indicates the sample element, $\mu(x_i)$ represents the membership function and $n$is the number of elements in the sample. However, for continuous membership function, $x^*$is defined as:

$$x^* = \frac{\int x\mu_A(x)dx}{\int \mu_A(x)dx} \quad (8)$$

Bisector: The method of defuzzification is defined by equation (9):

$$\int_{\propto}^{x^*} \mu_A(x)dx = \int_{x^*}^{\beta} \mu_A(x)dx \quad (9)$$

Where, $\alpha = min\{x|x \in X\}$and $\beta = max\{x|x \in X\}$

Mean of Maxima: For the mean of maxima method, the defuzzifier value is defined as (Saade & Diab, 2004):

$$x^* = \frac{\sum_{x_i \in M} x_i}{|M|} \quad (10)$$

Where, $M = \{x|\mu_A(x_i)\}$, is equal to the height of the fuzzy $set\{A\}$and $|M|$is the cardinality of the set M.

4 Vehicle Platoon Simulation Scenario

The performance evaluation of the 3-vehicle platoon under fuzzy control effort is carried out by simulation in phases, where the desired platoon velocity and intervehicle distance is set while the fuzzification and defuzzification methods are changed to observe the stability time, and performance through the distance, acceleration and velocity graphs. This is shown in Table 2 while the linguistic variables defined for the platoon control system is given in Table 3.

Table 2. Simulation Scenarios for Method Comparison

Platoon Settings (Scenarios)		**Controller Settings**	
Initial settings	***Desired Settings***	***Fuzzification***	***Defuzzification***
		Triangular	Centroid
Db_{i12}	Db_{12}	Triangular	Mean of Maxima
Db_{i23}	Db_{23}		
V_{iV}	P_V	Triangular	Bisector
V_{iA}	V_A	Gaussian	Centroid
		Gaussian	Bisector

5 Results and Discussion

The following results were obtained from MATLAB 2022a environment. The results obtained are as follows: Figure 4 shows the membership function at 15m/s desired velocity. From Figure 4, the desired velocity defined by the defined membership function serves as one of the fuzzy control inference systems using a triangular fuzzification system entirely for both inputs (velocity and distance) and also for the output method (acceleration). The triangular membership function for the acceleration is shown in Figure 5.

Table 3. Linguistic Variable Definition

Linguist variable	Notation
Distance between vehicles ($D_{n,n-1}$) – where n= 1, 2,3., and D_b Desired inter-vehicle distance.	
Too Far (when the distance is far > D_b)	TF
Far (when the distance is > D_b)	FR
Okay (when the distance is about = D_b)	OK
Too Close (when the distance is far < D_b)	TC
Close (when the distance is < D_b)	CL
Velocity of vehicles (V_n) – where n= 1, 2,3., and P_V is set platoon velocity.	
Too Slow (when the velocity is far < P_V)	TS
Slow (when the velocity is < P_V)	SL
Okay (when the velocity is about = P_V)	OK
Fast (when the velocity is > P_V)	FS
Too Fast (when the velocity is far > P_V)	TF
Acceleration of vehicles (A_n) – where n= 1, 2,3.,	
Accelerate High	AH
Accelerate	AC
Okay	OK
Decelerate	DC
Decelerate High	DH

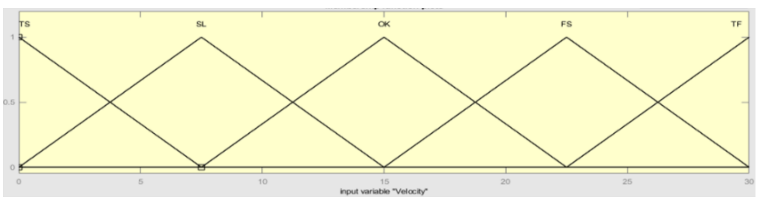

Fig. 4: Triangular Membership function at 15m/s desire velocity

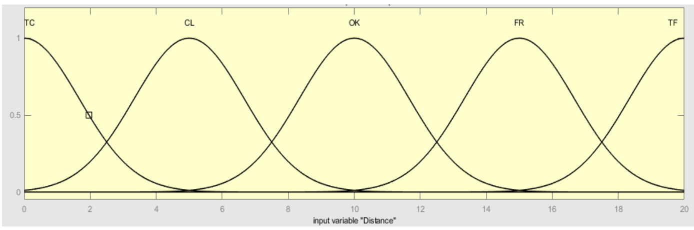

Fig. 6: Gaussian Membership Function for Distance

From Figure 6, it depicts the case of the lead vehicle in which only velocity and acceleration membership functions are required, as it does not compare distance between any other vehicles in the platoon. However, Figure 7 shows the Gaussian membership function representing acceleration parameter. From Figure 7, the acceleration membership function is the output of the fuzzy logic control system, which is required by both the lead vehicle and the follower vehicles.

The follower vehicles have a total of 25 rules, in the form of ‘If-and-If-Then’ relating the Distance and Velocity membership function to the output acceleration function. Also, the lead vehicle is governed by only 5 rules due to the absence of distance consideration.

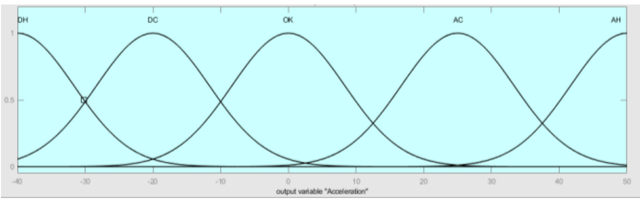

Fig. 7: Output Membership function for Acceleration

Figure 8 shows the fuzzy rule surface viewer which displays the relationship between the velocity, distance and acceleration.

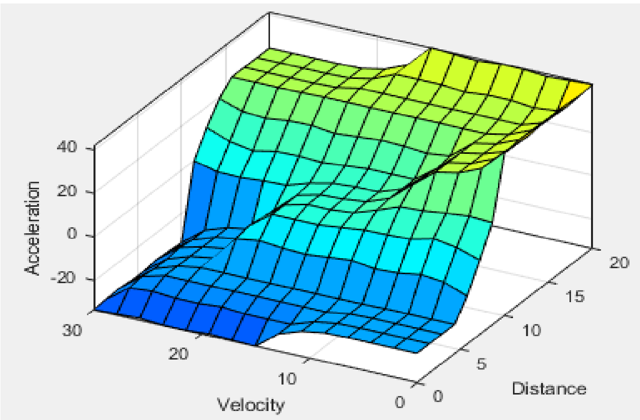

Fig. 8: Fuzzy Rule Surface Viewer

Considering the acceleration plot of the vehicles at the output, the performances of the platoon vehicles are compared under different combination of fuzzification and defuzzification methods as stated in Table 2. Figure 9 shows the acceleration performance plot of the platooning vehicles under triangular and centroid methods.

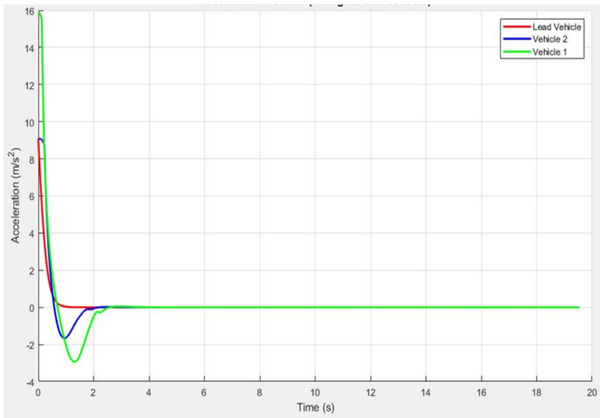

Fig. 9: Platoon performance under triangular and centroid methods

From Figure 9, it showed that the lead vehicle accelerates to about $9\frac{m}{s^2}$, and no change in acceleration from about 2seconds into the journey, while vehicle V2 starts at about $9\frac{m}{s^2}$, but decelerates to about $1.8\frac{m}{s^2}$before reaching the required velocity. Likewise, the third vehicle has maximum acceleration of $16\frac{m}{s^2}$, with a maximum deceleration of about $3\frac{m}{s^2}$. Figure 10 shows the performance of the platooning system under triangular/bisector method.

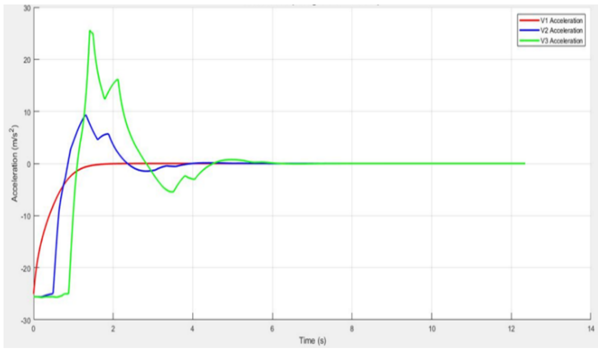

Fig. 101: Platoon Vehicle Acceleration plot with Triangular and Bisector Method

From Figure 10, it showed that the vehicles start in deceleration state of about $25\frac{m}{s^2}$, this is due to the initial velocity of the vehicles as set during the platoon setup phase. Although, the final value reaches zero without any positive acceleration in the case of the lead vehicle at about 1.5 seconds, the second and third platoon vehicles experienced positive acceleration to reach desired velocity in a time of about 5 and 6 seconds respectively. Figure 11 shows the performance of the platooning system under Gaussian and centroid methods.

http://doi.org/10.46792/fuoyejet.v8i3.1070 journal.engineering.fuoye.edu.ng/

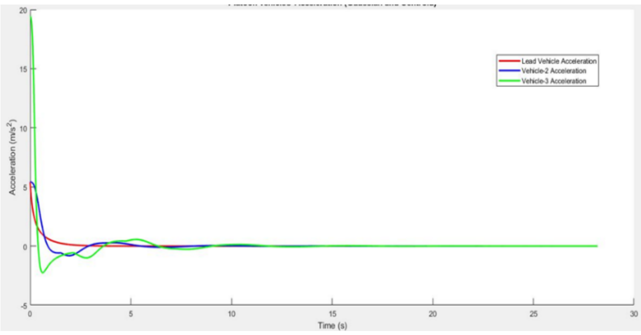

Fig. 112: Platoon acceleration under Gaussian and Centroid methods

From Figure 11, it showed that the vehicle acceleration took longer time to reach zero under the Gaussian and centroid methods. The lead vehicle reached 0 $\frac{m}{s^2}$after 3 seconds, V2 reached 0$\frac{m}{s^2}$after 6 seconds, while the third vehicle V3 reached 0$\frac{m}{s^2}$after about 8 seconds. This showed that the acceleration response of the vehicles under Gaussian and centroid is slower when compared to triangular fuzzification method. This affects the overall performance of the various method combination in terms of velocity and distance stability times. A comparative analysis was carried out between the various methods discussed above with respect to velocity and distance stability respectively. This is given in Table 4.

Table 4. Fuzzification/Defuzzification Comparison

Platoon Settings	Method	Velocity Stability (s)	Distance Stability (s)
Piv = 10 m/s	Triangular and Centroid	Lead (V1) = 1.74 secs V2 = 3.75 secs V3 = 4.44 secs	V1 and V2 = 1.51 secs V2 and V3 = 1.90 secs
Pv = 12 m/s	Gaussian and Centroid	Lead (V1) = 7.02 secs V2 = 15.2 secs V3 = 24.5 secs	V1 and V2 = 15.02 secs V2 and V3 = 17.77 secs
Dbi12 = 8 m	Gaussian and Bisector	Lead (V1) 27.12 secs V2 = 39.2 secs V3 = 33.35 secs	V1 and V2 = 12.11 secs V2 and V3 37.07 secs
Dbi23 = 7 m Dbp = 6 m	Triangular and Bisector	Lead (V1) = 3.5 secs V2 = 6.91 secs V3 = 9.15 secs	V1 and V2 = 3.07 secs V2 and V3 = 5.27 secs
	Triangular and MoM	Lead (V1) = 22.22 secs V2 = 32.21 secs V3 = 33.80 secs	V1 and V2 = 22.71 secs V2 and V3 = 41.05 secs
	Gaussian and MoM	Lead (V1) = 43.64 secs V2 = 79.91 secs V3 79.88 secs	V1 and V2 = 83.10 secs V2 and V3 = 85.89 secs

From Table 3 above, it can be observed that the combination of fuzzification and defuzzification methods have significant effect on the performance of the fuzzy control system. Different combination of triangular fuzzification and defuzzification were compared along with different Gaussian methods. The combination with the best stability time measure is triangular/centroid at 1.7 secs lead vehicle stability, 4.44 secs V3 vehicle stability and 1.91 secs distance stability between V2 and V3. The most underperforming combination is Gaussian/mean of maxima with 43.64 secs velocity stability for lead vehicle and 85.89 secs distance stability between V2 and V3 respectively.

6 Conclusion

This paper has developed a comparative analysis of various fuzzification/defuzzification methods in order to establish an empirical evidence on the performance of the vehicle platoon system to selectable fuzzy control techniques when applied as a control technique in the platoon system. The fuzzy control approach was applied to a 3-vehicle autonomous platoon, a combination of triangular/centroid, triangular/bisector and triangular/mean of maxima was compared Gaussian/centroid, Gaussian/bisector and Gaussian/mean of maxima under the same platoon parameter settings. The best performing combination was reported as triangular/centroid with 4.44 secs velocity stability for vehicle V3, and 1.91 secs distance stability for follower vehicle, when compared to Gaussian/MoM with 79.88 secs velocity stability V3 and 85.89 secs for follower vehicle being the worst performing combination. Future research will focus on using model predictive control (MPC) technique to see its effects on catchup and slow down strategies of the vehicle platoon system respectively.

References

Abdulnabi, A. (2017). PID Controller Design for Cruise Control System using Particle Swarm Optimization. *Iraqi Journal for Computers Informatics (IJCI), 43*(2), 30-35.

Abou-Zeid, H., Pervez, F., Adinoyi, A., Aljlayl, M., & Yanikomeroglu, H. (2019). Cellular V2X Transmission for Connected and Autonomous Vehicles Standardization, Applications, and Enabling Technologies. *IEEE Consumer Electronics Magazine, 8*(6), 91-98.

Ajayi, O.-o., Yahaya, S., & Umar, A. (2022). Application of Fuzzy Control System to Autonomous Vehicle Platoon. *Nigerian Journal of Engineering, 29*(2), 66-66.

Ajayi, O., Adebiyi, R., Abubakar, Z., Yusuf, S., Adekale, A., Abdulwahab, I., . . . Abdullahi, M. (2023). Simulation of Truck Platoon System using Anylogic Software. *FUW Trends in Science & Technology Journal, 8*(2), 224 – 227.

Axelsson, J. (2016). Safety in Vehicle Platooning: A Systematic Literature Review. *IEEE Transactions on Intelligent Transportation Systems, 18*(5), 1033-1045. doi:10.1109/TITS.2016.2598873

Chakraverty, S., Sahoo, D. M., & Mahato, N. R. (2019). Defuzzification. In *Concepts of Soft Computing* (pp. 117-127). Springer, Singapore: Springer.

Elliott, D., Keen, W., & Miao, L. (2019). Recent Advances in Connected and Automated Vehicles. *Journal of Traffic and Transportation Engineering (English Edition), 6*(2), 109-131. doi:https://doi.org/10.1016/j.jtte.2018.09.005

Fiengo, G., Lui, D. G., Petrillo, A., Santini, S., & Tufo, M. (2019). Distributed Robust PID Control for Leader Tracking in Uncertain Connected Ground Vehicles with V2V Communication Delay. *IEEE/ASME Transactions on Mechatronics, 24*(3), 1153-1165. doi:10.1109/TMECH.2019.2907053

Group, B. (2020). Technical Specifications BMW 520d Efficient Dynamics Edition. *Available: htt[s://www.press.bmwgrou[.com/global/.*

He, D., & Peng, B. (2020). Gaussian Learning-based Fuzzy Predictive Cruise Control for Improving Safety and Economy of Connected Vehicles. *IET Intelligent Transport Systems, 14*(5), 346-355.

Horowitz, R., & Varaiya, P. (2000). Control Design of an Automated Highway System. *Proceedings of the IEEE, 88*(7), 913-925. doi:10.1109/5.871301

Li, H., Tiwari, R., Pickert, V., & Dlay, S. (2018). *Fuzzy Control for Platooning Systems Based on V2V Communication.* Paper presented at the 2018 International Conference on Computing, Electronics & Communications Engineering (iCCECE), Southend, UK.

Li, S. E., Zheng, Y., Li, K., Wang, L.-Y., & Zhang, H. (2017). Platoon Control of Connected Vehicles from a Networked Control Perspective: Literature Review, Component Modeling, and Controller Synthesis. *IEEE Transactions on Vehicular Technology*, 1-1. doi:10.1109/TVT.2017.2723881

Ma, Y., Li, Z., Malekian, R., Zhang, R., Song, X., & Sotelo, M. A. (2018). Hierarchical Fuzzy Logic-based Variable Structure Control for Vehicles Platooning. *IEEE Transactions on Intelligent Transportation Systems, 20*(4), 1329-1340.

Nguyen, A.-T., Taniguchi, T., Eciolaza, L., Campos, V., Palhares, R, & Sugeno, M. (2019). Fuzzy Control Systems: Past, Present and Future. *IEEE Computational Intelligence Magazine, 14*(1), 56-68. doi:10.1109/MCI.2018.2881644

Nishida, M., & Sugeno, M. (1985). Fuzzy Control of Model Car. *Fuzzy sets systems, 60*(6), 103-113.

Nowakowski, C., Shladover, S. E., Lu, X.-Y., Thompson, D., & Kailas, A. (2015). Cooperative Adaptive Cruise Control (CACC) for Truck Platooning: Operational Concept Alternatives.

Pappis, C. P., & Mamdani, E. H. (1977). A Fuzzy Logic Controller for a Trafc Junction. *IEEE Transactions on Systems, Man, and Cybernetics, 7*(10), 707-717. doi:10.1109/TSMC.1977.4309605

Saade, J. J., & Diab, H. B. (2004). Defuzzification Methods and New Techniques for Fuzzy Controllers. *Iranian Journal of Electrical and Computer Engineering (IJECE), 3*(2), 161-174. doi:1682-0053(04)0238

Shrivastava, S. (2019). V2V Vehicle Safety Communication. In *Connected Vehicles* (pp. 117-155). Springer, Cham.: Springer.

Shukla, D., Kumar, V., & Prakash, A. (2020). Performance Evaluation of IEEE 802.11 p Physical Layer for Efficient Vehicular Communication. In *Advances in VLSI, communication, and signal processing* (pp. 51-60). Springer, Singapore: Springer.

Singh, H., & Lone, Y. A. (2020). Fuzzy Inference Systems. In *Deep Neuro-Fuzzy Systems with Python* (pp. 93-127): Springer.

Sugeno, M., Murofushi, T., Mori, T., Tatematsu, T., & Tanaka, J. (1989). Fuzzy Algorithmic Control of a Model Car by Oral Instructions. *Fuzzy sets systems, 32*(2), 207-219. doi:https://doi.org/10.1016/0165-0114(89)90255-8

Trabia, M., Shi, L. Z., & Hodge, N. E. (2006). A fuzzy logic controller for autonomous wheeled vehicles. *In Jonas Buchli, Mobile Robots, Moving Intelligence, Advanced Robotic Systems International; pro literatur Verlag*, 175-200.

Xavier, P., & Pan, Y.-J. (2009). *A Practical PID-Based Scheme for the Collaborative Driving of Automated Vehicles.* Paper presented at the Proceedings of the 48h IEEE Conference on Decision and Control (CDC) held jointly with 2009 28th Chinese Control Conference, Shanghai, China.

Yen, J. (1999). *Fuzzy logic: Intelligence, Control, and Information.* Prentice Hall Upper Saddle River, NJ, : Pearson Education India.

Zadeh, L. A. (1965). Information and Control. *Fuzzy sets, 8*(3), 338-353.

Ziebinski, A., Cupek, R., Grzechca, D., & Chruszczyk, L. (2017). *Review of advanced driver assistance systems (ADAS).* Paper presented at the AIP Conference Proceedings.

