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# Vehicle's Movement Control by Fuzzy Inference System Controller for a Collision Avoidance system

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**Abstract**-This work suggests using a fuzzy inference system controller to control vehicle movement. In a traffic lane scenario, it aids in the avoidance of collisions. It makes use of the fuzzy controller idea to both prevent collisions and regulate vehicle movement beneath roadside areas. The system's performance is assessed using a variety of metrics. It shows the situation where there are two or four cars in a single or two-lane stretch of road. It uses a controller to adhere to the left-side travel rule in every case. The controller is also used to present the vehicle's projected course. Additionally, their propagation velocity is assessed and quantified. In order to prevent unintentional collisions, it is helpful to determine the angle of propagation and the separation between other vehicles.

***Keywords:*** *Fuzzy Inference, Fuzzy Logic, Vehicle Movement, Collision Avoidance etc.*

## 1. Introduction

VANETs are a specific type of mobile ad hoc network, or MANET (mobile ad hoc network) designed for use in moving vehicles. A VANET is formed of a series of cars that connect with each other using communication devices wireless, with the help of a navigation system and without the need for an infrastructure fixed network.

One of the drawbacks of any transportation system is collisions, and emerging nations regularly suffer from traffic accidents. Inadequate traffic management, infrastructure, and accident prevention are the primary causes. The developing nations with the highest accident frequency are those in South Asia, especially Bangladesh and India. But in a universe where more sophisticated technologies are being created, technical superiority is imminent, and these methods can be used to our civilization to address its flaws. Currently, the term "Internet of Things" refers to a metaphorical idea that represents worldwide internet access. The goal is to use billions, if not trillions, of smart sensors that can analyse the data they have collected and identify any type of collision as well as the overall weather on the day the event occurs.

When a major risk accident is detected, collision avoidance (CA) systems are intended to alert the driver and even take control of the vehicle. They assist in averting the collision or lessening its effects. Usually, these are emergency features rather than comfort benefits. Accident scenarios are studied during the design process. Certain situations have to do with losing control and having issues with direction. This group includes the parties who were the sole ones involved and the parties who were involved in hitting another car after an offset or lane departure. The cops said they are primarily to blame for the accident. Circumstances involving colliding damaged vehicles. In this category of accidents, two users are involved in an intersection collision involving a driver. Pedestrian accidents are connected to certain situations. It is not the vehicle's manoeuvre that really affects the scenario; rather, it is the activity of the coded pedestrian. Circumstances involving broken conductors in a shared area without any human traffic and no issue with loss of control or direction Drivers engaged in a two-user collision without a pedestrian and out of an intersection are classified together in this class.

The analysis of the many accident scenarios enables the realisation that, in the majority of the cases found, the collision can be predicted by sometimes executing a few distinct moves, depending on the circumstances. By definition, it is harder to manage a vehicle in a collision that results in a loss of control. Therefore, collision avoidance system is presented in this work.

In the past, scholars have looked at traffic safety-related topics from a particular angle, such as motion planning techniques, vision-based vehicle detection and tracking for CA systems, and motion prediction and risk assessment algorithms for CA [1]. The writers of [2] concentrated on various detecting methods for car safety. However, we discovered that the advancement of CA systems requires sensing, AI, and vehicular communications. This work, in contrast to earlier surveys, focuses on integrating AI with sensing and vehicle communication technologies to enhance collision avoidance systems even more. Firstly, we offer an

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extensive overview of the main features, phases, research questions, and Key Performance Indicator (KPI) [3] of CA, which can give readers a methodical comprehension and fundamental ideas of this approach. We will go into great detail on the sensing, vehicular communications, and AI-based algorithms related to car safety in accordance with the main steps of the CA system. Some algorithms for autonomous decision methods are also implicated, since autonomous vehicle control can lower the danger of driver disobedience. From a communication standpoint, it also covered the advantages and disadvantages of the current technology as well as new developments in the CA application situation. Additionally, we define and evaluate the role that AI technology plays in CA and carry out a thorough analysis of the application of a few well-known algorithms to various CA system functions. We also examine several recent popular test beds and projects that help close the gap between academic research and industrial products [4].

The consumption of all the roads with heavy traffic causes the locals to encounter a number of issues when driving. The amount of traffic on the roadways has been steadily rising every day, and this increased traffic increases the likelihood of accidents occurring. An increasing number of accidents are caused by traffic, and driving on the wrong side of the road can sometimes be one of them. Numerous initiatives are underway to lessen traffic and offer an efficient means of managing traffic on the roadways. Certain approaches have already been put into practice in an adaptable manner. Vehicle networks differ greatly from other types of nodes in a number of ways that could influence the design of new technologies like IoT [5] and IoV [6]. These days, vehicle networking is commonplace since it facilitates the sharing of important information between vehicles and guarantees end-to-end connectivity. In addition to reducing the gap between vehicles to ensure pedestrian safety, this networking may enable cars to take certain safety precautions. Vehicle networks, which offer benefits like cost savings and improved fuel efficiency, traffic control, and safety, require certain techniques to avoid gridlock. These days, there is a greater demand for fuzzy logic controllers [7], which are based on the fuzzy logic process. The majority of embedded devices, air conditioners, light controls, and navigation systems use this logic. This logic system is highly capable of guaranteeing safety and offering a workable solution that can be readily adjusted to enhance performance and handle increasingly complicated uncertainties.

In this work, we provide a new fuzzy logic network-based collision avoidance system as a means of reducing traffic. The more effective method for boosting vehicle security in vehicular networks is fuzzy logic. For the purpose of improving public safety and reducing traffic, this fuzzy logic controller will provide an automated collision avoidance system that is more reliable and efficient.

This paper is ordered as follows: section II provides system configuration for controlling vehicle and fuzzy inference system. Results are presented in Section III. At last, conclusion is presented.

## 2. System Configuration for Controlling Vehicle

The nonlinear vehicle dynamics model used for control design and the autonomous vehicle's system configuration are the key topics of this section. The Inertial Navigation System (GNSS/INS) provides the autonomous vehicle with exact localization and information about its surroundings. The Industrial Personal Computer's (IPC) path planning layer plans the vehicle's intended trajectory. The vehicle's front-wheel and rear-wheel steering systems are part of its steering system. The controllers for the front and rear wheels of the steering system provide control demand signals to it, respectively. In order for the autonomous vehicle to satisfy the dynamics and path tracking requirements, both controllers receive control signals. The handling stability of a human-driven vehicle outfitted with four in-wheel motors was examined in our earlier study [8]. The autonomous vehicle uses the car's chassis driving system.

### 1. Dynamic Modelling of the Autonomous Vehicle

The autonomous vehicle's nonlinear dynamics model, which takes tyre characteristics into account, is shown as

$$\begin{cases}\dot{x} = f(x,u) \\ y = cx\end{cases} \tag{1}$$

where, the vector $x = [v \quad u \quad \psi \quad r \quad Y \quad X]^r$ represents the system sate vector. The vector $u = \left[\delta_f \delta_r\right]^r$ and the vector $y = [\psi \; Y]^r$ represent the input vector and the output vector of the vehicle system, respectively. The coordinates are represented by:

$$\begin{cases}\dot{x} = ucos\psi - vsin\psi \\ y = usin\psi + vcos\psi\end{cases} \tag{2}$$

Where, in the absolute coordinate system, X and Y stand for the coordinate coordinates of the vehicle's centroid. The tyre model and the nonlinear dynamics model via planner motion are described in full below. The differential equations of planer motion are shown by:

$$\begin{bmatrix} m_v(\dot{u} - vr) \\ m_v(\dot{v} - ur) \\ l_2\dot{r} \end{bmatrix} = Q_1F_x + Q_2F_y + d \tag{3}$$

where mv and l2 stand for the vehicle's mass and moment of inertia, respectively. Two matrices, Q1 and Q2, are connected to the tyre force in two different orientations.

The tire's longitudinal force and lateral force are represented by the matrices Fx and Fy, respectively. d stands for the external disturbances, which are made up of roll resistance and wind resistance.

$$\begin{cases} Q_1 = \begin{bmatrix} cos\delta_f & sin\delta_f & -dcos\delta_f + l_f sin\delta_f \\ cos\delta_f & sin\delta_f & dcos\delta_f + l_f sin\delta_f \\ cos\delta_r & sin\delta_r & -dcos\delta_r - l_r sin\delta_r \\ cos\delta_r & sin\delta_r & dcos\delta_r - l_r sin\delta_r \end{bmatrix}^T \\ Q_2 = \begin{bmatrix} -sin\delta_f & cos\delta_f & l_f cos\delta_f + dsin\delta_f \\ -sin\delta_f & cos\delta_f & l_f cos\delta_f - dsin\delta_f \\ -sin\delta_r & cos\delta_r & -l_r cos\delta_r + dsin\delta_r \\ -sin\delta_r & cos\delta_r & -l_r cos\delta_r - dsin\delta_r \end{bmatrix}^T \end{cases}$$

(4)

$$\begin{cases} F_x = [F_{x11}F_{x12}F_{x21}F_{x22}]^T \\ F_y = [F_{y11}F_{y12}F_{y21}F_{y22}]^T \end{cases}$$

(5)

Where the tyre slip angle ϙij, the road adhesion coefficient μij, the tyre vertical force Fzij, and the slip ratio Sij can all be used to express the tyre longitudinal force and lateral force [10].

$$F_{xij} = f_x(F_{zij}, S_{ij}, \alpha_{ij}, \mu_{ij}), F_{yij} = f_y(F_{zij}, S_{ij}, \alpha_{ij}, \mu_{ij})$$

(6)

Tire vertical force $F_{zij}$ can be determined by:

$$\begin{cases} F_{zfl} = \frac{m_v g l_r}{2l} - \frac{m_v h_g a_x}{2l} - \frac{m_v h_g a_y}{dl} + \frac{m_v a_x a_y h_g^2}{gdl} \\ F_{zfl} = \frac{m_v g l_r}{2l} - \frac{m_v h_g a_x}{2l} + \frac{m_v h_g a_y}{dl} - \frac{m_v a_x a_y h_g^2}{gdl} \\ F_{zfl} = \frac{m_v g l_r}{2l} + \frac{m_v h_g a_x}{2l} - \frac{m_v h_g a_y}{dl} - \frac{m_v a_x a_y h_g^2}{gdl} \\ F_{zfl} = \frac{m_v g l_r}{2l} + \frac{m_v h_g a_x}{2l} + \frac{m_v h_g a_y}{dl} + \frac{m_v a_x a_y h_g^2}{gdl} \end{cases}$$

(7)

Where axe, ay, and hg stand for the autonomous vehicle's longitudinal acceleration, lateral acceleration, and height of C.G., respectively. Gravity-related acceleration is measured in g. Each wheel's angular speed, ωij, can be found by applying driving torque. Wheel rolling dynamics determine the in-wheel motor's Tdij or braking torque (Tbij).

$$l_w \omega_{ij} = T_{dij} - T_{bij} - F_{xij} R_e - f F_{zij} R_e \qquad (8)$$

Where, the parameters lw, Re and f are the moment of inertia, the radius of wheel, and rolling resistance coefficient of tire-road, respectively.

$$S_{ij} = \begin{cases} \frac{R_e \omega_{ij}}{v_{wij}} - 1, & v_{wij} > R_e \omega_{ij} \\ 1 - \frac{v_{wij}}{R_e \omega_{ij}} v_{wij} < R_e \omega_{ij} \end{cases}$$

(9)

Based on wheel dynamics analysis, the tire slip angle can be described by

$$\begin{cases} a_{fl} = \delta_f - \tan^{-1}\left(\frac{v + l_f r}{u - dr}\right) a_{rl} = \delta_r - \tan^{-1}\left(\frac{v + l_r r}{u - dr}\right) \\ a_{fr} = \delta_f - \tan^{-1}\left(\frac{v + l_f r}{u + dr}\right) a_{rr} = \delta_r - \tan^{-1}\left(\frac{v - l_r r}{u + dr}\right) \end{cases}$$

(10)

Numerous academics have used data fitting and experimental analysis to create a variety of tyre models, including the brush model and Magic Formula [11]. Because of Magic Formula's strong unity, easy programming, and high fitting precision, tyre manufacturers and researchers are beginning to accept it more.

$$F_p = Dsin\{Carctan[BX - E(BX - \arctan(BX))]\}$$

(11)

Thus, when X represents tyre slip ratio s or tyre slip angle under pure slip conditions, Fp indicates the longitudinal tyre force Fxp or the lateral tyre force Fyp. The stiffness factor, form factor, peak factor, and curvature factor are represented by the parameters B, C, D, and E, in that order. The tire-road coefficient of adhesion and the vertical tyre load are connected to the peak factor D.

$$\begin{cases} F_x = \frac{\sigma_x}{\sqrt{\sigma_x^2 + \sigma_y^2}} F_{xp} \\ F_y = \frac{\sigma_y}{\sqrt{\sigma_x^2 + \sigma_y^2}} F_{yp} \end{cases} \begin{cases} \sigma_x = \frac{s}{1+s} \\ \sigma_y = \frac{tan\alpha}{1+s} \end{cases}$$

(12)

Where, Fxp and Fyp represent the pure tyre longitudinal force and the pure tyre lateral force, respectively. The lateral slip angle and the normalised slip ratio are denoted by σx and σy, respectively.

**2. Fuzzy Inference System**

It establishes a trapezoidal region for a vehicle depending on its location, speed, acceleration, and direction in order to detect unsafe circumstances. It is likely that a pedestrian and a car will collide if the pedestrian walks into this region. In these scenarios, we assess the required characteristics for our system to identify unsafe situations and issue two degrees of warning, depending on the severity of the accident risks. As a result, the following three phases comprise our system:

- Phase 1 (Activation phase): The system actives for a vehicle and a pedestrian in vehicle's activation region see Fig. 1.
- Phase 2 (prediction phase): Using the various effective parameters, the system projects the number of future collisions.
- Phase 3, or the warning phase, is when the system determines whether a warning is necessary and may sound an alarm.

***A. Details of Activation Phase***

We ascertain the activation area in this step in relation to the vehicle specifications and VRU. The distance at which the driver perceives a risk and applies the brakes to stop the car is one of the essential criteria to establish this area. The stopping distance parameter as:

$$d_{stop} = \frac{v_v^2}{2g(\mu+G)} \tag{13}$$

Where vv is the speed of the vehicle, G is the percentage roadway slope, is the friction coefficient that changes with regard to the road surface, and g is the acceleration of gravity, which equals 9.8 m/s2. In addition, we compute the upper and lower longitudinal distances between VRUs and vehicles using Equations (14) and (15). There are two functions of vehicle speed at these distances.

$$d_{front}(min) = (t_{reaction}(min).\, v_v) + d_{stop} \tag{14}$$

$$d_{front}(max) = \left(t_{reaction}(max) + TTC_v(critical)\right).\, v_v$$
(15)

where treaction(min) is the shortest amount of time a motorist must react after perceiving danger (1 second). In actuality, the lower limit is the shortest amount of time a driver has after receiving an alarm to avoid an accident. In a similar vein, the maximum driver reaction time, or treaction (max), is three seconds. The critical TTC, or TTCv (critical), is three seconds. And lastly, the vehicle velocity is vv. Because of these parameter settings, the mean brake reaction time was calculated to be 1.5 seconds; in the worst situation, this might reach 2.5 seconds, depending on perception-reaction time. To account for these scenarios, we took into account the driver brake reaction time range of 1 to 3 seconds in equations (14) and (15).

Equations (16) and (17), on the other hand, calculate the upper and lower bounds for the lateral distance between the vehicle and VRU. These limitations depend on both the vehicle's speed and the pedestrian's speed. As a result, there is little chance of a collision outside of this region at the current speed.

$$d_{side}(min) = v_p(min).\left(t\left(d_{front}(min)\right)\right) \tag{16}$$

$$d_{side}(max) = v_p(max).\left(t\left(d_{front}(max)\right)\right) \tag{17}$$

Where the lowest and greatest pedestrian speeds are represented by vp(min) and vp(max). According to it, they are 1 m/s and 5 m/s, respectively. The traversal times for a vehicle to cross the distances dfront (min) and dfront (max) are t(dfront(min)) and t(dfront (max)), respectively. The following equations are used to determine them:

$$t(d_{front}(min)) = \frac{-v_v}{a_{stop}} + \sqrt{\frac{v_v^2 - 2a_{stop}.d_{front}(min)}{(a_{stop})^2}} \tag{18}$$

$$t(d_{front}(max)) = \left(t_{reaction}(max) + TTC_v(critical)\right)$$
(19)

The pedestrian's GPS position falls within this zone, at which point the warning system begins to calculate the required parameters and collision probability. Equations (18), (19), and (20) are utilised to verify that the pedestrian is within the activation area:

$$dy_{v,p} \geq \left|6.66 v_v.\, dx_{v,p}\right| \tag{19}$$

$$y_v + d_{front}(min) \leq y_p \leq y_v + d_{front}(max) \tag{20}$$

$$x_v + d_{side}(max) \leq x_p \leq x_v + d_{side}(max) \tag{21}$$

$$dx_{v,p} = \left|x_p - x_v\right|$$

$$dy_{v,p} = \left|y_p - y_v\right|$$

where the distances between the car and the pedestrian are represented by the variables dyv and dxv, respectively. Vehicle and pedestrian longitudes are represented by xv and xp, and vehicle and pedestrian latitudes by yv and yp.

***B. Details of Prediction Phase***

In this, it calculates the time to collision (TTC) parameter for each pedestrian in the activation area. The TTC parameter indicates when a collision is likely to occur. The chance of a collision increases as the TTC value declines. Additionally, it takes TTCv seconds for the car to reach the crossing point and TTCp seconds for the pedestrian to do the same.

***C. Details of Warning Phase***

It takes into account the vehicle's TTC, acceleration, speed, and the distinction between the pedestrian and vehicle TTC factors in this suggested method. We also take into account the effects of environmental factors, features for drivers and pedestrians in this scenario.

## 3. Results & Simulation

The primary concept of this study is the Fuzzy Inference System Controller's Vehicle Movement Control for a Collision Avoidance system. The primary purpose of an automatic vehicle collision avoidance system is to lower the likelihood of accidents by warning and alerting drivers when their cars are approaching an obstacle on the road. It is a more potent system that is intended to aid in preventing collisions. It is composed of sensors, radars, and more lasers that are used to detect collisions, alert drivers to impending crashes, and occasionally even apply the brakes. The fuzzy logic controller, on which this collision avoidance system is built, is a more secure mechanism for the creation of safe and secure systems. The collision avoidance system's sensors, which include several lasers and cameras that detect collisions from a distance and issue warnings, will assist in stopping the vehicles by changing and providing information. Since these systems use GPS, long- and short-range radar, and even machine vision to monitor and gather data on local events, they are also sometimes referred to as radar systems. Because fuzzy logic is a more affordable, reliable, and adjustable technique than other logic techniques, fuzzy logic controllers are employed in the design of these optimised systems. This will raise the automatic collision avoidance system's effectiveness and dependability.

The way a collision avoidance system operates is by employing radars, lasers, and cameras to identify potential collision-causing obstructions in the path. This verified system keeps an eye on every car, cyclist, and pedestrian along every path, including blind spots and traffic areas. This gives touch-based reaction for identifying the places where the collision is still pending and employs AI technology along with several GPS units to determine the path's location. The driver receives notifications and warnings to halt the car as quickly as feasible. Therefore, a multitude of tiny machines are installed inside the collision avoidance system to ensure optimal performance and smooth operation. Among the primary tasks carried out by collision avoidance systems are alerting drivers and providing warnings about blind spots and cross traffic. This collision avoidance technology aids in removing hazards for drivers. When a car is in an emergency or in danger of colliding, the automatic emergency brakes are engaged. All of the cars on the road will have their speeds detected by the automatic collision avoidance system, which can be stopped by beeping and varying voices if a collision is not imminent. This automated system reduces traffic and collisions by issuing critical alerts.

In this instance, there is some traffic in the two-way lane due to an accident or another issue. In this situation, the base station immediately responds to the car so that vehicle may turn the vehicle and change the way accordingly. This lessens the chance of collisions along roadsides. Figure 1 depicts the route a car took along the side of the road. The route never came into contact with vehicles on the street. It takes into account the motion of four cars at once that are travelling in the same direction on the road.

Next, it takes into account the case of lane blocking, where traffic completely blocks a lane. As a result, it gets the signal early and can select a different route for travel. Vehicle velocity is used to quantify performance, and m/sec is used as the unit of measurement. In terms of second measurement, the graph is presented. The vehicle's maximum speed is 7 m/sec, with an average of 4.5 m/sec.

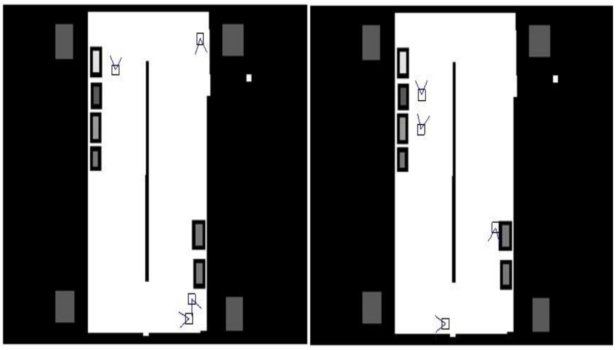

**Fig 1.** Scenario for Vehicle Collision Avoidance System with Four Vehicles in Traffic Lane/Obstacle

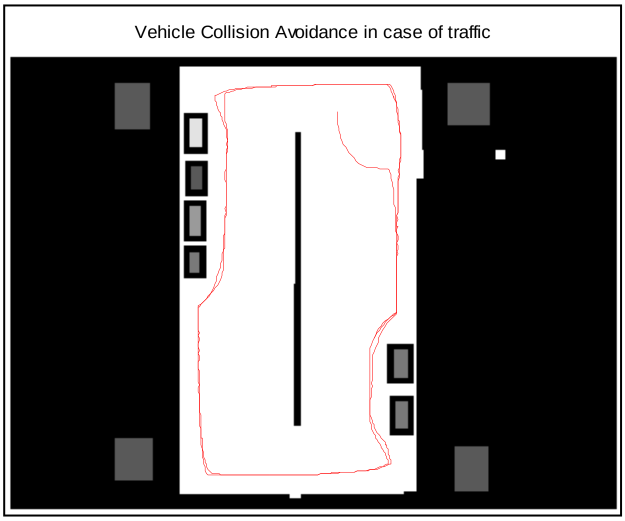


**Fig 2**. Path Traced with Four Vehicles in Traffic Lane/Obstacle

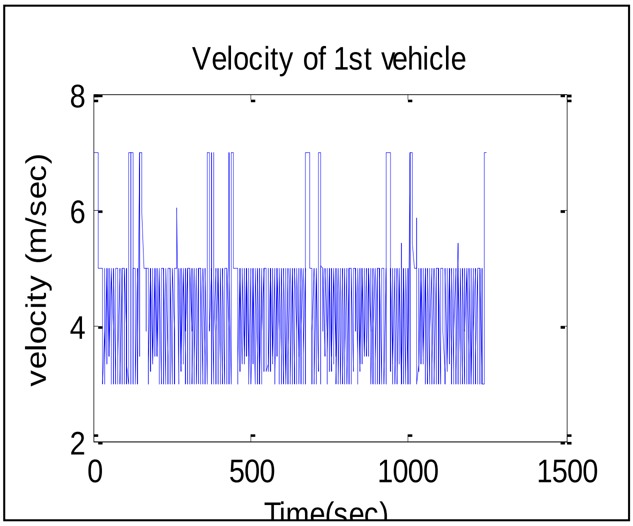


**Fig 3.** Velocity of 1st Vehicle in Traffic Lane/Obstacle

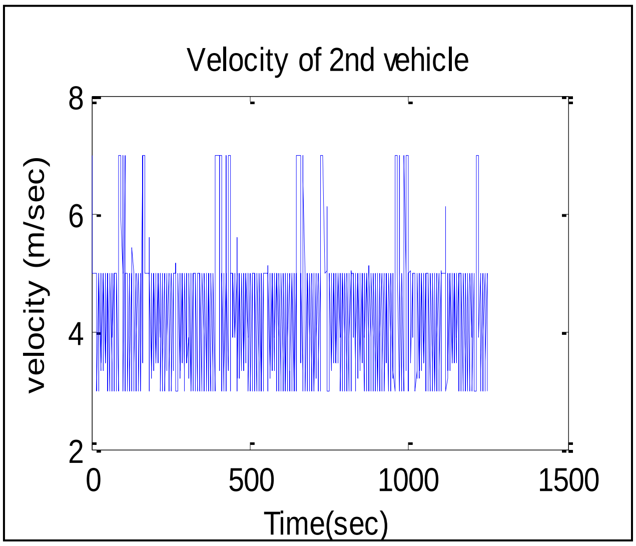


**Fig 4.** Velocity of 2nd Vehicle in Traffic Lane/Obstacle

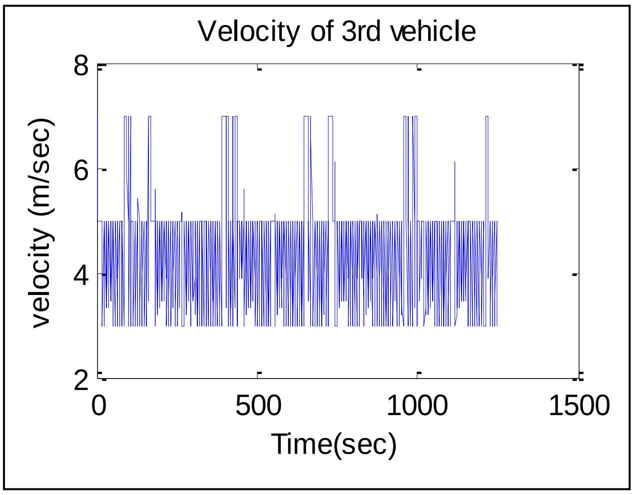


**Fig 5.** Velocity of 3rd Vehicle in Traffic Lane/Obstacle

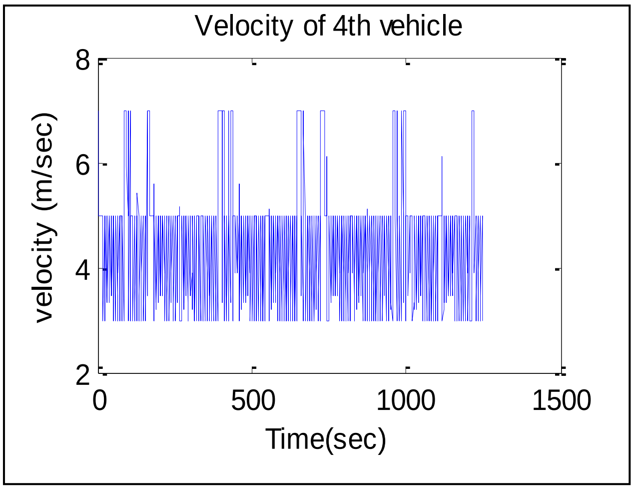


**Fig 6.** Velocity of 4th Vehicle in Traffic Lane/Obstacle

## 4. Conclusion

An atmosphere where driving is safer is promised via vehicle-to-vehicle communication. The US Department of Transportation has made the decision to install safety equipment in lightweight cars so that data on the position, direction, and speed of the vehicles can be shared. The purpose of the safety systems is to alert drivers so they may take the appropriate precautions to avoid collisions. The suggested outcomes of a vehicle collision prevention system using wireless communication are described in this paper. It makes use of the fuzzy controller idea to both prevent collisions and regulate vehicle movement beneath roadside areas. The system's performance is assessed using a variety of metrics. It shows the situation where there are two or four cars in a single or two-lane stretch of road. It uses a controller to adhere to the left-side travel rule in every case. The controller is also used to present the vehicle's projected course. They are also measured and analysed for their angle of orientation, distance from sides, and propagation velocity.

This work's primary drawback is that it only considers vehicles travelling in a single direction. When utilising a fuzzy controller, additional eventualities must be considered. This shows a significant improvement in overall braking performance and guarantees a safer and smoother driving experience, in sharp contrast to the behaviour seen in the current system. This study's future focus will be on investigating and analysing the problem of vehicle accidents brought on by drivers using their brakes later than necessary.

### Conflicts of interest

The authors declare no conflicts of interest.

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