

Hardware simulation of cooperative adaptive cruise control based on fuzzy logic

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ABSTRACT

Cooperative adaptive cruise control (CACC) is a system designed to maintain a vehicle's distance according to the driver's preset value. It is an advancement of adaptive cruise control (ACC), which suffers from response delays when reacting to changes in the leading vehicle's speed. CACC addresses this limitation by reducing response delay through the use of speed data from the preceding vehicle, obtained via wireless communication. In this research, the CACC system was simulated using a 1:10 scale remote-control (RC) car equipped with ultrasonic sensors and radio frequency (RF) communication. Speed control was implemented using a fuzzy logic controller with the Mamdani inference method, while an active steering assistance system was added to maintain lane alignment. Hardware simulation results demonstrate that the CACC system functions effectively and significantly improves the response time of the following vehicle when the leading vehicle changes speed. Experimental results show that the CACC maintained the desired following distance in 10 seconds, compared to 15 seconds for the ACC system.

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1. INTRODUCTION

Several elements of the advanced driver assistance system (ADAS) have become mandatory for vehicles produced in Europe starting in 2022. These elements include adaptive cruise control (ACC), which functions to enhance driving safety and reduce driver fatigue particularly during highway driving by minimizing the need for frequent gas and brake pedal adjustments. Other ADAS subsystems include intelligent speed assistance (ISA) [1], [2], electronic stability control (ESC) [3], [4], automatic braking system (ABS) [5], lane keeping assistance system (LKAS) [6], [7], and overtaking assistance system (OAS) [8], [9].

ACC technology is an advancement of the cruise control system (CCS). The evolution of ACC, from its earliest form to the cooperative adaptive cruise control (CACC), is illustrated in Figure 1. In manual cruise control, the driver adjusts the throttle and brake pedals based on visual observation of road conditions. In the distance warning system (DWS) [10], [11], situation monitoring is performed by sensors, and when an object is detected at a dangerously close distance ahead, an alarm is triggered, prompting the driver to brake to avoid a collision. In CCS, the driver still monitors traffic conditions manually but can activate the cruise control to automate throttle and brake control when appropriate [12], [13]. In ACC, both monitoring of the surrounding environment and adjustment of the throttle and brake pedals are performed automatically by the system [14], [15]. With the advent of connected vehicle technology, ACC has evolved into CACC. At CACC

level 1, cooperation between vehicles occurs in the monitoring stage, whereas at CACC level 2, cooperation extends to both monitoring and control of throttle and brake inputs.

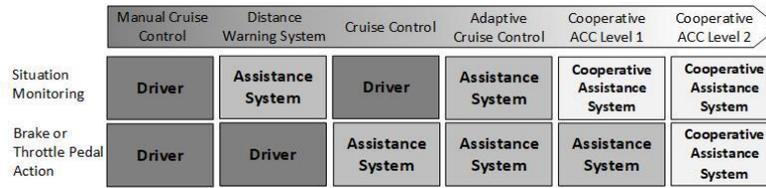


Figure 1. The development of CCS

The development of ACC generally focuses on two main aspects: algorithms and sensors. Several studies have enhanced ACC algorithms, such as [16], [17]. Researchers [16], [18], ACC was implemented using fuzzy logic, while [19], [17] proposed operational characteristic estimation and personalized adaptive cruise control, respectively. ACC development in electric vehicles has also targeted energy efficiency, as studied in [20]. Sensor-focused ACC improvements include the work of [21], which utilized sensor fusion techniques.

In the connected vehicle era, CACC development has accelerated due to advancements in inter-vehicle communication. Trinidad-Rendon *et al.* [22], CACC was implemented using the adaptive Kalman filter, while [23], [24] investigated CACC in real-world environments and conducted safety analyses. Studies [25], [26] explored CACC for vehicle platooning applications.

In this study, a CACC hardware simulation is developed using fuzzy logic control. Communication between vehicles is established via radio frequency (RF) signals transmitted from the leading vehicle to the following vehicle.

The remainder of this paper is organized as follows: section 2 provides an overview of ACC and CACC operations, hardware simulation, and the conducted experiments. Section 3 presents the experimental results and analysis. Finally, section 4 concludes the paper.

2. RESEARCH METHOD

The research methodology commences with an examination of the operational principles of CACC, followed by the design of a fuzzy logic controller for vehicle speed regulation. A block diagram is subsequently developed to support the implementation of the CACC hardware simulation. Finally, conclusions are drawn based on the results obtained from simulation and analysis.

2.1. ACC System

ACC is a subsystem of the ADAS designed to assist drivers when traveling on relatively monotonous roads [27]. On such roads, for example toll highways, drivers may experience fatigue or drowsiness. To mitigate this, auxiliary systems are employed to maintain a relatively constant vehicle speed without requiring continuous manual adjustment of the throttle and brake pedals. The ACC system operates by referencing the vehicle directly ahead, as illustrated in Figure 2.

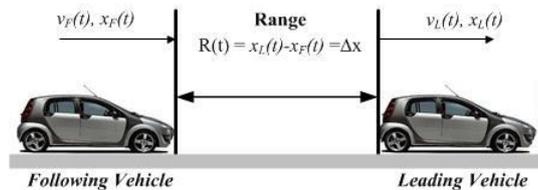


Figure 2. Adaptive CCS

The ACC adjusts v_F so that $R(t)$ remains relatively constant even when v_L is changed. As a reference for the ACC system, the relatively constant distance $R(t)$ can be maintained and the speed $x_L - x_F$ is kept relatively zero. The ACC system regulates the following vehicle's speed v_F such that the inter-vehicle

distance $R(t)$ remains relatively constant, even when the leading vehicle's speed v_L changes. As a control reference, the ACC may either maintain a predetermined fixed distance $R(t)$ or monitor the relative velocity $x_L - x_F$ to ensure it remains approximately zero.

2.2. CACC

CACC is an advancement of the ACC system, which operates on a similar principle. In addition to using sensors to measure the distance between vehicles, CACC also integrates vehicle-to-vehicle (V2V) communication to transmit speed data from the leading vehicle to the following vehicle. This system maintains the desired distance according to the driver's specifications. The operational concept of CACC is illustrated in Figure 3. The development of CACC has been enabled by the availability of inter-vehicle communication technologies, such as wireless access in vehicular environments (WAVE).

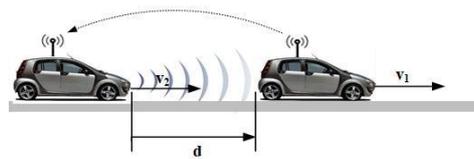


Figure 3. CACC system

2.3. Fuzzy logic controller design

In the CACC system simulation, two variables are used as inputs for fuzzy logic control: distance error and leading vehicle speed. Distance error is defined as the difference between the desired setpoint value and the actual inter-vehicle distance. This input is categorized into six fuzzy sets: smallest, very small, small, large, very large, and largest. The second input, the speed of the leading vehicle, is obtained through RF communication and is classified into two fuzzy sets: slow and fast. The membership functions for these fuzzy inputs are shown in Figures 4 and 5. The fuzzy inference rules for the CACC system are formed using the fuzzy associative memory (FAM) table, as shown in Table 1. The membership functions for the fuzzy outputs are presented in Figure 6.

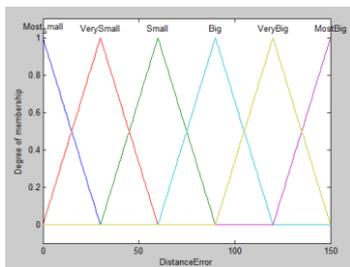


Figure 4. Membership function of distance error

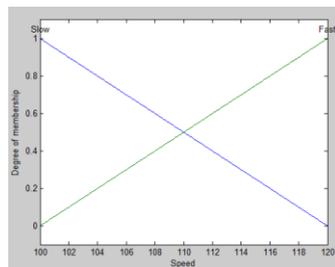


Figure 5. Membership function of speed

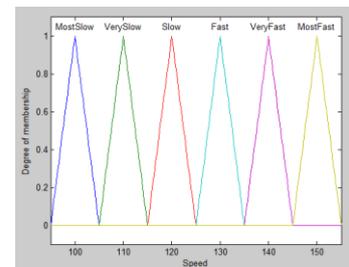


Figure 6. Membership function of output speed

Table 1. Rule base

		Distance				
Speed	Most small	Very small	Small	Big	Very big	Most big
Slow	Most slow	Very slow	Slow	Fast	Very fast	Most fast
Fast	Fast	Fast	Very fast	Very fast	Most fast	Most fast

2.4. CACC hardware simulation

The block diagram of the leader–follower vehicle system is illustrated in Figure 7, where Figure 7(a) shows the leading vehicle control system and Figure 7(b) presents the following vehicle control system. The primary function of the CACC system is to maintain a specified following distance from the leading vehicle by adjusting the speed of the following vehicle. Speed regulation is based on two parameters: the distance error defined as the difference between the actual distance and the setpoint and the speed of the leading

vehicle, transmitted via a RF communication device. Vehicle speed adjustments are achieved by controlling both acceleration and braking. In this research, the simulation is implemented using a 1:10 scale remote-control (RC) car.

The line sensor functions as a lane detector during simulations to ensure that the RC car moves straight and remains within its designated lane. This sensor generates a logic “1” output when detecting a white lane, where the white color is used to simulate road lane markings commonly found on actual streets. The sensor selected for this system is the line tracking robot V4 sensor. It is chosen because it produces a logic “0” output when reading gray surfaces, whereas other comparable sensors produce a logic “1” output. The detection distance can be adjusted by rotating the onboard potentiometer.

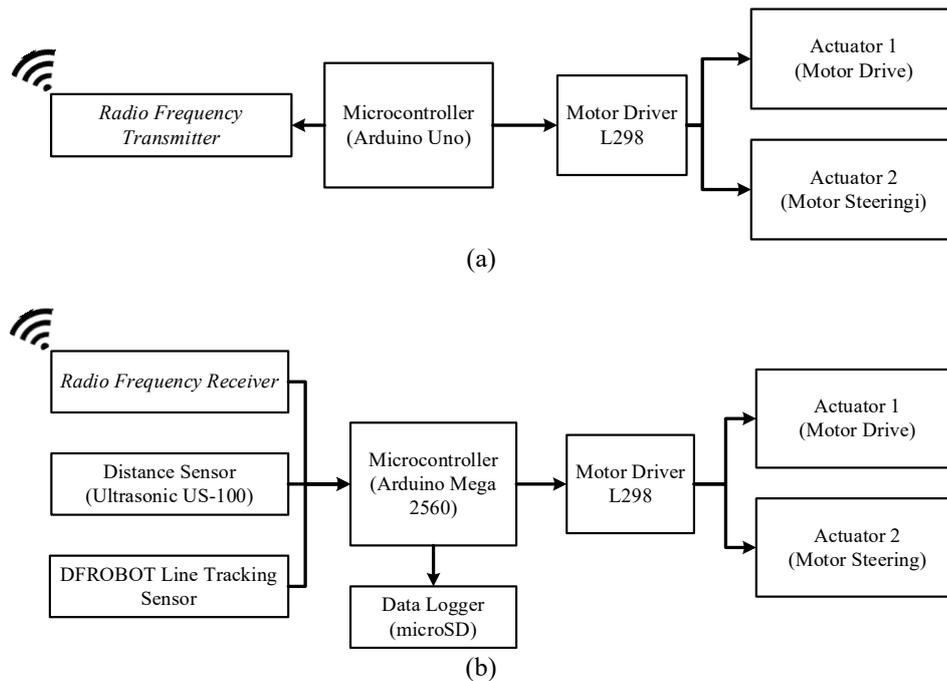


Figure 7. Block diagram of the leader follower vehicle system: (a) block diagram of the leading vehicle control system and (b) block diagram of the following vehicle control system.

The robot line tracking sensor for Arduino is capable of detecting white lines on a black background or black lines on a white background. It provides a stable transistor-transistor logic (TTL) output signal to ensure reliable and accurate line detection. In addition, multi-channel configurations can be implemented if more complex line-tracking requirements are needed.

The sensor outputs are fed into the microcontroller, which processes the signals into pulse width modulation (PWM) values and logic outputs. The PWM values determine the steering angle, while the logic outputs determine the direction of wheel movement. Two-line sensors are placed on the left side and two on the right side of the RC car. Using two sensors on each side allows the system to determine how far the car has deviated from its lane. If the outer left sensor detects the lane, the steering system turns slightly to the right to guide the vehicle back toward the center. If the inner left sensor detects the lane, the RC car performs a sharper right turn. The same control principle applies symmetrically to the sensors on the right side.

The distance error serves as an input to the fuzzy logic controller, which determines the control output. Distance measurements are obtained using ultrasonic sensors, which detect objects by emitting ultrasonic waves and processing the reflected signal. The sensor output is converted into distance values in centimeters via a microcontroller program. The maximum detection range of the ultrasonic sensor is 3 meters.

In addition to distance measurement sensors, the CACC system is equipped with a communication module to receive speed data from the leading vehicle. This communication operates in a one-way configuration, transmitting data from the leading vehicle to the following vehicle via RF communication. RF devices that use radio waves are the transmission medium, with the maximum range depending on the transmitter power and antenna specifications.

The distance error and leading vehicle speed are processed by a fuzzy logic controller running on an Arduino Mega 2560. The controller output is a PWM signal, which regulates the following vehicles speed through an L298 motor driver. The control output magnitude is determined by both the distance error and the speed of the following vehicle.

To ensure lane adherence during simulation, an active steering assistance system [28] is implemented. This system utilizes four DFRobot V4 line-tracking sensors, each providing binary logic outputs (“1” or “0”). These outputs are processed by the microcontroller to generate both PWM and logic signals, which in turn determine the steering angle and direction of the RC car.

The operational sequence of the CACC system implemented on the RC car is as:

- The RC car follows a predetermined path using an active steering assistance system.
- During simulation, the distance sensor continuously measures the gap between the leading and following RC cars.
- When the inter-vehicle distance decreases, the following vehicle decelerates by reducing the PWM value, determined from the distance error relative to the setpoint and the speed of the leading vehicle.
- As the distance between vehicles increases, the following vehicle accelerates by increasing the PWM value, which is based on the distance and speed error of the vehicle in front.

The 1:10 scale RC car developed for the CACC hardware simulation in Figures 8 and Figure.



Figure 8. Hardware simulator of the following vehicle



Figure 9. Hardware simulator used in testing

3. RESULTS AND ANALYSIS

The results and analysis section presents the outcomes of three experiments: data transmission testing between vehicles, CACC performance testing at a constant speed, and CACC performance testing under varying speed conditions.

3.1. Data transmission testing

Data transmission testing was conducted by sending data from the transmitter to the receiver. The data sent consisted of integer values obtained from the Arduino’s analog input. This test aimed to evaluate the reliability of RF communication used for data transmission between vehicles. The test results are presented in Figures 10 and 11.

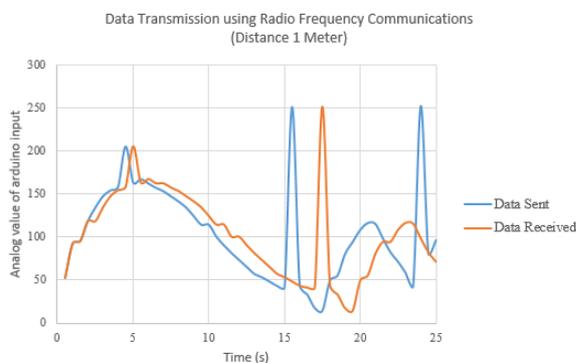


Figure 10. Graph of testing data transmission at a distance of 1 m

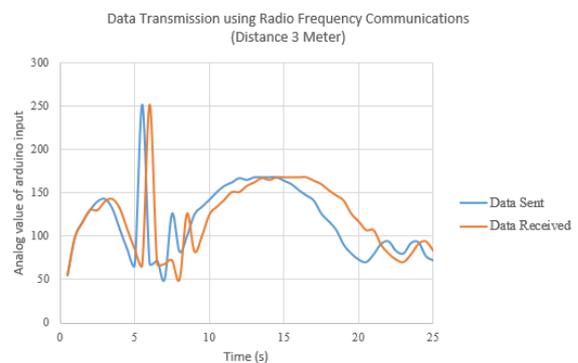


Figure 11. Graph of testing data transmission at a distance of 3 m

3.2. CACC testing with fixed speed

In this experiment, the speed of the leading vehicle was kept constant. The test was conducted by placing the following vehicles at initial distances of 50 cm and 100 cm from the leading vehicle. An illustration of the test configuration in Figure 12.

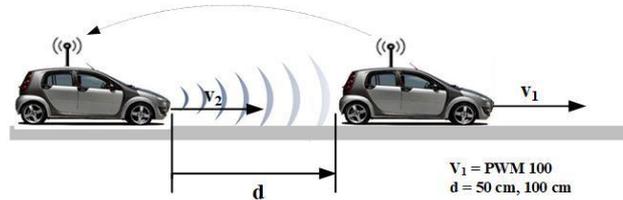


Figure 12. Illustration of testing at constant speed

As seen from the data, when the distance between the follower vehicle and the leader vehicle exceeds the setpoint, the fuzzy logic controller increases the PWM output value, thereby increasing the speed of the follower vehicle and reducing the distance between the two RC cars. Conversely, when the distance between the vehicles approaches the threshold value, the fuzzy logic controller reduces the PWM output value used to reduce the speed of the following vehicle so that the distance can converge to the predetermined threshold value. The test results are shown in Figures 13 and 14.

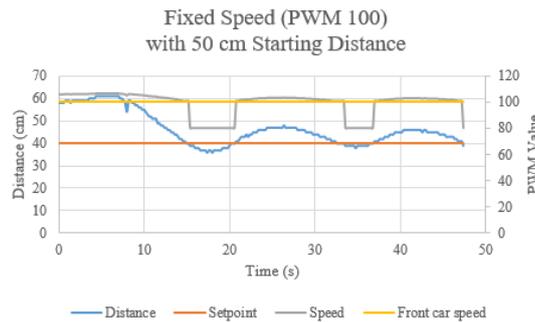


Figure 13. Graph of CACC system testing at constant speed with an initial inter-vehicle distance of 50 cm

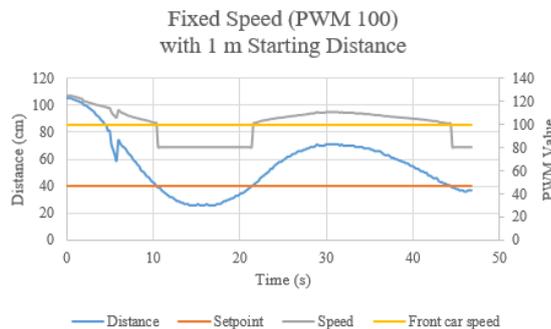


Figure 14. Graph of CACC system testing at constant speed with an initial inter-vehicle distance of 100 cm

3.3. CACC testing with speed changed

In this experiment, the speed of the leading vehicle was changed from a PWM value of 100 to 120. The test was conducted under two conditions: with RF communication enabled and without RF communication. This test was conducted to analyze the performance of the CACC system when there was a

change in speed in the leading vehicle. In this configuration, the leading vehicle moves at a speed controlled by a PWM signal in the range of 100 to 120. Meanwhile, the following vehicle adjusts this speed by maintaining a safe distance measured by an ultrasonic sensor. In addition to relying on distance measurements, the system also utilizes V2V communication to receive actual speed information from the leading vehicle, as shown in Figure 15, where Figure 15(a) represents the condition with communication enabled, while Figure 15(b) presents the condition without communication [18]. The results are shown in Figures 16 and 17.

From the data shown in Figure 16, it can be observed that when the vehicle behind uses a communication system to receive speed data from the vehicle in front, it can quickly adjust the distance between vehicles to match the specified setpoint, even when the speed of the vehicle in front changes. Conversely, Figure 17 shows that without communication, the following vehicle takes much longer to adjust to the setpoint, which in some cases cannot achieve the desired distance.

When the speed of the lead vehicle (V_1) increases, the ultrasonic sensor on the follower vehicle (V_2) detects an increase in the distance (d) between the two vehicles. Speed information from the lead vehicle is transmitted wirelessly and processed by a fuzzy logic controller to generate a new control signal in the form of an increase in the PWM value of the follower vehicle's drive motor. As a result, the follower vehicle accelerates its movement until the actual distance returns to a value close to the reference distance (d_0). This response demonstrates the CACC system's ability to synchronously adjust speed without causing significant delays in the speed changes of the leading vehicle. Conversely, when the speed of the lead vehicle decreases, the sensor detects a smaller distance between the two vehicles. The fuzzy logic system then commands a reduction in the PWM value so that the follower vehicle slows down proportionally. This process continues until the distance returns to the desired value of d_0 . This test proves that the system is capable of adaptively controlling the speed of the follower vehicle during both acceleration and deceleration of the lead vehicle, while maintaining a safe distance between the two.

Additional testing is performed with a speed variation pattern of 100–120–100 PWM. The resulting data are presented in Figures 18 and Figure. As shown in Figure 18, when the communication system is active, the following vehicle responds rapidly to changes in the leading vehicle's speed, enabling it to maintain the setpoint distance more effectively. When the leading vehicle accelerates, the following vehicle increases its speed to reduce the gap, and when the leading vehicle decelerates, the following vehicle reduces its speed to prevent a collision and restore the setpoint distance. However, the system still exhibits a maximum deviation of 15 cm from the setpoint during these tests.

Overall, the test results show that combining ultrasonic sensors and V2V communication improves the performance of conventional ACC systems. The fuzzy logic-based CACC system is able to anticipate changes in the speed of the lead vehicle with a faster and more stable response, thereby minimizing the potential for collisions. These results indicate that the implementation of CACC in small-scale hardware simulation can represent the dynamics of the actual vehicle system quite well, especially in terms of speed coordination between vehicles moving collaboratively.

In contrast, as shown in Figure 19, when communication is not used, the following vehicle reacts more slowly to changes in the leading vehicle's speed and takes longer to reach the desired distance, further demonstrating the advantage of incorporating RF communication in the CACC system.

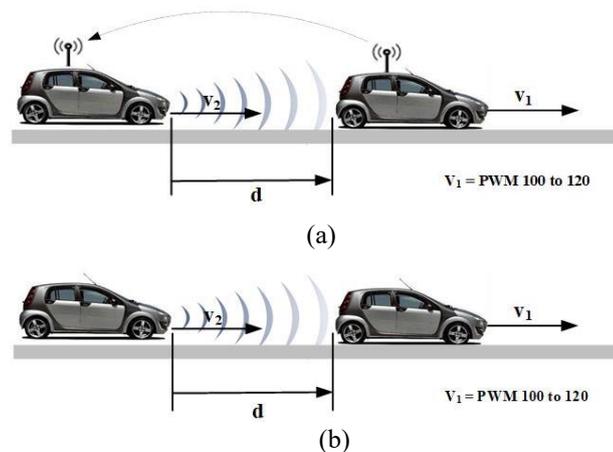


Figure 15. Illustration of the variable-speed test: (a) with communication enabled and (b) without communication

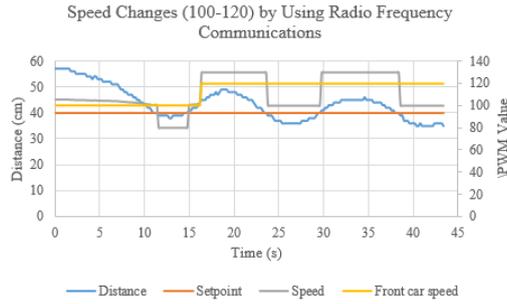


Figure 16. Test results for variable speed (100–120 PWM) with RF communication

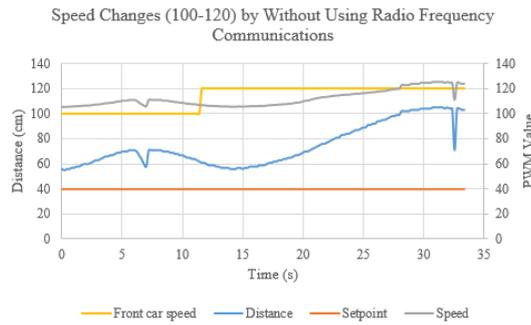


Figure 17. Test results for variable speed (100–120 PWM) without RF communication

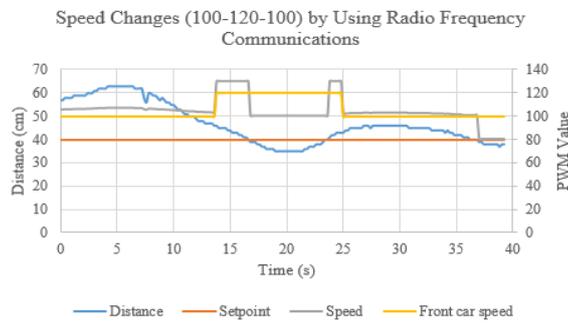


Figure 18. Test results for variable speed (100–120–100 PWM) using RF communication

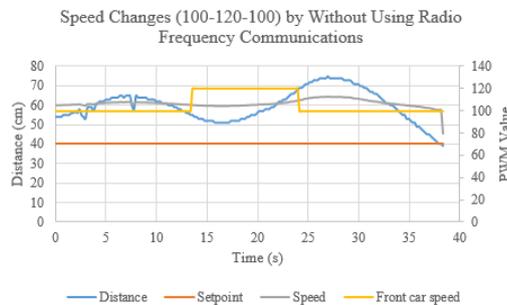


Figure 19. Test results for variable speed (100–120–100 PWM) without using RF communication

For a 1:10 scale model means that each linear dimension (length, width, height) is reduced by a factor of 10. However, the laws of physics (mass, force, inertia, and aerodynamics) are not reduced linearly

causing fundamental differences between the behavior of the model and the actual vehicle. This simulation remains useful for proof of concept, but the results cannot be directly generalized without considering scale effects. The scaling effect on vehicle dynamics affects mass and inertia. The mass will decrease approximately in proportion to L^3 . Clearly, a 1:10 model has a mass $\approx (1/10)^3 = 1/1000$ of the original vehicle. In addition, the moment of inertia is drastically reduced, making the system much more responsive and resulting in relatively greater traction and tire/air friction forces compared to the mass, or a response that is too fast compared to the real world. [29].

4. CONCLUSION

The hardware simulation results demonstrate that the CACC system operates effectively and improves the response time of the following vehicle when the leading vehicle changes its speed. By utilizing inter-vehicle communication, the CACC system successfully transmits speed data from the leading vehicle to the following vehicle, enabling the latter to respond appropriately by adjusting its speed to maintain a relatively constant inter-vehicle distance. The response time of the following RC car is reduced by approximately 5 seconds when using the CACC system. Specifically, with CACC enabled, the following vehicle requires approximately 10 seconds to adjust to the desired distance, whereas with ACC alone, the adjustment time increases to approximately 15 seconds.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization

M : **M**ethodology

So : **S**oftware

Va : **V**alidation

Fo : **F**ormal analysis

I : **I**nvestigation

R : **R**esources

D : **D**ata Curation

O : Writing - **O**riginal Draft

E : Writing - Review & **E**ditting

Vi : **V**isualization

Su : **S**upervision

P : **P**roject administration

Fu : **F**unding acquisition

CONFLICT OF INTEREST STATEMENT

There are no conflicts of interest in this research.

INFORMED CONSENT

This study does not involve human participants or identifiable personal data. Therefore, informed consent was not required.

ETHICAL APPROVAL

This research does not involve humans or animals as subjects.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, R.H., upon reasonable request.

REFERENCES

- [1] A. L. Yadav and S. K. Goyal, "An Efficient and Intelligent System for Controlling the Speed of Vehicle using Fuzzy Logic and Deep Learning," *International Journal of Advanced Computer Science and Applications (IJACSA)*, vol. 15, no. 3, pp. 96-106, 2024, doi: 10.14569/IJACSA.2024.0150311.
- [2] S. Waykole, N. Shiwakoti, and P. Stasinopoulos, "Review on Lane Detection and Tracking Algorithms of Advanced Driver Assistance System," *Sustainability - MDPI*, vol. 13, no. 20, pp. 2-29, 2021, doi: 10.3390/su132011417.
- [3] Z. Wu, C. Kang, B. Li, J. Ruan, and X. Zheng, "Dynamic Modeling, Simulation, and Optimization of Vehicle Electronic Stability Program Algorithm Based on Back Propagation Neural Network and PID Algorithm," *Actuators - MDPI*, vol. 13, no. 3, pp. 1-22, 2024, doi: 10.3390/act13030100.
- [4] L. A. Torres, A. Murilo, R. V. Lopes, and V. Leal, "Analysis and Virtual Validation of Vehicle Dynamics Models for Electronic Stability Control," *IEEE Latin America Transactions*, vol. 22, no. 2, pp. 166-172, 2024, doi: 10.1109/tla.2024.10412038.
- [5] R. Pete and D. M. Deosarkar, "Automatic Braking System," *Journal of Electrical Systems (JES)*, vol. 20, no. 7, pp. 957-964, 2024, doi: 10.52783/jes.3476.
- [6] S. Wei, P. E. Pfeffer, and J. Edelmann, "State of the Art: Ongoing Research in Assessment Methods for Lane Keeping Assistance Systems," in *IEEE Transactions on Intelligent Vehicles*, vol. 9, no. 9, pp. 5853-5875, Sept. 2024, doi: 10.1109/TIV.2023.3269156.
- [7] H. Liu, C. Liu, L. Hao, and D. Zhang, "Stability Analysis of Lane-Keeping Assistance System for Trucks under Crosswind Conditions," *Applied Sciences*, vol. 13, no. 7, 2023, doi: 10.3390/app13179891.
- [8] J. Ortega, H. Lengyel, and Z. Szalay, "Overtaking maneuver scenario building for autonomous vehicles with PreScan software," *Transportation Engineering*, vol. 2, 2020, doi: 10.1016/j.treng.2020.100029.
- [9] G. Mandai, D. Bhattacharya, and P. De, "Real Time Vision Based Overtaking Assistance System for Drivers at Night on Two-Lane Single Carriageway," *Computación y Sistemas*, vol. 25, no. 2, 2021, doi: 10.13053/cys-25-2-3783.
- [10] S. Odngam and C. Sumpavakup, "Design of a Lidar-Based Safe Braking Distance Warning System for Small Electric Vehicles," *Recent Science and Technology*, vol. 17, no. 1, 2025.
- [11] H. Ma, Y. J. Gao, Q. Yang, J. X. Tao, and Z. Ji, "Foggy distance warning system based on LoRa technology," *2021 International Conference on Intelligent Transportation, Big Data & Smart City (ICITBS)*, Xi'an, China, 2021, pp. 550-553, doi: 10.1109/ICITBS53129.2021.00140.
- [12] D. Hu, J. Zhao, J. Zheng, and H. Liu, "An Adaptive Cruise Control Strategy for Intelligent Vehicles Based on Hierarchical Control," *World Electric Vehicle Journal - MDPI*, vol. 15, no. 11, 2024, doi: 10.3390/wevj15110529.
- [13] Z. Song, H. Ding, J. Wang, C. Huang, and Y. Guo, "Research on the strategy of cruise control system for urban traffic jam assistant," *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, vol. 239, no. 12, 2024, doi: 10.1177/09544070241283886.
- [14] N. C. Basjaruddin, K. Kuspriyanto, D. Saefudin, and I. K. Nugraha, "Developing Adaptive Cruise Control Based on Fuzzy Logic Using Hardware Simulation," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 4, no. 6, Dec. 2014, doi: 10.11591/ijece.v4i6.6734.
- [15] Z. Mehraban, A. Y. Zadeh, H. Khayyam, R. Mallipeddi, and A. Jamali, "Fuzzy adaptive cruise control with model predictive control responding to dynamic traffic conditions for automated driving," *Engineering Applications of Artificial Intelligence*, vol. 136, no. Part B, 2024, doi: 10.1016/j.engappai.2024.109008.
- [16] K. Alomari, R. C. Mendoza, S. Sundermann, and D. Goehring, "Fuzzy Logic-based Adaptive Cruise Control for Autonomous Model Car," in *Proceedings of the International Conference on Robotics, Computer Vision and Intelligent Systems ROBOVIS - Volume 1, 121-130*, Setúbal, Portugal, 2020, doi: 10.5220/0010175101210130.
- [17] M. F. Ozkan and Y. Ma, "Personalized Adaptive Cruise Control and Impacts on Mixed Traffic," *2021 American Control Conference (ACC)*, New Orleans, LA, USA, 2021, pp. 412-417, doi: 10.23919/ACC50511.2021.9482812.
- [18] J. Mao, L. Yang, Y. Hu, K. Liu, and J. Du, "Research on Vehicle Adaptive Cruise Control Method Based on Fuzzy Model Predictive Control," *Machines - MDPI*, vol. 9, no. 160, 2021, doi: 10.3390/machines9080160.
- [19] J. Chen, G. Yu, and X. Yan, "Data Based Parameter Setting Method for Adaptive Cruise Control," in *IEEE Access*, vol. 8, pp. 15291-15302, 2020, doi: 10.1109/ACCESS.2020.2967321.
- [20] C. Pan *et al.*, "Energy-optimal adaptive cruise control strategy for electric vehicles based on model predictive control," *Energy*, vol. 241, 2022, doi: 10.1016/j.energy.2021.122793.
- [21] M. Hasanujjaman, M. Z. Chowdhury, and Y. M. Jang, "Sensor Fusion in Autonomous Vehicle with Traffic Surveillance Camera System: Detection, Localization, and AI Networking," *Sensors - MDPI*, vol. 23, no. 3335, pp. 1-23, 2023, doi: 10.3390/s23063335.
- [22] J. S. D. L. Trinidad-Rendon, J. A. Reyes-Avendaño, and H. G. Gonzalez-Hernandez, "A Comparative Study of Scaled Autonomous Vehicle Platforms for Research and Education," *2025 IEEE Mexican Humanitarian Technology Conference (MHTC)*, Puebla, Mexico, 2025, pp. 123-129, doi: 10.1109/MHTC65808.2025.11086476.
- [23] D. Lee, S. Lee, and Z. Chen, "Design and field evaluation of cooperative adaptive cruise control with unconnected vehicle in the loop," *Transportation Research part C: Emerging Technologies*, vol. 132, 2021, doi: 10.1016/j.trc.2021.103364.
- [24] Y. Liu, W. Wang, X. Hua, and S. Wang, "Safety Analysis of a Modified Cooperative Adaptive Cruise Control Algorithm Accounting for Communication Delay," *Sustainability - MDPI*, vol. 12, pp. 1-17, 2020, doi: 10.3390/su12187568.
- [25] F. Li and Y. Wang, "Cooperative Adaptive Cruise Control for String Stable Mixed Traffic: Benchmark and Human-Centered Design," in *IEEE Transactions on Intelligent Transportation Systems*, vol. 18, no. 12, pp. 3473-3485, Dec. 2017, doi: 10.1109/TITS.2017.2760805.
- [26] A. Borneo, L. Zerbatto, F. Miretti, A. Tota, E. Galvagno, and D. A. Misul, "Platooning Cooperative Adaptive Cruise Control for Dynamic Performance and Energy Saving: A Comparative Study of Linear Quadratic and Reinforcement Learning-Based Controllers," *Applied Sciences - MDPI*, vol. 13, no. 10459, pp. 1-23, 2023, doi: 10.3390/app131810459.
- [27] N. C. Basjaruddin, D. B. Margana, Kuspriyanto, R. Rinaldi, and Suhendar, "Hardware Simulation of Rear-End Collision Avoidance system Based on Fuzzy Logic," *Jurnal Rekayasa ElektriKa*, vol. 16, no. 1, pp. 23-28, 2020, doi: 10.17529/jre.v16i1.15107.
- [28] H. T. Ngoc and L.-D. Quach, "Adaptive Lane Keeping Assist for an Autonomous Vehicle based on Steering Fuzzy-PID Control in ROS," *International Journal of Advanced Computer Science and Applications (IJACSA)*, vol. 13, no. 10, pp. 725-731, 2022, doi: 10.14569/IJACSA.2022.0131086.
- [29] F. Caleffi, L. d. S. Rodrigues, J. d. S. Stamboroski, and B. M. Pereira, "Small-scale self-driving cars: A systematic literature review," *ScienceDirect - JTTE*, vol. 11, no. 2, pp. 272-292, 2024, doi: 10.1016/j.jtte.2023.09.005.

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