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Car Controller Design Using Fuzzy Logic

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A B S T R A C T

This work focuses on developing a car controller using fuzzy logic to enhance vehicle performance in various driving conditions. The controller aims to manage speed, distance, and acceleration more adaptively and robustly than traditional methods. The design process includes defining system requirements, implementing, and testing the fuzzy logic controller primarily through Matlab simulations. These simulations tested different combinations of speed, distance, and acceleration, demonstrating the controller's robust performance in diverse scenarios and effective management of acceleration for safety. The study concludes that the fuzzy logic controller provides adaptable, efficient vehicle control across various driving conditions. Future work may explore using machine learning to automate fuzzy rule generation, potentially improving the controller's adaptability and broadening its scenario handling through hybrid systems combining fuzzy logic and neural networks.

Keywords: Fuzzy Logic, Car Controller, Vehicle Control Systems, Autonomous Driving, Acceleration Control, Advanced Driver Assistance Systems (ADAS)

1. Introduction

Intelligent vehicle control systems are crucial for modern transportation, aiming to enhance safety, efficiency, and driving comfort. These systems are designed to make autonomous or semi-autonomous decisions that mimic human driving behaviour. The ultimate goal is to reduce the number of accidents, improve traffic flow, and provide a more comfortable driving experience for passengers.

Intelligent Vehicle Control Systems have seen significant advancements in recent years, leveraging technologies like artificial intelligence, edge computing, deep learning, and automation to enhance operational efficiency, safety, and automation in various transportation scenarios. Research has focused on developing intelligent transport systems that integrate different modes of transport to improve overall efficiency and safety (Roman Redko & Grigorii Milenin, 2023). Additionally, the design of intelligent vehicles capable of navigating complex environments, such as commercial greenhouses, has been proposed to reduce labour intensity and enhance operational efficiency (Wu et al. 2023). Control algorithms, including switch control strategies, fuzzy control algorithms, and Convolutional Neural Networks (CNN), have been utilized to enhance vehicle stability, trajectory tracking, and recognition of surroundings, showcasing the potential of intelligent control systems based on cutting-edge technologies (Ming, 2023). Furthermore, path tracking control methods based on curvature optimization have been developed to address performance conflicts and improve stability in intelligent vehicles, demonstrating significant enhancements in tracking accuracy and stability under various conditions (Qing et al, 2023). The evolution of advanced intelligent vehicle control systems has been attributed to the use of artificial intelligence techniques, new sensors, and technological advancements (Cabrera, 2022).

Traditional control systems, such as PID (Proportional-Integral-Derivative) controllers, have been widely used in automotive applications. These systems rely on precise mathematical models and typically perform well under well-defined conditions (Arafat et al. 2023). However, they often struggle to cope with the inherent uncertainties and complexities of real-world driving environments, such as varying road conditions, unpredictable traffic scenarios, and diverse driver behaviours (Alenany, 2023).

Fuzzy logic, introduced by Lotfi Zadeh in 1965, offers an effective solution to the limitations of traditional control systems by handling imprecision and uncertainty (Uberl et al. 2018). Unlike binary logic, which deals with true or false values, fuzzy logic allows for degrees of truth, enabling it to process information in a way that resembles human reasoning (Paudel et al. 2022). This makes fuzzy logic particularly suitable for complex and dynamic systems like vehicle control (Pourabdollah et al. 2021). Fuzzy logic systems consist of three main components: Fuzzification, Converts crisp input values into fuzzy values using membership functions; Inference Engine, Applies a set of fuzzy rules to the fuzzy input values to infer the fuzzy output values; Defuzzification, Converts the fuzzy output values back into crisp values that can be used to control actuators.

The use of fuzzy logic in car control systems offers several advantages: Fuzzy logic can handle the uncertainties and variabilities in driving conditions better than traditional control methods (Sánta et al. 2023). It mimics human decision making processes, making it more adaptable to complex and unpredictable scenarios (Li et al. 2021). Fuzzy logic systems are relatively easy to design and implement, especially when expert knowledge is available to define the rule base.

Fuzzy logic has been extensively applied in various automotive applications, showcasing its versatility and effectiveness. Research has explored its use in adaptive cruise control (ACC) systems for speed control and safe distance maintenance (Simic, 2022), as well as in direct torque control (DTC) methods for electric vehicle (EV) traction chains, enhancing speed, precision, stability, and robustness metrics (Max et al. 2021). Furthermore, fuzzy logic control (FLC) has been implemented in semi-active shock absorbers to improve vehicle ride comfort, demonstrating superior performance compared to other controllers at a fraction of the cost (Mokhiamar et al. 2022). Additionally, fuzzy logic-based controllers have been successfully utilized in line following model cars, with on-going efforts to enhance performance by utilizing more capable microcontrollers (Boldizsá & Könczöl, 2020). These studies collectively highlight the wide-ranging applications and benefits of fuzzy logic in the automotive industry, from enhancing driving assistance features to improving vehicle dynamics and comfort.

2. Methodology

The methodology for designing a car controller using fuzzy logic involves several steps, ranging from defining the system requirements to implementing and testing the fuzzy logic controller.

2.1 System Description

Figure 1 illustrates two cars on a road with a distance of 50 meters apart. Car 1 is positioned at the 20-meter mark and Car 2 is positioned at the 70-meter mark, making the distance between the two cars 50 meters. The road is depicted with lane markings, and an arrow indicates the distance between the two cars. This visual representation helps illustrate the spatial relationship between the two cars for the fuzzy logic controller scenario.

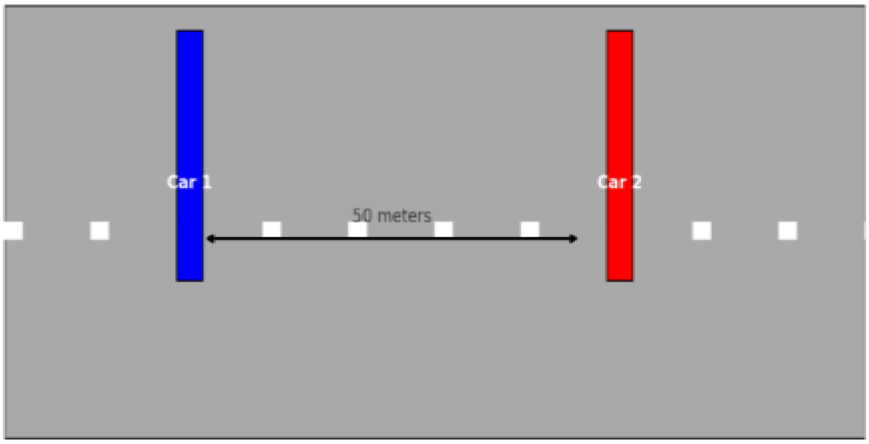

Figure 1: Two cars on a road with a distance of 50 meters apart

Figure 2 shows the architectural diagram for the two cars illustrating the flow of information from sensors to the fuzzy logic controller and then to the actuators.

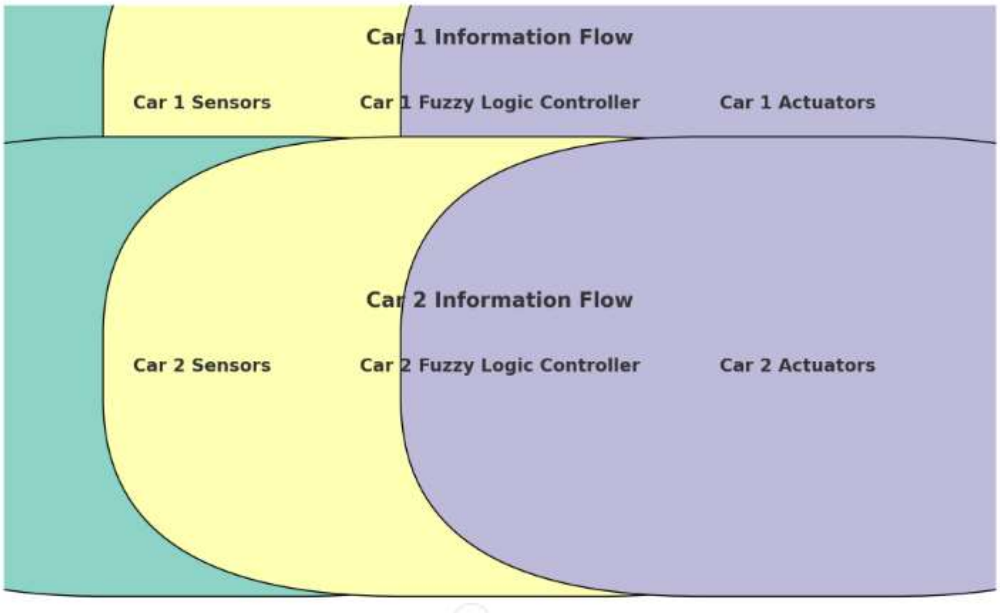

Figure 2: car controller system for two vehicles

Car 1 Information Flow:

Sensors: These sensors detect various inputs such as speed, distance to obstacles, road conditions, and steering angle.

Fuzzy Logic Controller: This controller processes the sensor inputs using fuzzy logic to make decisions.

Actuators: Based on the controller's decisions, the actuators perform actions like adjusting acceleration, braking, and steering.

Car 2 Information Flow:

Sensors: Similar to Car 1, these sensors gather input data about the vehicle's environment and status.

Fuzzy Logic Controller: The controller interprets the sensor data and determines the appropriate actions.

Actuators: The actuators execute the necessary adjustments as directed by the fuzzy logic controller.

Key Components:

Sensors: Collect real-time data.

Fuzzy Logic Controllers: Process data and make decisions.

Actuators: Implement the decisions by controlling vehicle dynamics.

Flow: Arrows indicate the direction of information flow from sensors to the controller, and from the controller to the actuators.

This diagram represents the core architecture of a fuzzy logic-based car controller system for two vehicles, showing how data flows and decisions are made and executed.

2.2 Fuzzy Logic Controller Design

2.2.1 Design Process

i. Fuzzification: Convert crisp inputs from sensors into fuzzy values using membership functions.

ii. Inference: Apply the fuzzy rules to the fuzzified inputs to determine the fuzzy outputs.

iii. Defuzzification: Convert the fuzzy outputs into crisp values that can be used to control the vehicle's actuators.

2.2.2 Integration with Vehicle Control System

The fuzzy logic controller is integrated with the vehicle's existing control system, ensuring seamless communication between the sensors, controller, and actuators.

2.2.3 Design Components

Input Variables: Speed of the vehicle and Distance to the obstacle (e.g., other vehicles, pedestrians).

Output Variables: Acceleration.

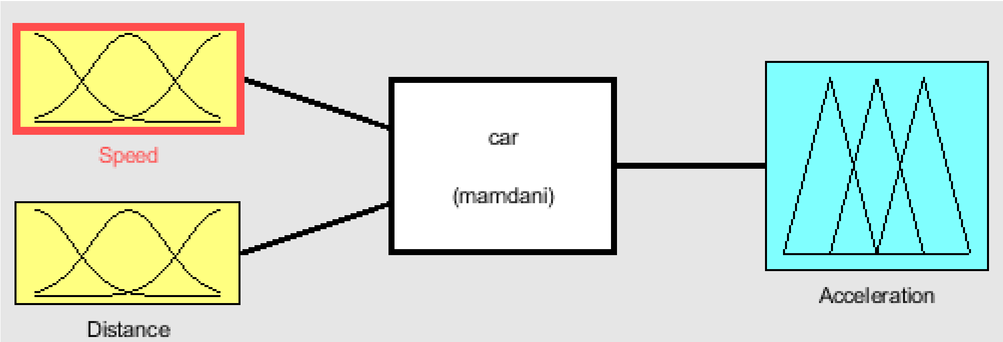

Figure 3: Input and output variable block diagram

2.2.4 Membership Functions

Membership functions define how each input and output variable is fuzzified. Common shapes for membership functions include triangular, trapezoidal, and Gaussian. For each variable, the range and shape of the membership functions are determined based on empirical data and expert knowledge. Triangular membership function is used in this study for simplicity.

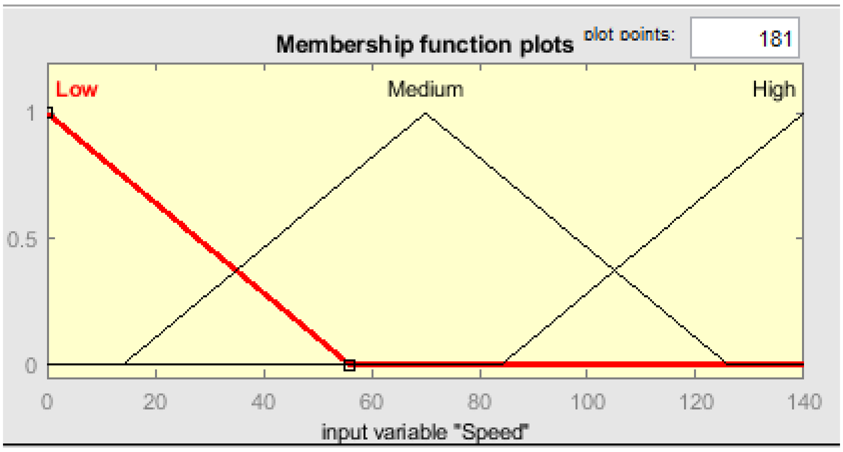

Figure 4: Input variable “Speed”

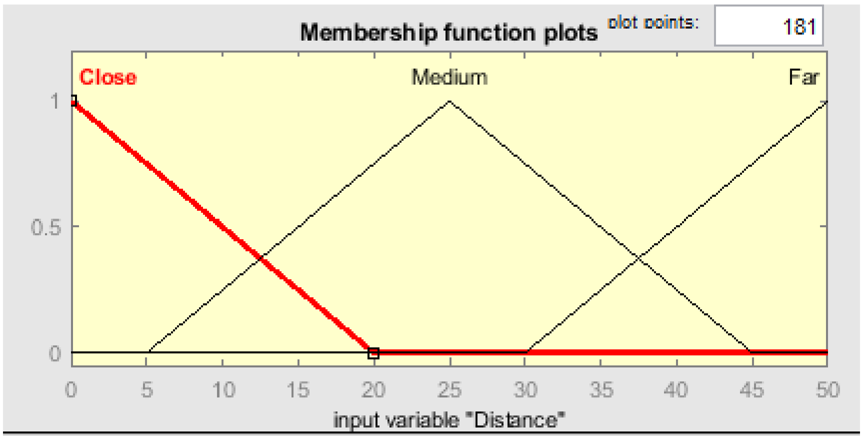

Figure 5: Input variable “Distance”.

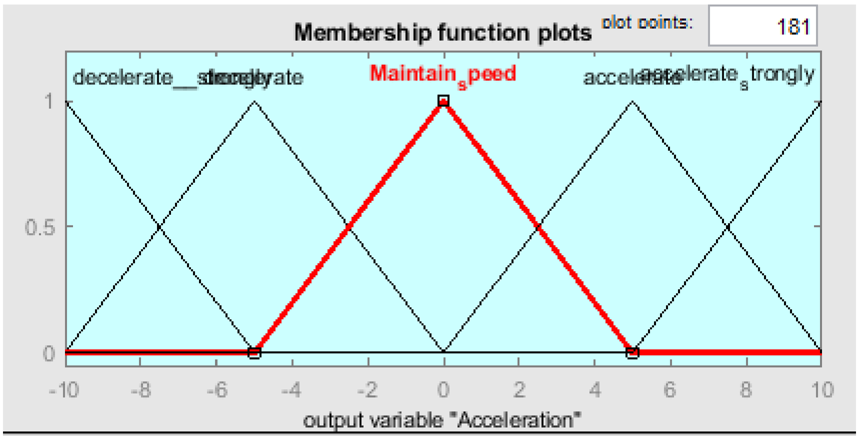

Figure 6: Output variable “Acceleration”

2.2.5 Rule Base Development

The fuzzy rules are created based on expert knowledge, driving heuristics, and empirical data. Each rule is structured in an IF-THEN format and describes the relationship between input and output variables. A table is developed to include all possible combinations of input variables and their corresponding output actions.

1. If (Speed is Low) and (Distance is Close) then (Acceleration is maintain_speed) (1)

2. If (Speed is Low) and (Distance is Medium) then (Acceleration is accelerate) (1)

3. If (Speed is Low) and (Distance is far) then (Acceleration is accelerate_strongly) (1)

4. If (Speed is Medium) and (Distance is Close) then (Acceleration is decelerate) (1)

5. If (Speed is Medium) and (Distance is Medium) then (Acceleration is maintain_speed) (1)

6. If (Speed is Medium) and (Distance is far) then (Acceleration is accelerate) (1)

7. If (Speed is High) and (Distance is Close) then (Acceleration is decelerate_strongly) (1)

8. If (Speed is High) and (Distance is Medium) then (Acceleration is decelerate) (1)

9. If (Speed is High) and (Distance is far) then (Acceleration is maintain_speed) (1)

3. Results and Discussion

Simulations were conducted to test the fuzzy logic controller under various driving scenarios. From the scenario, if speed is slow (9.63km/h) and distance to obstacle is far (47m), the car will accelerate strongly (8.35m/s^2).

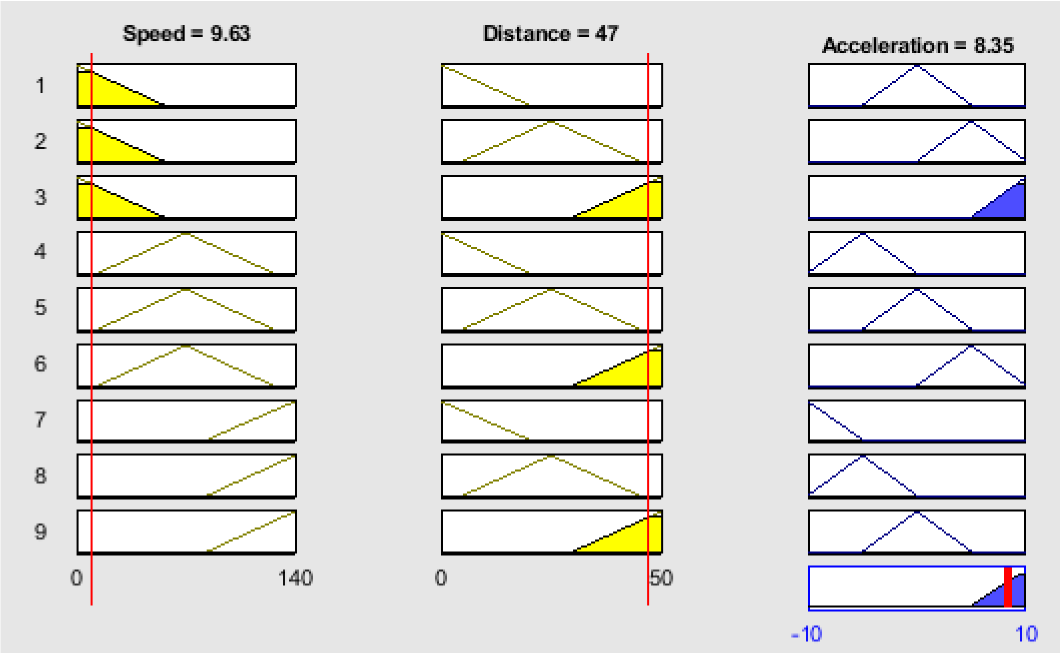

Figure 7: Relationship between speed, distance and acceleration

From the scenario in figure 8, if speed is slow (9.63km/h) and distance to obstacle is medium (25m), the car will accelerate (5m/s^2)

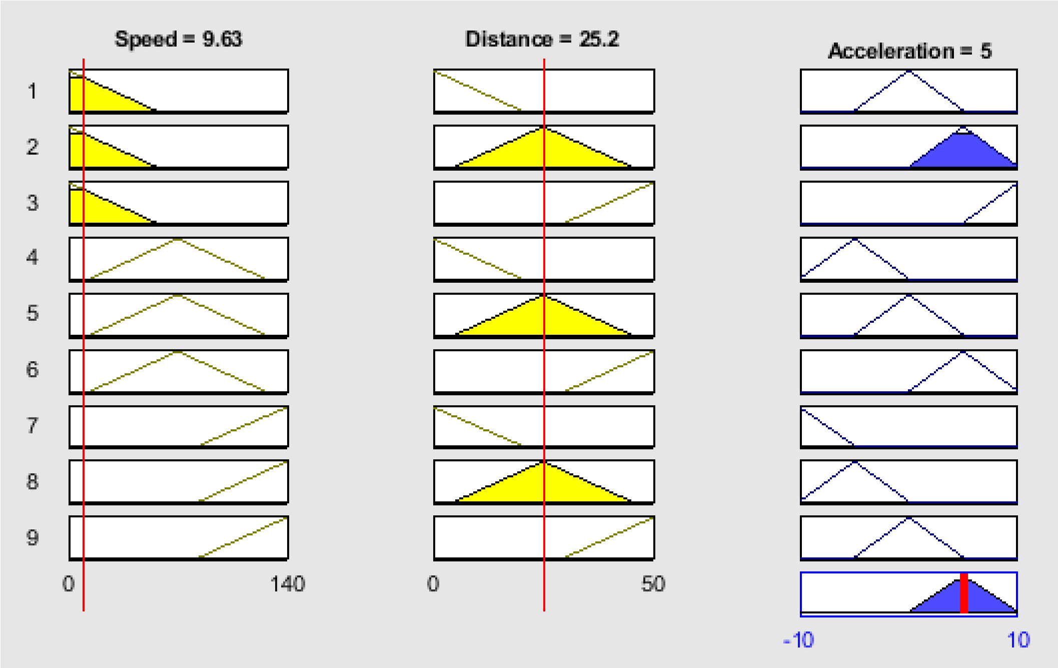

Figure 8: Relationship between speed, distance and acceleration

From the scenario in Figure 9, if speed is medium (71.3 km/h) and distance to obstacle is medium (25.2 m/), the car will maintain its speed with no acceleration.

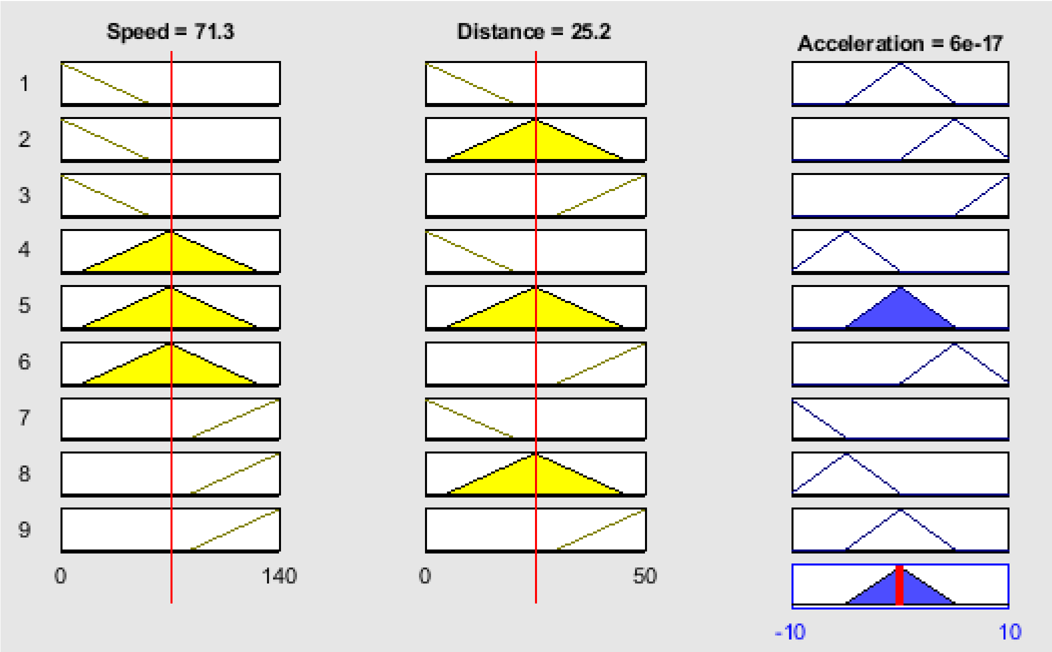

Figure 9: Relationship between speed, distance and acceleration

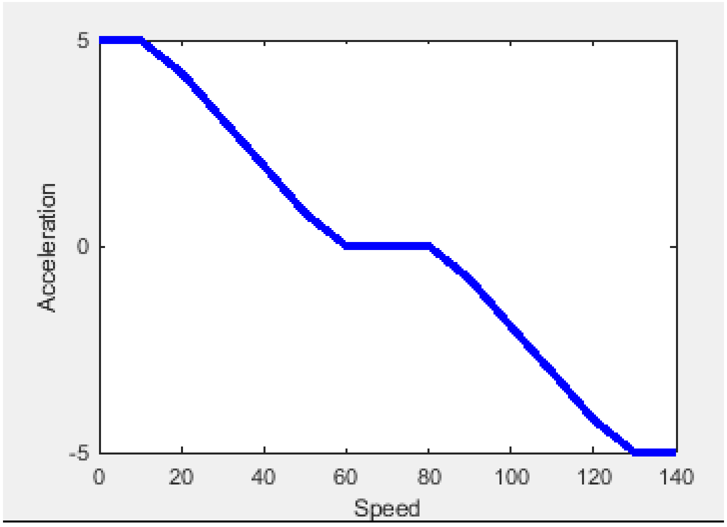

Figure 10: Relationship between speed and acceleration

The graph shows the relationship between the speed and acceleration. As the speed increases, the acceleration decreases.

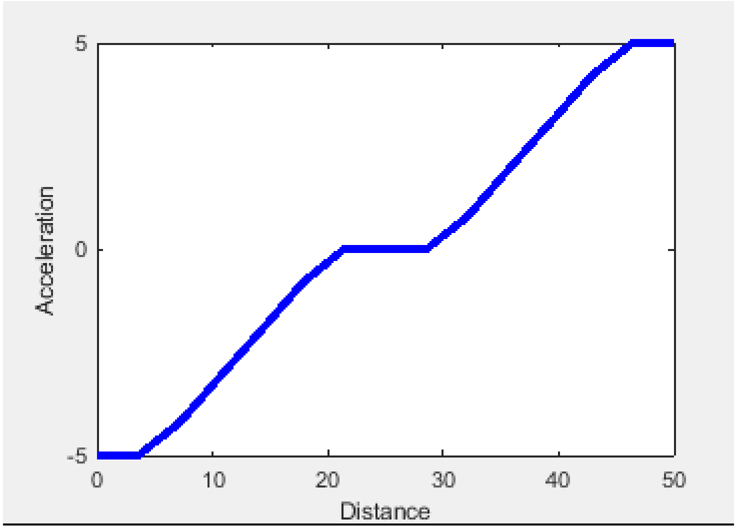

Figure 11: Relationship between distance and acceleration

The graph shows the relationship between the distance and acceleration. As the distance increases, the acceleration increases.

4. Conclusion

The fuzzy logic controller performed well in the simulation scenarios, demonstrating the controller's quick adaptability to changes in input conditions, providing appropriate control actions such as accelerate strongly, maintain speed, accelerate and so on. The controller's ability to handle varying driving conditions and adapt to changes demonstrates its robustness and reliability.

Future work may involve further refinement of the fuzzy rules and membership functions, as well as integration with advanced driver-assistance systems (ADAS) and autonomous driving technologies.

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