Electronic and Telecommunication Engineering

University of Moratuwa

EN4562: Autonomous Systems

Fuzzy logic throttle controller for vehicle collision avoidance

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Question 01 - Identify input fuzzy sets for the three crisp variables.

1. Distance to Obstacle

- Crisp range: `[0, 100]` meters
- Fuzzy sets:
  - **Near**: Close proximity to the obstacle.
    - Membership function: `gaussmf([10, 0])`
  - **Medium**: Intermediate distance from the obstacle.
    - Membership function: `gaussmf([15, 50])`
  - **Far**: Obstacle is far away.
    - Membership function: `gaussmf([20, 100])`

2. Speed

- Crisp range: `[0, 120]` km/h
- Fuzzy sets:
  - **Slow**: Low-speed range.
    - Membership function: `gaussmf([10, 0])`
  - **Medium**: Moderate-speed range.
    - Membership function: `gaussmf([20, 60])`
  - **Fast**: High-speed range.
    - Membership function: `gaussmf([30, 120])`

3. Throttle Percentage (Output)

- Crisp range: `[0, 100]` %
- Fuzzy sets:
  - **Brake**: Negative throttle, effectively braking.
    - Membership function: `gaussmf([5, 0])`
  - **Low**: Small throttle percentage.
    - Membership function: `gaussmf([15, 25])`
  - **Moderate**: Medium throttle percentage.
    - Membership function: `gaussmf([20, 50])`
  - **High**: Maximum throttle percentage.
    - Membership function: `gaussmf([15, 80])`

Question 02 - Write fuzzy control rules (Mamdani or TSK) that you think are appropriate for throttle control.

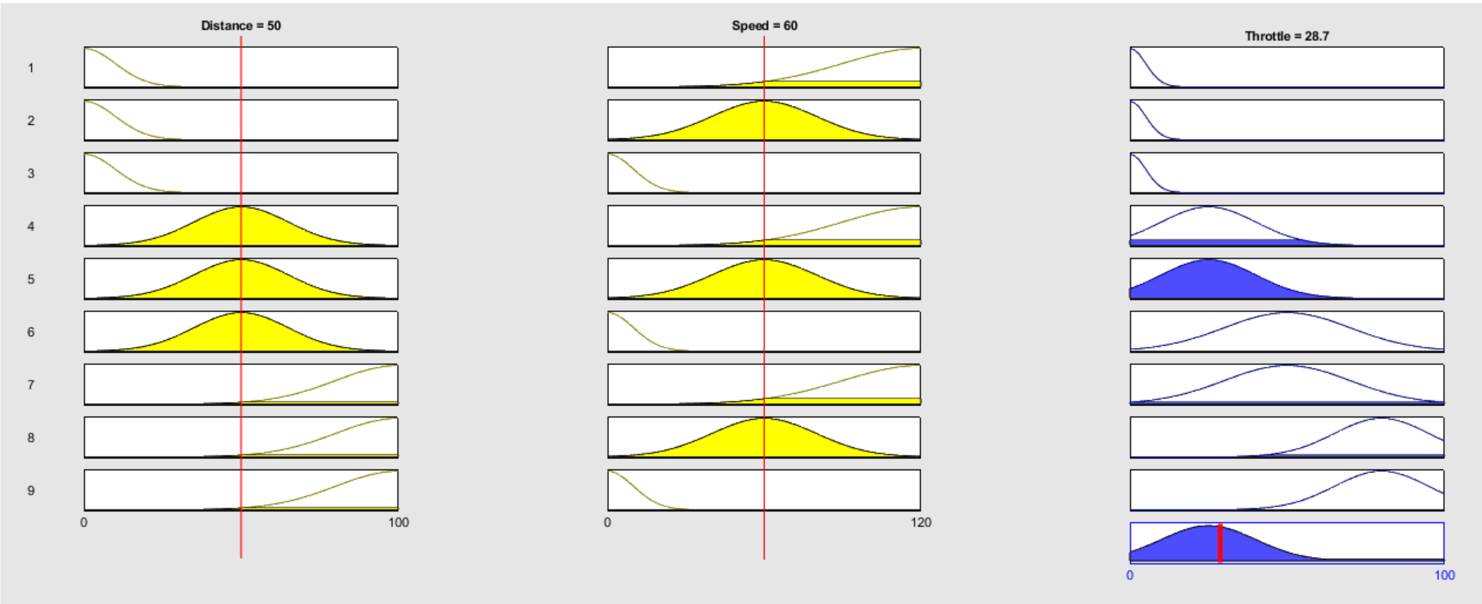
Fuzzy Rules (Mamdani Style)

1. If Distance is Near AND Speed is Fast, THEN Throttle = Brake.
2. If Distance is Near AND Speed is Medium, THEN Throttle = Brake.
3. If Distance is Near AND Speed is Slow, THEN Throttle = Low.
4. If Distance is Medium AND Speed is Fast, THEN Throttle = Low.
5. If Distance is Medium AND Speed is Medium, THEN Throttle = Moderate.
6. If Distance is Medium AND Speed is Slow, THEN Throttle = High.
7. If Distance is Far AND Speed is Fast, THEN Throttle = Moderate.
8. If Distance is Far AND Speed is Medium, THEN Throttle = High.
9. If Distance is Far AND Speed is Slow, THEN Throttle = High.

Question 03 - Calculate fuzzy memberships and corresponding throttle (as a %) for a given crisp input state.

Selected instance

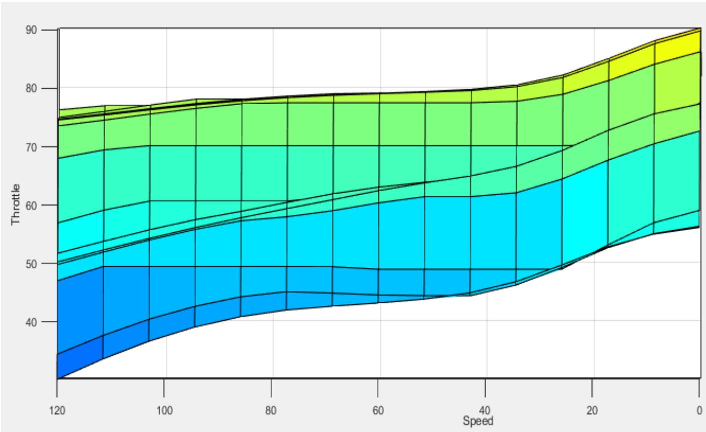
- Speed = 2.5 ms^{-1}
- Distance = 30 m



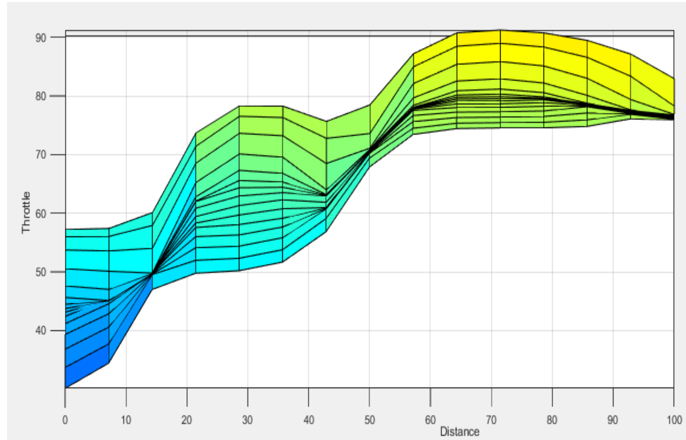
Rule Viewer

Throttle value is 28.7 % when the initial speed is 2.5 ms^{-1} and the distance to the obstacle is 30 meters.

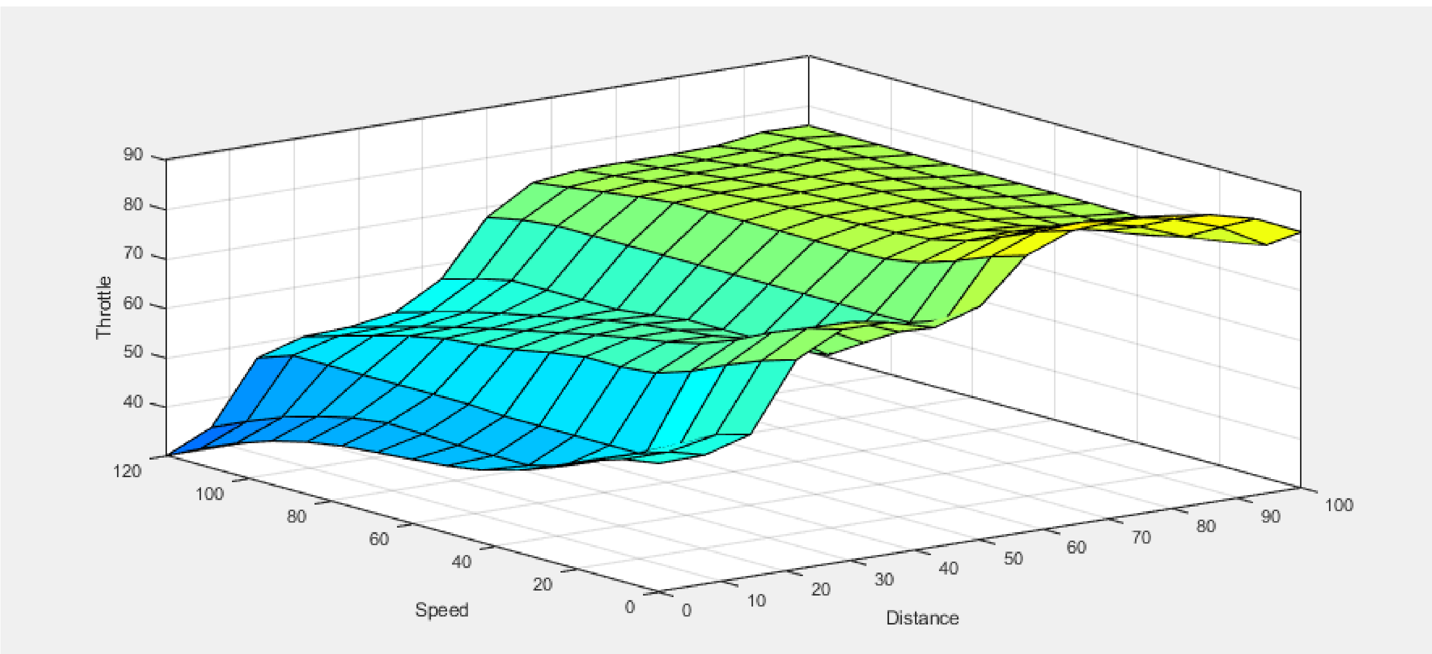
Question 04 - Show the control surface and evaluate its quality.



Throttle variation with speed



Throttle variation with distance



Throttle variation with speed and distance

The throttle control system shows a smooth and logical behavior, with throttle decreasing as the distance to the obstacle reduces and adjusting based on speed. Also, input space for both distance and speed is well-covered, and the system seems well-tuned for real-world applications. However, there are areas for improvement.

Near the obstacle, the throttle should decrease more sharply to simulate braking, but in the low distance/high speed region, it remains elevated, which could still lead to a collision.

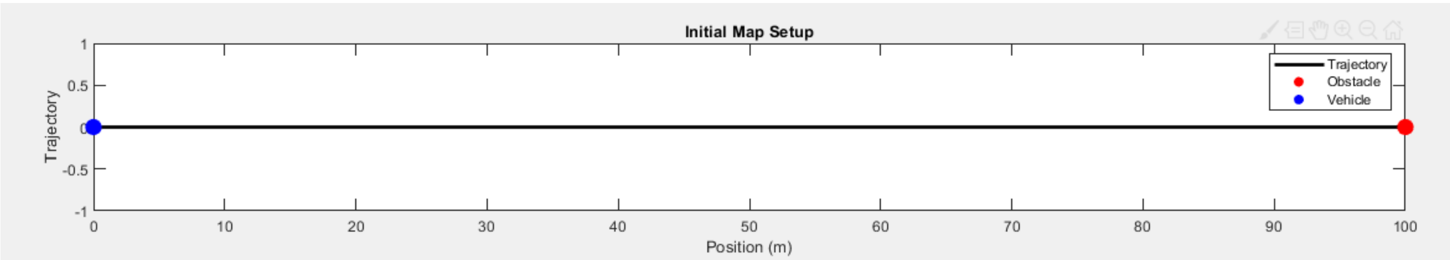
Also, at high speeds with a far obstacle, the throttle should be higher for efficient acceleration, but it remains moderate.

The Gaussian membership functions used for distance and speed may be too broad, which could soften the throttle response. Narrowing these functions or using more nonlinear shapes could enhance the system's performance.

Also, handling edge cases like low speeds with far obstacles or zero distance with high speed should be improved to ensure the system reacts appropriately in all scenarios, such as maintaining high throttle for far obstacles at low speeds or triggering an emergency stop when the vehicle is too close to the obstacle.

Question 05 - Use a simple vehicle model and simulate the FLC in Matlab.

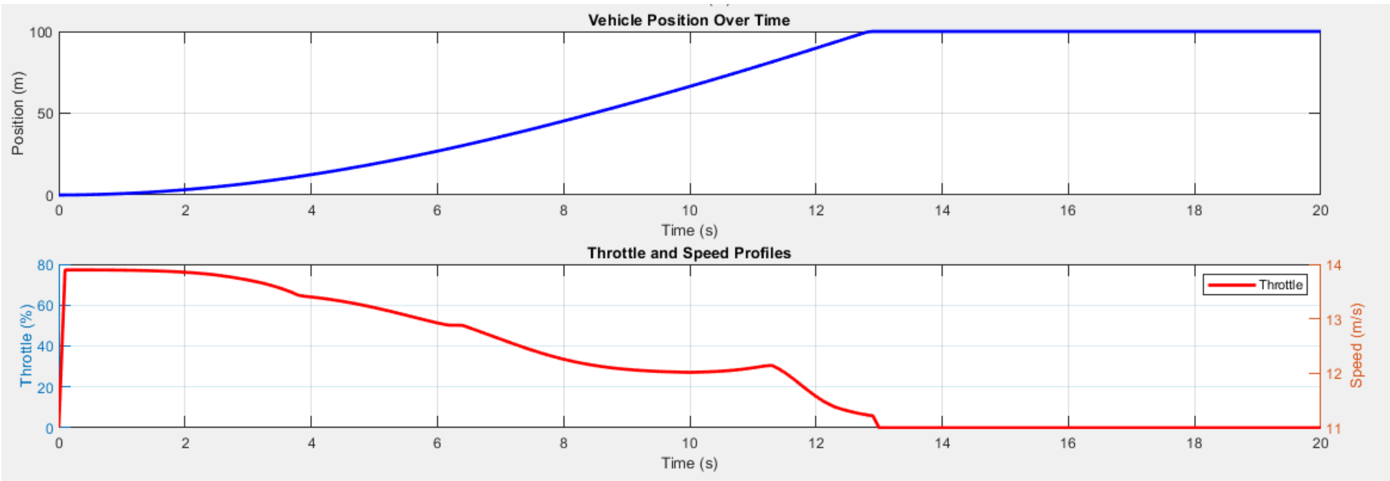
Simple vehicle model



1D environment with one obstacle placed at the end of the map. The vehicle travels towards the obstacle, and the fuzzy logic-based throttle control adjusts the vehicle's speed depending on the distance to the obstacle and its current speed.

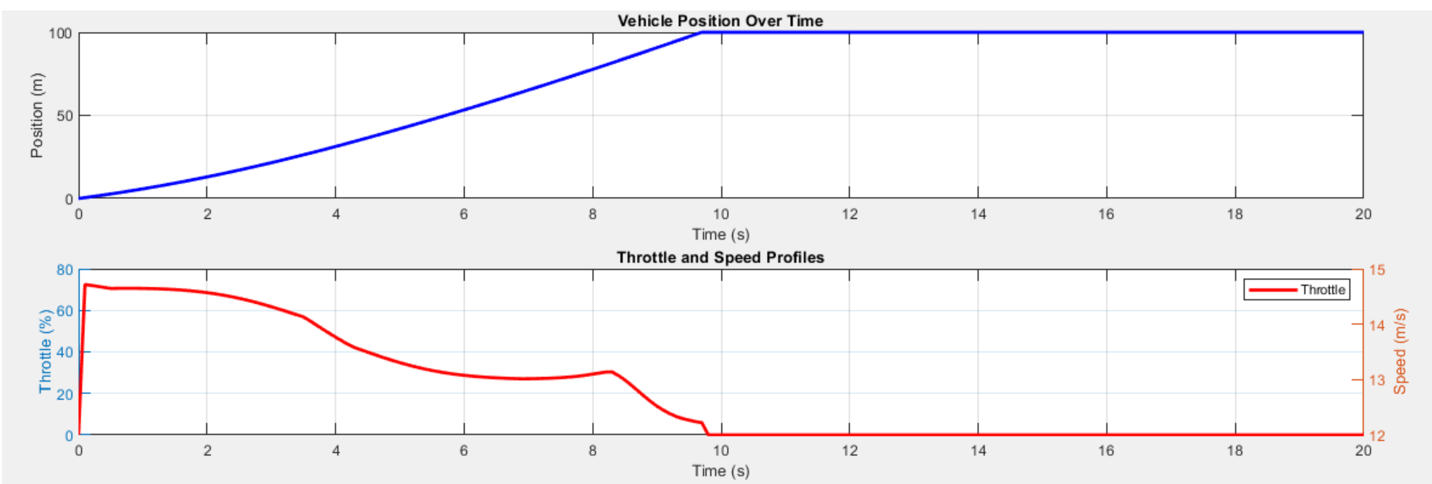
Question 06 - Present your simulation results for five different initial conditions.

1. Initial speed = 0 ms^{-1} , starting position = 0 m



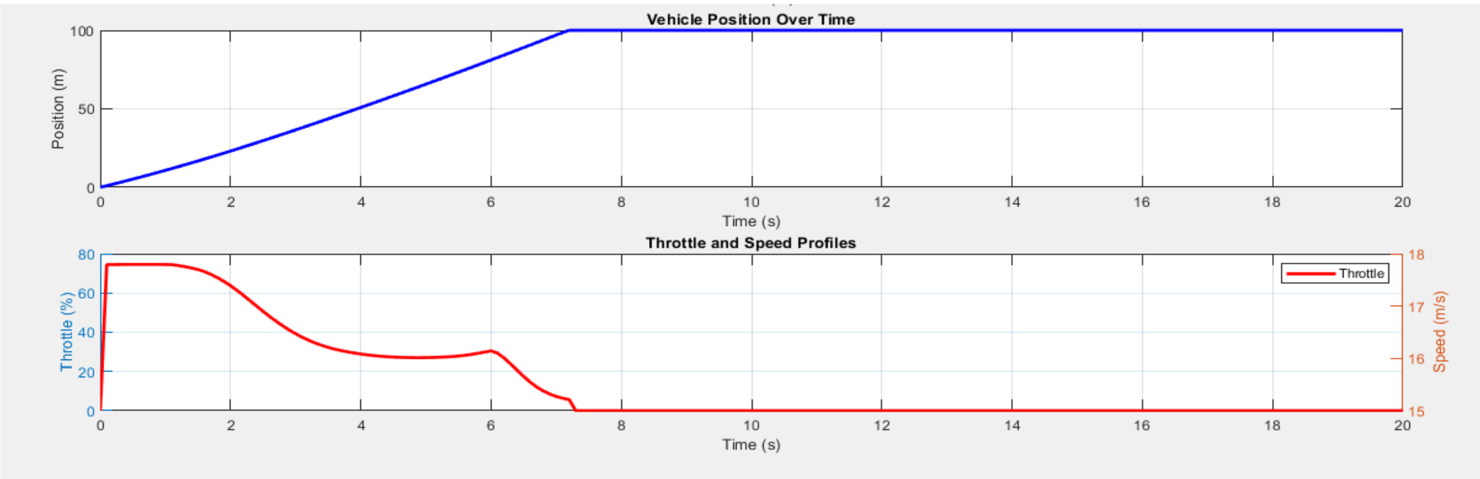
The vehicle is stationary, so the throttle control will likely remain at a high value to begin accelerating. Since there is no motion initially, the system doesn't need to slow down yet. The throttle will gradually increase as the vehicle accelerates, depending on the distance to the obstacle.

2. Initial speed = 5 ms^{-1} , starting position = 0 m



At this low speed, the vehicle will start moving slowly towards the obstacle. The throttle will be adjusted based on the distance to the obstacle. The fuzzy logic system will likely provide a moderate throttle, but as the vehicle approaches the obstacle, the system will reduce the throttle to lower values to prevent collision

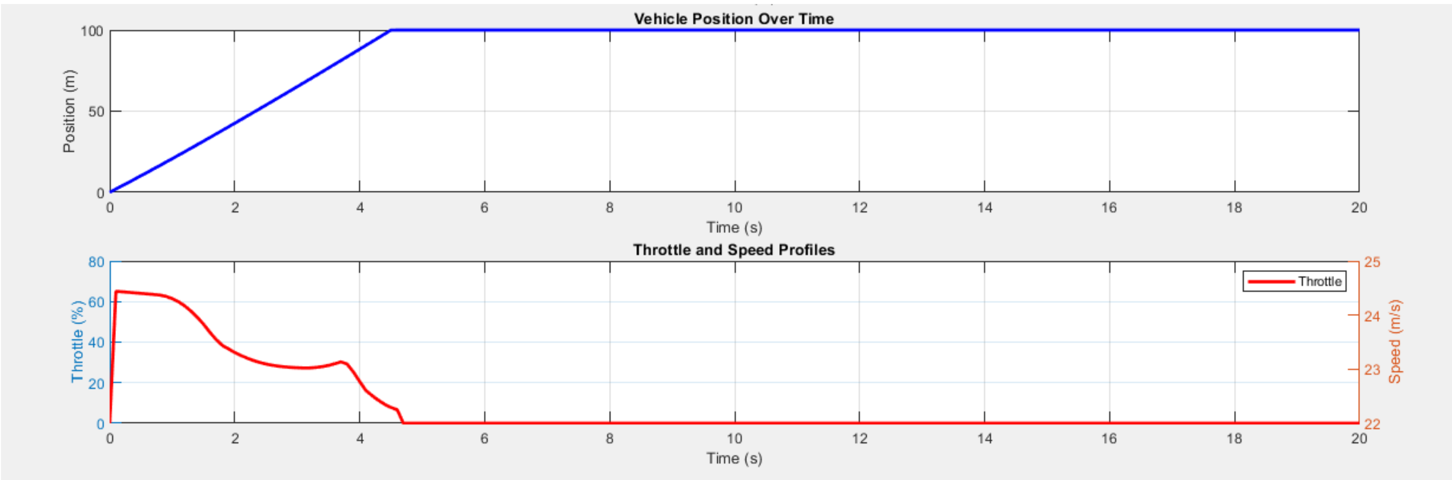
3. Initial speed = 10 ms^{-1} , starting position = 0 m



With a moderate speed, the vehicle will have a higher momentum, and the throttle needs to adjust more quickly to prevent collision. As the vehicle moves toward the obstacle, the fuzzy logic system will reduce the throttle to slow down or possibly trigger a braking action when the obstacle is close.

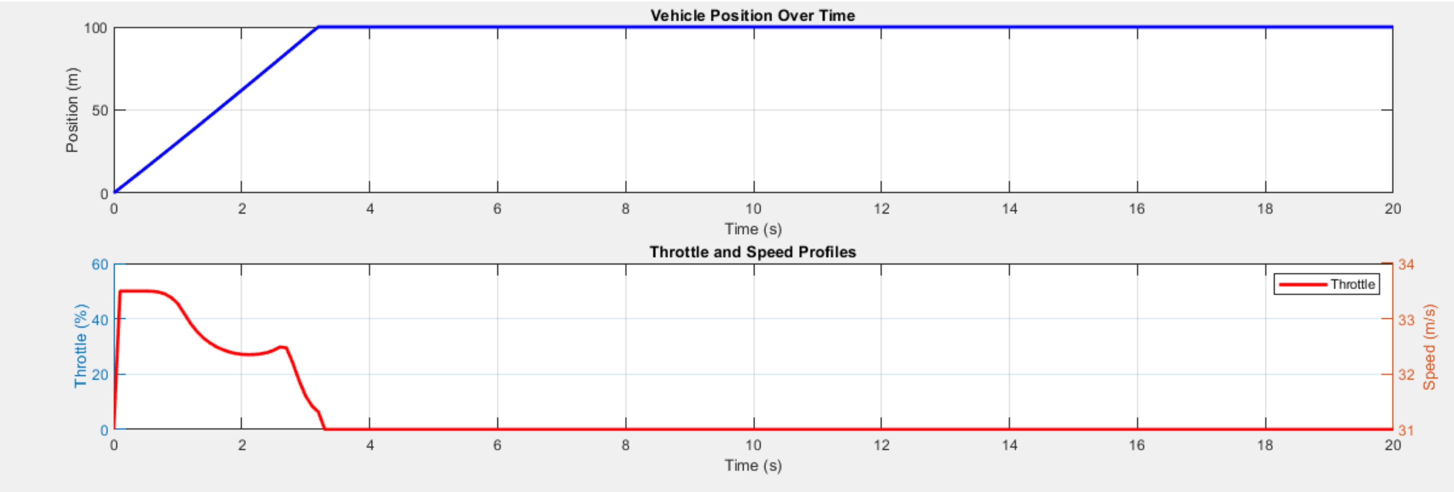
At this speed, the system will likely balance between maintaining forward motion and decelerating smoothly. The throttle will be reduced earlier than at 5 m/s to ensure that the vehicle doesn't approach the obstacle too quickly.

4. Initial speed = 20 ms^{-1}, starting position = 0 m



At 20 m/s, the vehicle will move towards the obstacle much faster. The fuzzy logic system will need to apply a significant reduction in throttle to avoid collision.

1. Initial speed = 30 ms^{-1}, starting position = 0 m



At 30 m/s (about 108 km/h), the vehicle will approach the obstacle quickly, and the fuzzy logic system will need to react very swiftly to reduce the speed. The throttle will initially be higher for acceleration, but as the vehicle approaches the obstacle, the throttle will be aggressively reduced to avoid collision.

Conclusion

In this project, a fuzzy logic-based throttle controller was developed to manage a vehicle's speed and ensure safe collision avoidance in a dynamic environment. By utilizing inputs such as the vehicle's speed and the distance to an obstacle, the controller adjusts the throttle to either accelerate or decelerate the vehicle appropriately. Through the use of fuzzy membership functions and carefully defined rules, the system efficiently handles various driving scenarios, from low-speed acceleration to high-speed braking as the obstacle approaches.