EN4562: Autonomous Systems

Take Home Assignment

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a) Identify input fuzzy set and output fuzzy set

According to given data two input crisp set and one output crisp set which should map to fuzzy sets during fuzzification and defuzzification. Block diagram of the FLC provided below.

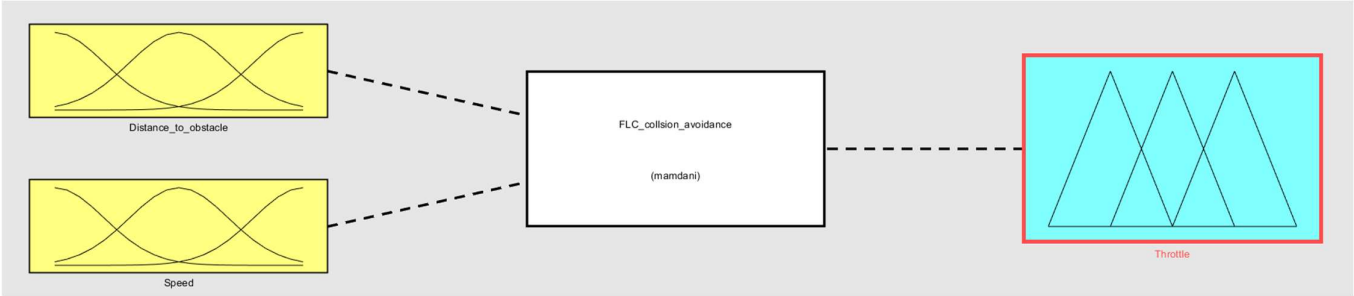


Figure 1- Block diagram of FLC

Linguistic descriptions of each input and output and ranges of their crisp values have provided. These fuzzy sets are represented using following membership functions.

- For Distance to obstacle

Membership function	Range (m)
Very_Close	0 – 20
Close	10 - 40
Medium	30 – 60
Far	50 - 80
Very_Far	70 - 80

Figure 2-Linguistic descriptors for distance

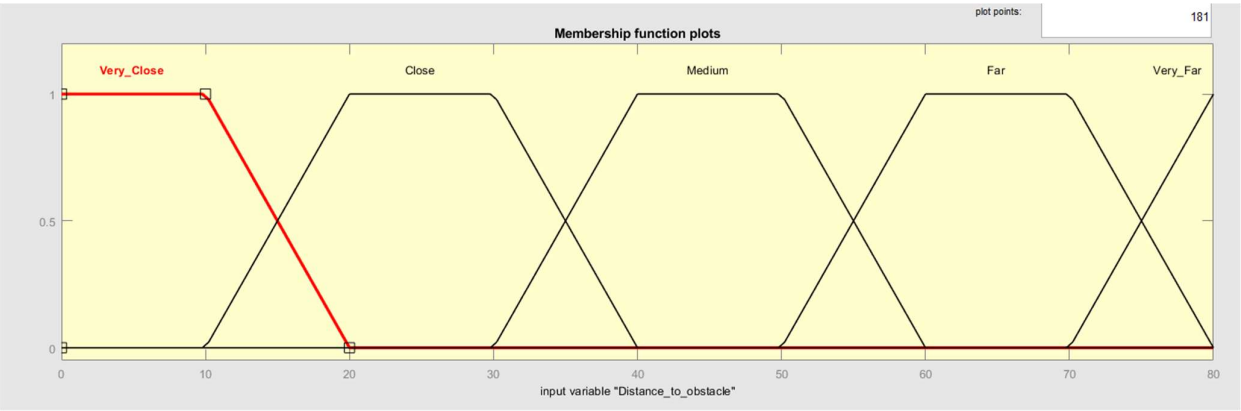


Figure 3- Membership function for distance

➢ For Speed

Membership function	Range (kmh^{-1})
Slow	0 – 90
Medium	90 - 180
Fast	90 – 180

Figure 4- Linguistic descriptors for speed

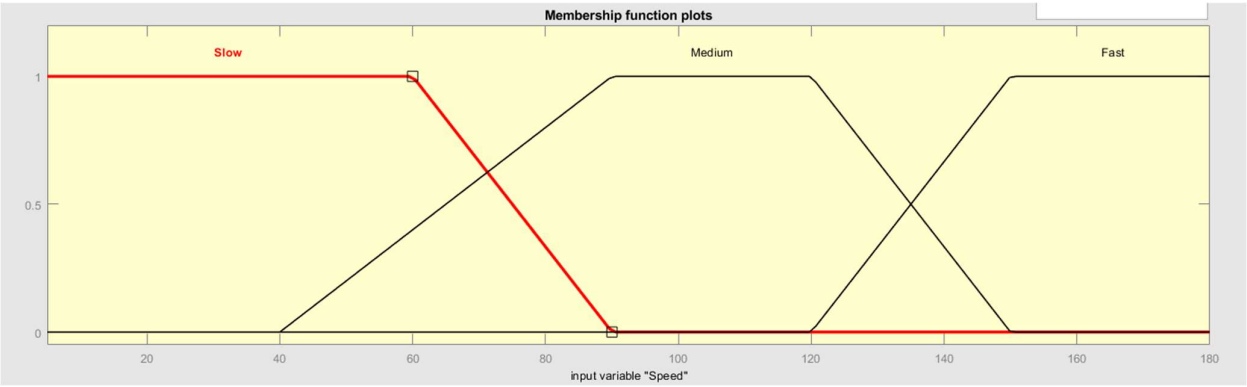


Figure 5 - Membership functions for speed

➢ For Throttle

Membership function	Range (%)
No_Trottle	0 – 30
Low_ Trottle	10 - 40
Medium_ Trottle	30 – 70
High_ Trottle	60 - 90
Full_ Trottle	80 - 100

Figure 6- Linguistic descriptors for throttle

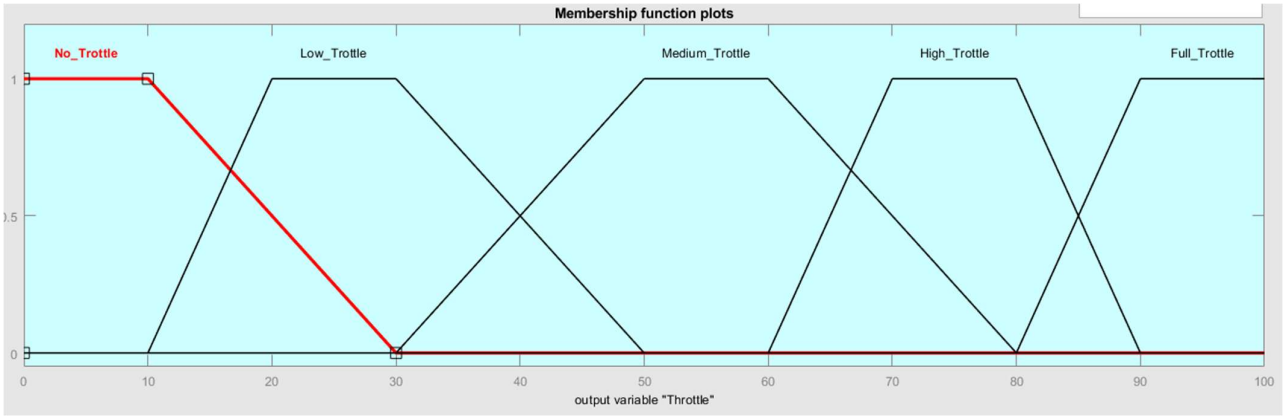


Figure 7- Membership functions for trottle

b) Mamdani rule base

For the inference process 15 rules have been defined. Their descriptive and graphical representation is included. When defined the rules we have to go through several trail error iteration to reach it's maximum capabilities.

Rule No.	Rule
01	If (Distance_to_obstacle is Very_Close) and (Speed is Slow) then (Throttle is No_Trottle)
02	If (Distance_to_obstacle is Very_Close) and (Speed is Medium) then (Throttle is No_Trottle)
03	If (Distance_to_obstacle is Very_Close) and (Speed is Fast) then (Throttle is No_Trottle)
04	If (Distance_to_obstacle is Close) and (Speed is Slow) then (Throttle is Low_Trottle)
05	If (Distance_to_obstacle is Close) and (Speed is Medium) then (Throttle is Low_Trottle)
06	If (Distance_to_obstacle is Close) and (Speed is Fast) then (Throttle is No_Trottle)
07	If (Distance_to_obstacle is Medium) and (Speed is Slow) then (Throttle is Medium_Trottle)
08	If (Distance_to_obstacle is Medium) and (Speed is Medium) then (Throttle is Low_Trottle)
09	If (Distance_to_obstacle is Medium) and (Speed is Fast) then (Throttle is No_Trottle)
10	If (Distance to obstacle is Far) and (Speed is Slow) then (Throttle is High Trottle)
11	If (Distance_to_obstacle is Far) and (Speed is Medium) then (Throttle is Medium_Trottle)
12	If (Distance to obstacle is Far) and (Speed is Fast) then (Throttle is Low Trottle)
13	If (Distance to obstacle is Very Far) and (Speed is Slow) then (Throttle is Full Trottle)
14	If (Distance to obstacle is Very Far) and (Speed is Medium) then (Throttle is High Trottle)
15	If (Distance_to_obstacle is Very_Far) and (Speed is Fast) then (Throttle is Medium_Trottle)

Figure 9- Descriptive representation of rule base

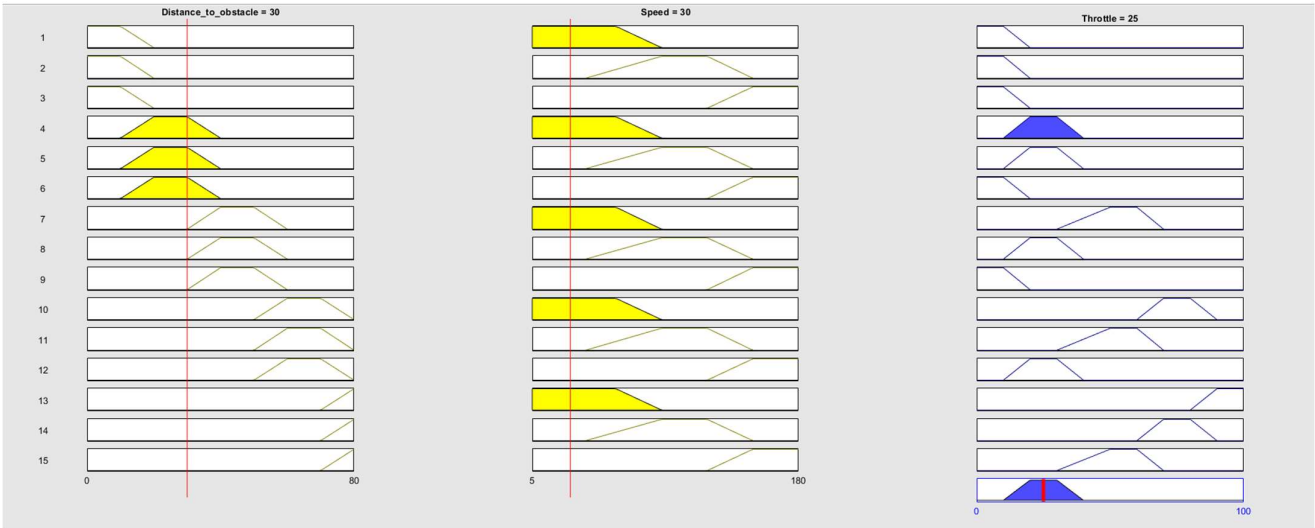


Figure 8 - Graphical representation of rule base

c) Fuzzy memberships and corresponding throttle calculation

In here we are going to calculate the throttle for speed=30km/h and distance to obstacle = 30m by FLC develop using Fuzzy Logic Designer toolbox in MATLAB. Centroid of Area (COA) method is used for defuzzification.

```
>> output = evalfis(FLC_collsion_avoidance, [30, 30])

output =

    28
```

Figure 10 - Result of FLC for given inout

d) Control surface and evaluate its quality

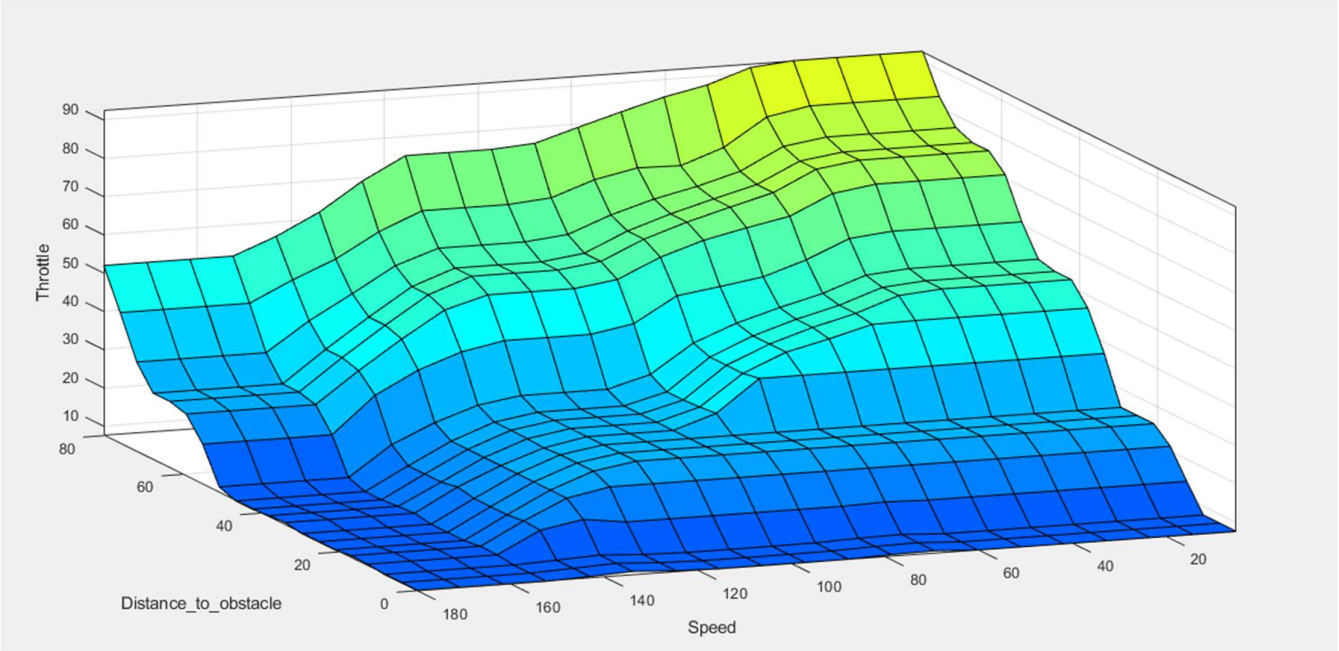


Figure 11 - Control surface

The control surface demonstrates the relationship between throttle, speed, and distance to the obstacle in a fuzzy logic-based collision avoidance system. It shows logical behavior, where the throttle decreases as the distance to the obstacle decreases or as the speed increases, ensuring safe operation. The surface is smooth, with no abrupt transitions, indicating a well-designed fuzzy logic system that handles inputs continuously. It covers the full range of inputs, providing reliable control under various conditions

e) Simple vehicle model and simulate the FLC in MATLAB

In simple vehicle model, initially we give velocity (v_0) and distance to obstacle(d_0). Duty of FLC is providing the throttle for given input speed and distance. We calculate the acceleration/deacceleration as follows.

$$a(t) = k_{throttle} * T - braking\ force$$

T is throttle provided by engine and breaking force is applied according to below equations in which current speed, distance to obstacle and k_{brake} are contributed.

$$braking_{force} = k_{brake} * \frac{v^2}{d};$$
$$v - current\ speed$$
$$d - current\ distance\ to\ obstacle$$

After that we calculate current speed and distance to obstacle using following equations.

$$v(t) = v_0 + \int a(t)dt$$
$$d(t) = d_0 - \int v(t)dt$$

Then v(t) and d(t) feedback to FLC and scope to see their behavior. Additionally, I have used constant compare block to find when the velocity is going be zero and what is distance at that time. This can be used to debug FLC to achieve maximum performance.

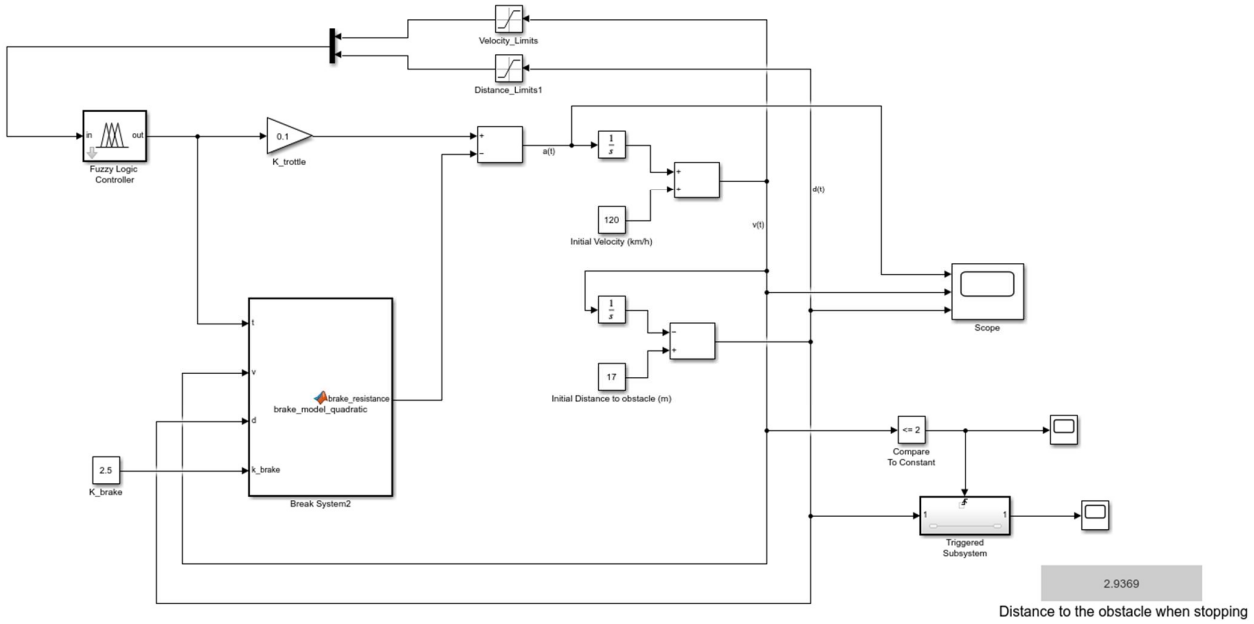


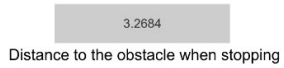
Figure 12 - Simulink model for simulation

f) Simulation results

In here simulation results are illustrated for five different initial conditions and shown speed, distance and throttle variation with respect to time. Additionally, distance to obstacle when car is stopping is included.

1. Initial velocity = 40 km/h, Initial distance to obstacle = 50m

   Distance to the obstacle when stopping = 3.26m



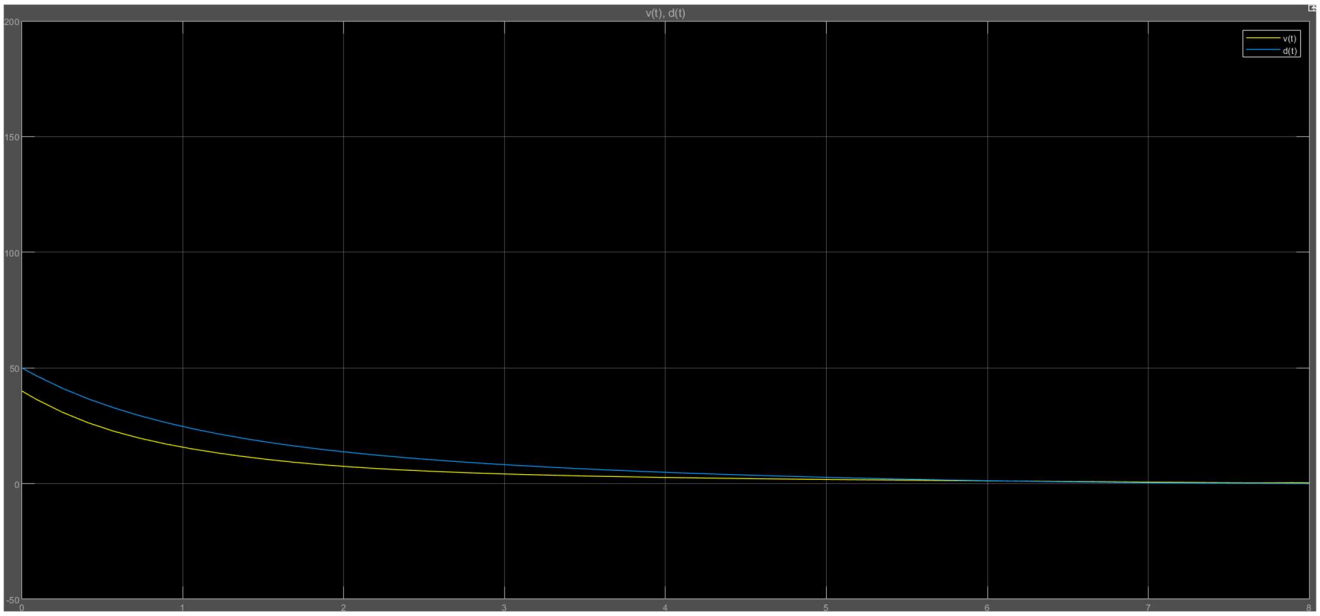


Figure 13 - Speed, Distance to obstacle with time

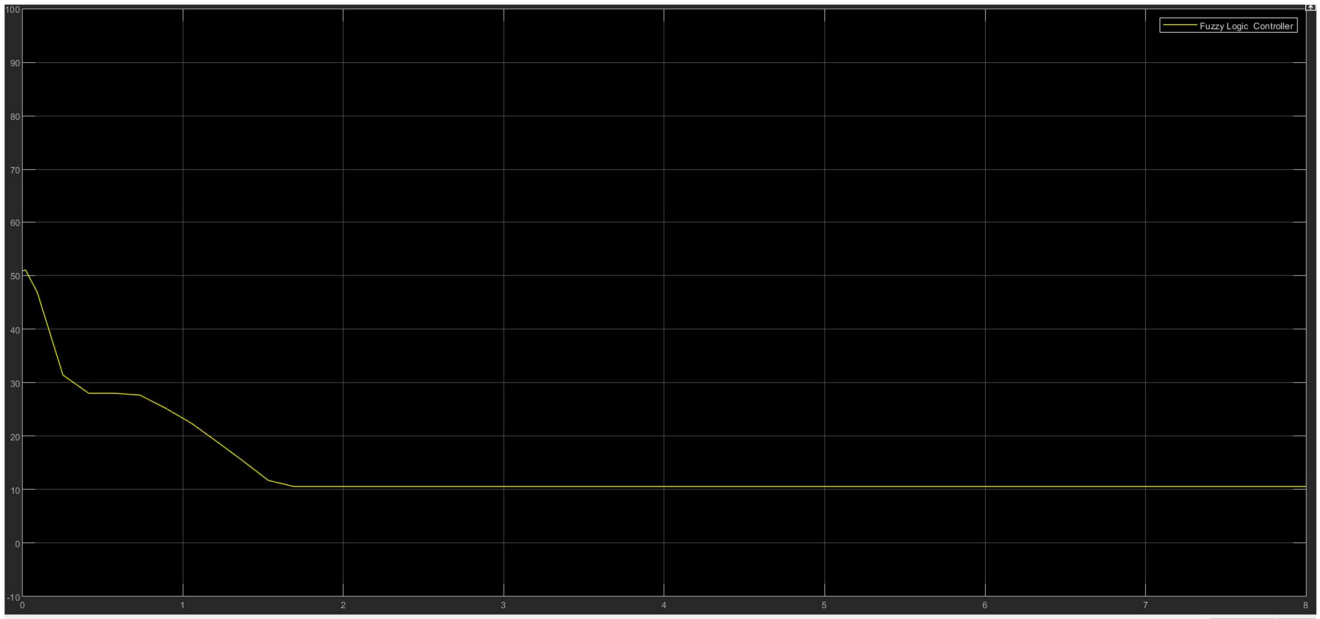
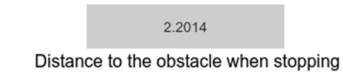


Figure 14 - Throttle with time

2. Initial velocity = 130 km/h, Initial distance to obstacle = 50m

   Distance to the obstacle when stopping = 2.2m



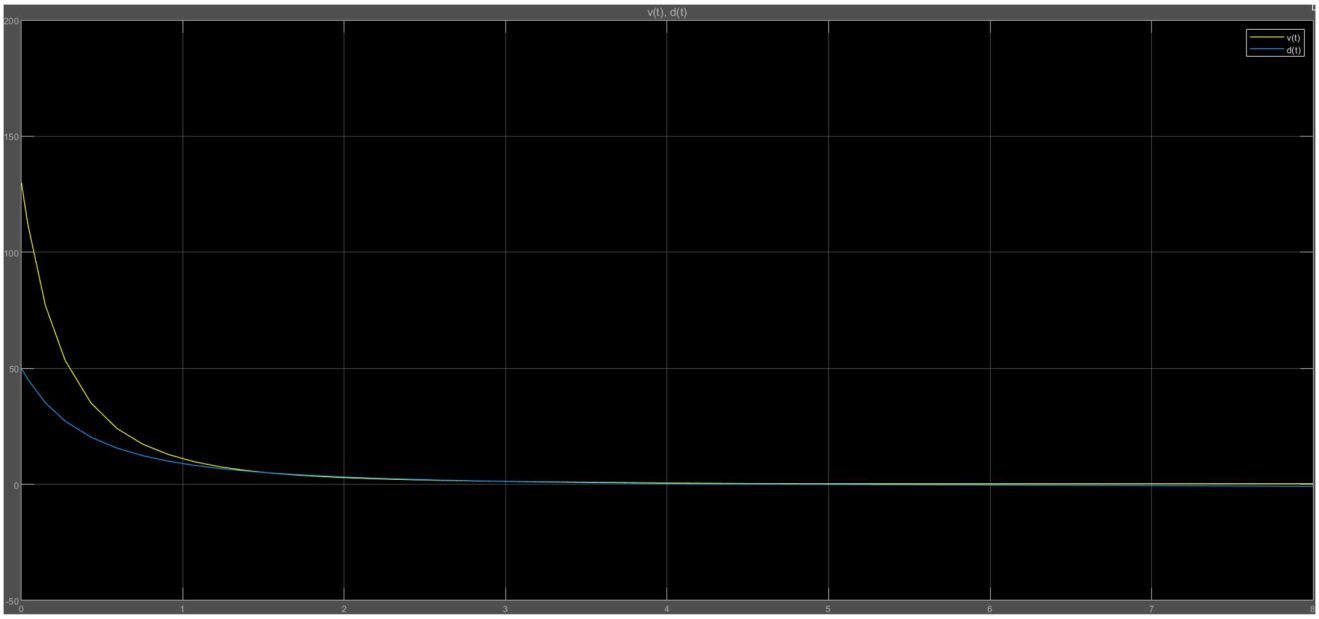


Figure 15 - - Speed, Distance to obstacle with time

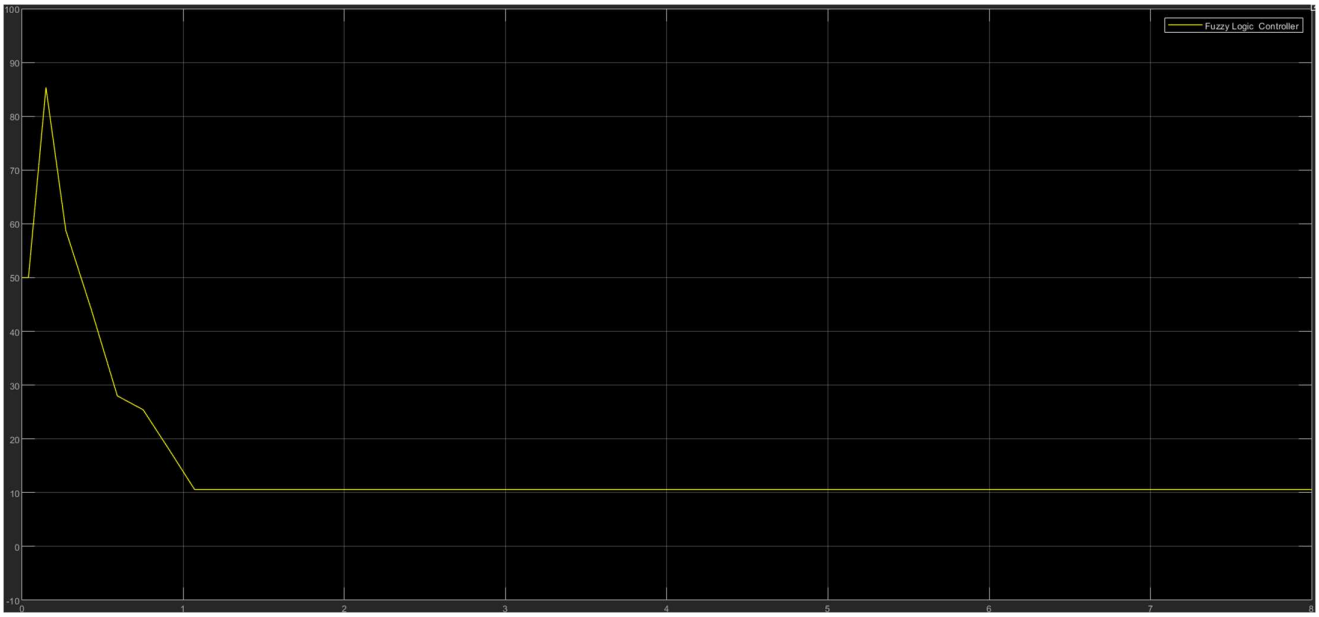
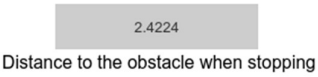


Figure 16 - Throttle with time

3. Initial velocity = 170 km/h, Initial distance to obstacle = 70m

   Distance to the obstacle when stopping = 2.42m



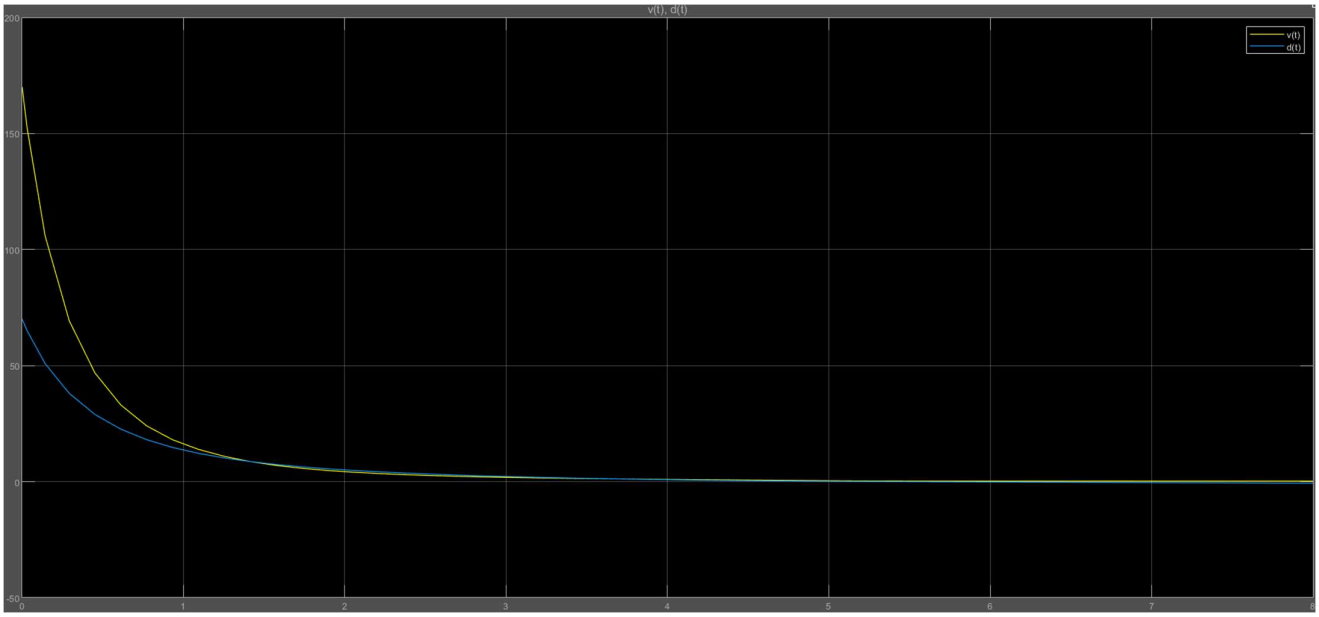
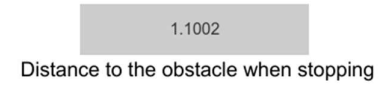


Figure 17 - Speed, Distance to obstacle with time

Figure 18 - Throttle with time

4. Initial velocity = 160 km/h, Initial distance to obstacle = 12

   Distance to the obstacle when stopping = 1.1 m



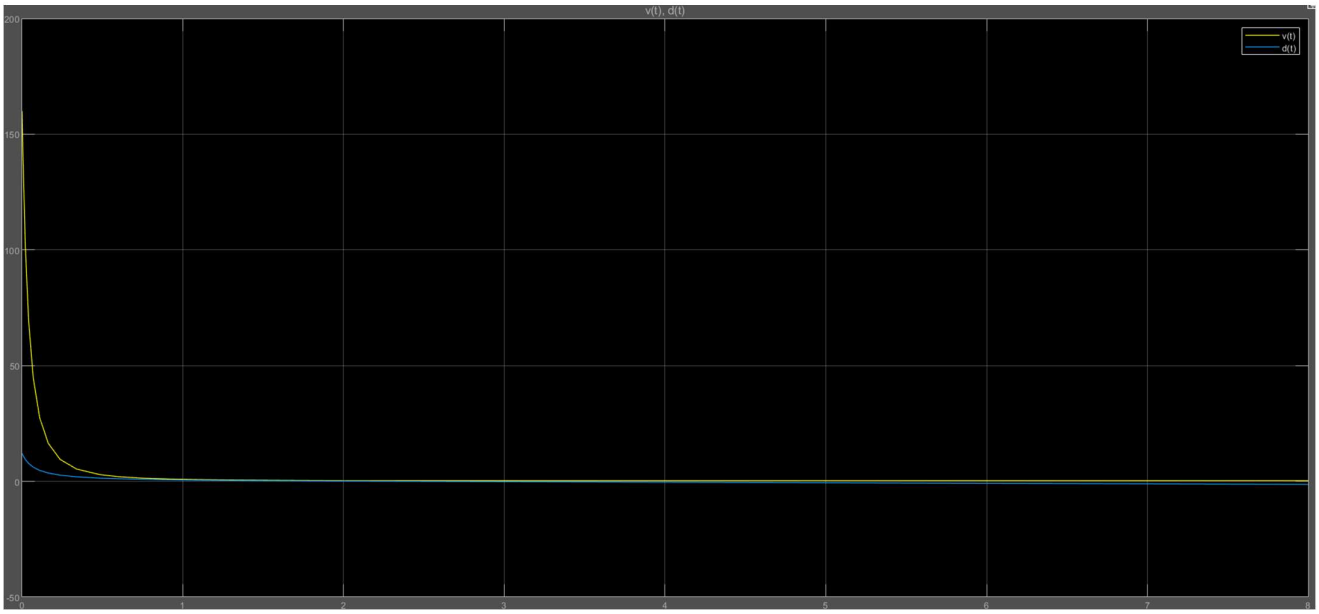


Figure 19 - - Speed, Distance to obstacle with time

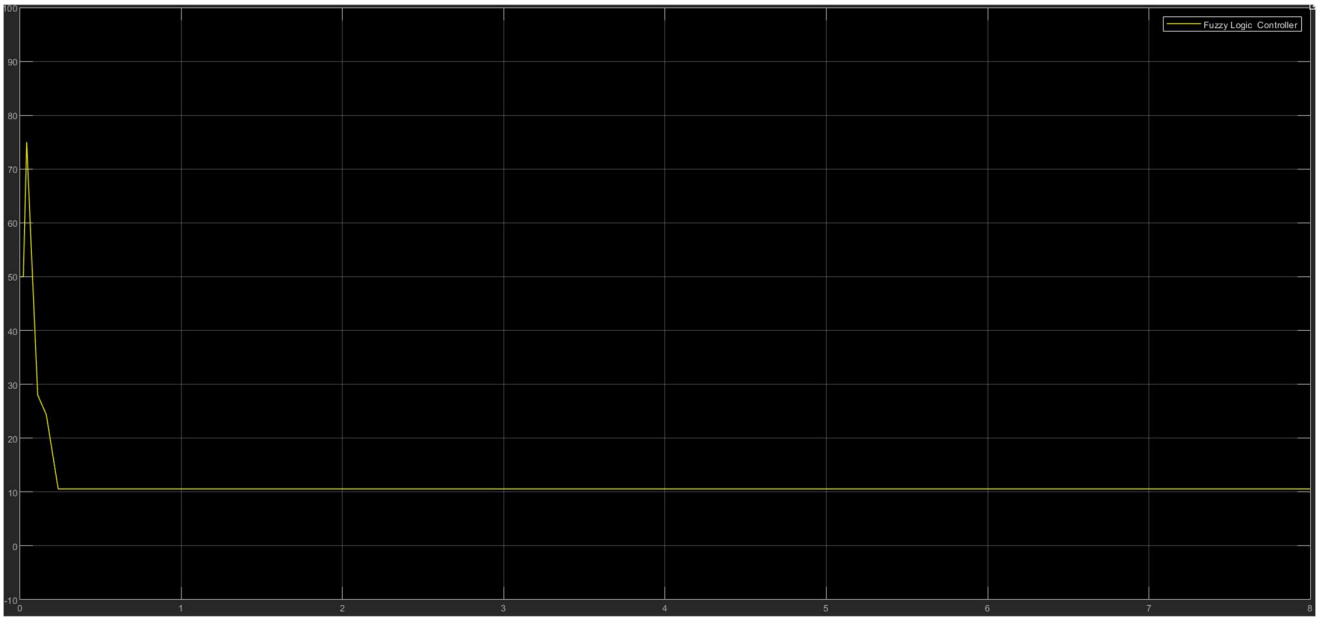
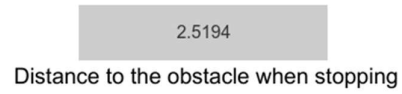


Figure 20 - Throttle with time

5. Initial velocity = 20 km/h, Initial distance to obstacle = 65m

   Distance to the obstacle when stopping = 2.51m



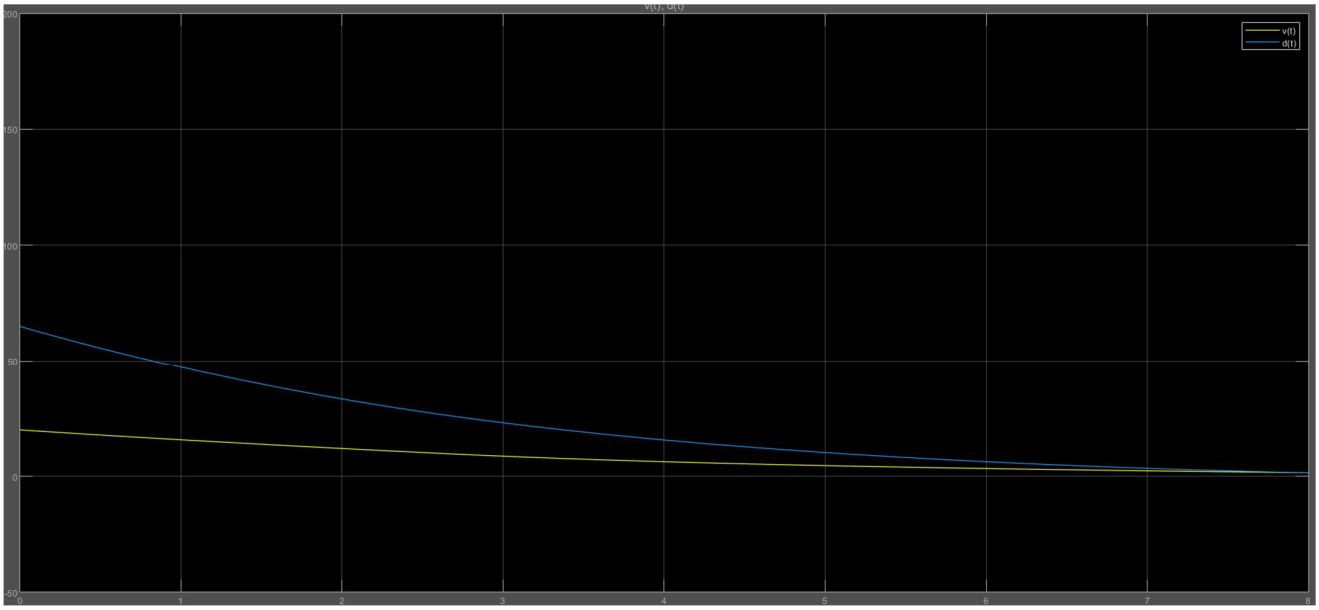


Figure 21 - Speed, Distance to obstacle with time

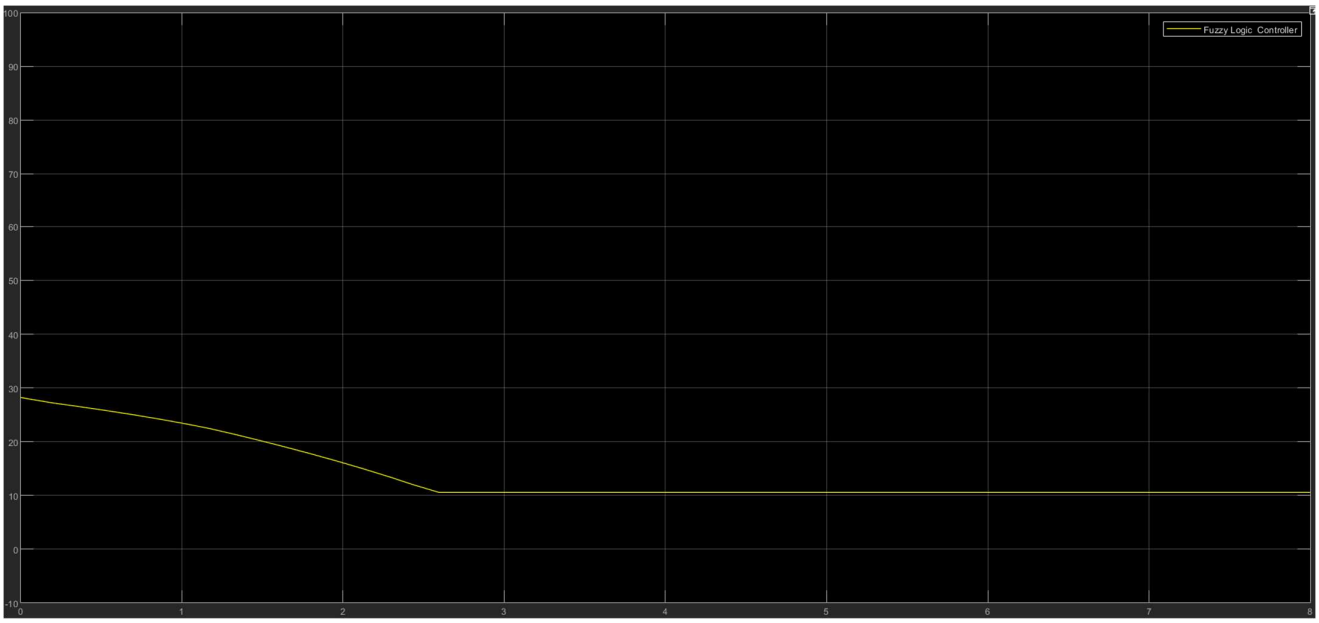


Figure 22 - Throttle with time