Design and Simulation of a Car-Following Collision-Prevention Controller

Omar Houalla, Hasan Merhi, Jamil Kabbani
Electrical & Computer Engineering Department
American University of Beirut
{ohh02, hrm08, jmk03}@aub.edu.lb

Abstract- **This study presents the design and simulation of an intelligent, fuzzy logic-based controller to control the speed of a car, called the following vehicle (FV), moving behind another one, the leading vehicle (LV), on roads or highways. The objective of the speed control is to provide a smooth and safe car following and stoppage when needed. Henceforth, the controller needs to be designed so as to permit the necessary on-line adjustment of the acceleration (deceleration) of the FV, considered to be the controller output, based on the relative distance and relative speed between the FV and the LV. These latter entities, which are considered as the input variables of the controller, can be obtained from appropriate sensors installed on the FV. Given that the FV is moving at a specific set speed and it gets confronted with a LV moving at a lower speed, then the controller needs to introduce changes to the speed of the FV so as to keep a safe distance from the LV and achieve a speed equal to that of the LV. Furthermore, a speed increase needs to be implemented by the controller of the FV if it moves at a speed lower than the set one and if it happens that the LV speeds up. This needs to be done while still observing the previously mentioned smoothness and safety objectives. In such a situation, however, the set speed of the FV must not be exceeded. The success of the fuzzy controller design is tested through simulations and the results are compared with previous introduced fuzzy inferences and fuzzy-neural solutions.**

1. Introduction

The car following collision prevention has been considered as an essential problem for the control of vehicle separation and traffic flow on highways. The main aspects of the problem consist of controlling the speed of a car, called the FV, moving behind another one, called the LV, in a manner to permit a smooth and safe car following.

Having the FV equipped with the appropriate range and speed sensors, then the sensory data represented by the relative distance and relative speed between the FV and LV need to be used by a controller in order to provide the needed acceleration or deceleration so as to achieve a final safe distance between the FV and LV and equal speeds. This has to be done irrespective of the initial cars speeds and initial distance separating them. In the achievement of the stated objectives care needs to be taken so as to permit smoothness and safety.

Prior to the introduction of the fuzzy approaches [1,2], the car following problem has been dealt with using classical approaches and through the use of the mathematical formulations [3,4]. These approaches have been shown, however, to possess serious disadvantages, which mainly resulted from the fact that classical mathematics can hardly capture the complex and humanistic aspects of the problem [1]. Linguistic, rule-based methodologies have been argued to be more suitable for handling this problem and its objectives. Hence, the theory of the fuzzy logic and inference has been used [1]. Noting some disadvantages of the introduced fuzzy model, a recent fuzzy-neural approach has been introduced and it has been shown to overcome these disadvantages [2]. They mainly relate the oscillations that could arise in reaching the final objectives and the dependence on the initial relative distance and speed. The approach in [2] has also been shown to reduce the time needed to reach the specified design goals.

This study considers the design of a purely fuzzy system in order to control the speed of the FV and ultimately achieve a relative distance equal to the safe distance and zero relative speed. This is done while still preserving the advantages of the latest neuro-fuzzy approach, but without the use of the online adjustment of the neural related parameters or the determination of the reference signal. The fuzzy inference system used as a controller, with inputs the relative speed and relative distance – safe distance and output represented by the FV acceleration or deceleration, is designed off-line and it is then used on-line, in a feedback system that permits the successive adjustments of the FV acceleration based on the successive samples related to the relative distance and relative speed. Case studies and simulated results are also given and compared with the previously introduced fuzzy and neuro-fuzzy approaches.

2. Objectives

As was explained in section 1, the purpose of this work is to design and simulate a fuzzy controller system to automate the speed of a car that moves on highways so as to provide a smooth and safe ride, while the car follows another one. Hence, a safe and smooth car following is to be achieved in addition to a safe and smooth stoppage when needed.

By safe it is meant that FV is to be prevented from colliding with the LV. It is also meant that when the FV is required to accelerate or decelerate due to the movement behavior of the LV, the resulting speed change is to be done in a gradual manner so as to prevent the discomfort or injuries to the FV passengers. Of course, this latter aspect can also be considered under the smoothness objective.

Yet, smoothness also includes the prevention of unnecessary lengthy oscillations about a specific speed when the FV attempts to achieve this speed. This could occur, for example, when the FV moves at a speed higher than some fixed speed, of the LV. In such a case, the FV needs to decelerate so as to achieve the speed of the LV while keeping a safe distance between the two cars for emergency cases; such as the sudden stoppage of the LV.

Another example, is when the LV, being followed by the FV and both are moving at the same speed, decides to increase its speed to a value greater than some set speed by the FV. In such a case, the FV needs to increase its speed to make it equal to the set speed.

3. Highway Applicability

Our system should be applicable to highways of international standards which are of considerable length and composed of several lanes. The highway type should prevent any sudden appearance of cars in front the FV. Hence, interchanges need to be infrequent, and should they exist, are spaced fairly wide.

The driver must activate the system from the interface provided by the automobile. It is important to note that the system's job is to relieve the driver from the stress and strain of driving and provide him with the ability to relax to a certain extent, but the system cannot be expected to take over all the decision-making situations. There are certain situations in which the driver must interfere. An example is the sudden appearance of a car between the FV and LV. Also, every highway no matter how long must eventually comes to an end, and thus should the car arrive at an intersection, the driver must decide what to do. Since the system sees no car in front of it, it keeps on going. If the driver does not interfere to brake the results would be disastrous. Hence, the driver needs to be able to override the system at any time by pressing the brake or gas pedal.

In addition to the above, the system is not to be used in poor weather conditions such as high winds, rain or snow. In such conditions, the system should be turned off. Only the driver is able to accurately judge the situation and react accordingly because the sensors could have returned echoes from sources other than the LV and the system could not work properly due to incorrect inputs.

4. Methodology

As explained previously, safety and smoothness need to be achieved through the careful design of the controller that perform the online adjustment of the FV speed through its output that can be considered as the amount of acceleration or deceleration that needs to be applied. Of course, the amount of acceleration or deceleration needs to be related directly to the distance between the two cars (Relative Distance: RD) and the speed of the FV relative to the speed of the LV (Relative Speed: RV).

The relative distance is to be considered as one of the inputs that determine whether the FV speed needs to be increased (acceleration) or decreased (deceleration) so as to maintain a safe distance between the two cars. This safe distance (SD) depends on the speed of the FV. It needs to permit a collision-free and smooth stoppage when needed (sudden stoppage of the LV). Therefore, the difference between the relative distance and the safe distance is considered as the first input variable of the fuzzy controller. The relative speed RV is to be considered as the second input variable of the controller so as to permit the FV to adjust its speed and ultimately reach that of the LV.

Hence, the objective of the project as they relate to the input variables of the controller becomes to have the FV decelerate or accelerate until reaching a speed for which the safe distance is equal to the relative distance and the relative speed is equal to zero.

5. The Fuzzy Inference System

The fuzzy system, which is formed of a set of linguistic inference rules, provides the relationship between its output (acceleration or deceleration) and inputs represented by RV and (RD – SD) and defined as follows:

- Variable 1: RV

RV: Relative Velocity of the two cars following each other: (FV Velocity– LV Velocity).

- Variable 2: (RD – SD)

(RD – SD): Relative Distance between the two cars – Safe Distance with respect to the FV velocity.

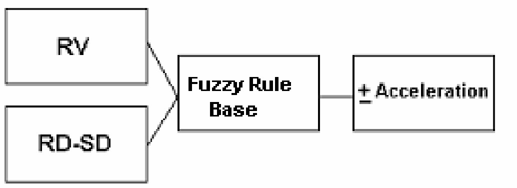


Fig. 1 Representation of the Fuzzy inference system.

The sensors used in the application determine the RV relative velocity and the relative distance RD. The FV velocity and the safe distance SD are directly entered from the vehicle where the FV velocity at each sample sets the corresponding SD from a stored look up table in the system. The SD values, which consist of the total distance needed to bring the FV to a complete stop while maintaining safety and smoothness, are assigned according to Table1 from the Australian department of transportation [5].

FV Speed Km/hr	SD meters
0	0
10	4
20	8
30	13
40	20
50	28
60	37
70	48
80	60
90	72
100	88

Table 1. FV speed with corresponding safe distance.

The output of the fuzzy system is grouped into 6 natural language based categories, while each input is grouped into 5 natural language based categories. These are given in table 2.

	Distance between LV and FV (RD-SD)	Relative speed (RV)	Acceleration or Deceleration of FV
1	Very small	FV slower	Dec Strong
2	Small	FV slightly slower	Dec Normal
3	Adequate	Near zero	Dec mildly
4	Large	FV Slightly faster	None
5	Very large	FV faster	Acc mildly
6			Acc normal

Table 2. Linguistic categories of the fuzzy system variables.

From the language-based categories above, we derived the different combinations for the fuzzy rules as shown in Table3.

(RV)					
FV Slower	Dec. Normal	Acc. Mildly	Acc. Normal	Acc. Normal	Acc. Normal
FV Slightly Slower	Dec. Normal	None	Acc. Mildly	Acc. Normal	Acc. Normal
RV Near 0	Dec. Strong	Dec. Mildly	None	Acc. Mildly	Acc. Normal
FV Slightly Faster	Dec. Strong	Dec. Normal	Dec. Mildly	Dec. Mildly	Acc. Mildly
FV Faster	Dec. Strong	Dec. Strong	Dec. Normal	Dec. Mildly	None
(RD-SD)	Very Small	Small	Adequate	Large	Very Large
	RD<<SD	RD<SD	RD = SD	RD>SD	RD>>SD

Table 3. Fuzzy rules.

Using Mat-Lab Fuzzy Tool Box, the rules in Table 3 are used along with the membership functions in Figures 2, 3 and 4. The fuzzy inference system is Mamdani type, and it has the following specifications:

- And method: Min
- Or method: Max
- Implication: Min
- Aggregation: Max
- Defuzzification: Centroid

The membership functions shape and density were obtained from previous work [1], yet some tuning and modifications have been introduced so as to make them more consistent with the assigned rules (Table 3) in terms of achieving improved performance. The performance improvement has accounted not only for the output (acceleration or deceleration) that need to be assigned to each linguistic pair of RV and (RD – SD), but also to the needed linguistic output that corresponds to each new linguistic input pair obtained from previous output through the structured feedback system shown in Figure 5. Also, the rules and membership functions have been modified, tuned and improved through simulated case studies.

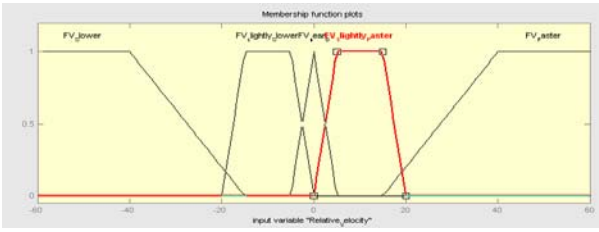


Fig.2 The Relative Velocity Membership Functions

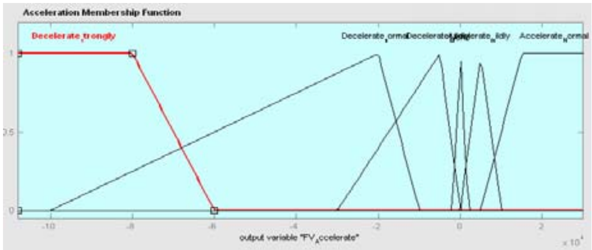


Fig.3 The Relative Distance-Safe Distance Membership Functions

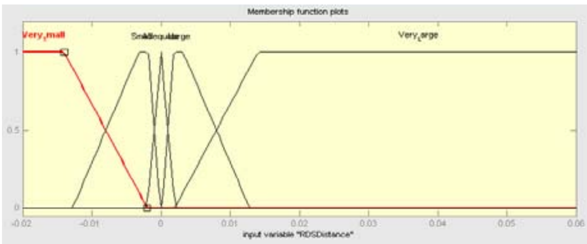


Fig.4 The Acceleration Membership Functions

6. Testing Framework

In order to test the car following collision prevention controller in real time, which is the same as implementing it on a road vehicle, we used the Simulink workspace available in the Mat-Lab software. The system consists of two inputs (RD-SD and RV), the fuzzy controller already designed in the Mat-lab Fuzzy Toolbox, and a feedback loop (Fig.5)

Starting with the input of the system, the subsystem at the left hand sets the scenario that the user creates for the Leading Vehicle (for example constant velocity between 0 and 2 seconds, deceleration between 2 and 6 seconds…). The output of the subsystem is the LV velocity (scope 10) and the LV distance (scope 9) being traveled every sample. Initially, the user sets the velocity of the FV as the velocity at t=0.

The velocity of the LV is then subtracted from the FV (feedback loop) and the RV (scope 7) is determined in order to get the first input. The distance traveled by the leading vehicle is also subtracted from the distance traveled by the FV (feedback loop) to get the RD (scope 12). If we were to implement our project on hardware, the values of the RD and RV would be determined by the sensors present in the vehicle. The determined RD is subtracted from the safe distance, taken from the look-up table; to get the second input RD-SD (scope 6).

The two values are entered into the fuzzy controller where the desired acceleration is the output (scope 1). The acceleration at time t of the FV is entered into the distance and velocity solver, located in the subsystem under the controller and the interpolating look-up table, to calculate the FV distance (scope 4) and the FV velocity (scope 2) at T+1. Notice that the velocity and distance of the FV are the outputs of the feedback loop and therefore these values are subtracted from the LV subsystem to determine the RV, RD, and SD from the look-up table (scope 5) at T+1.

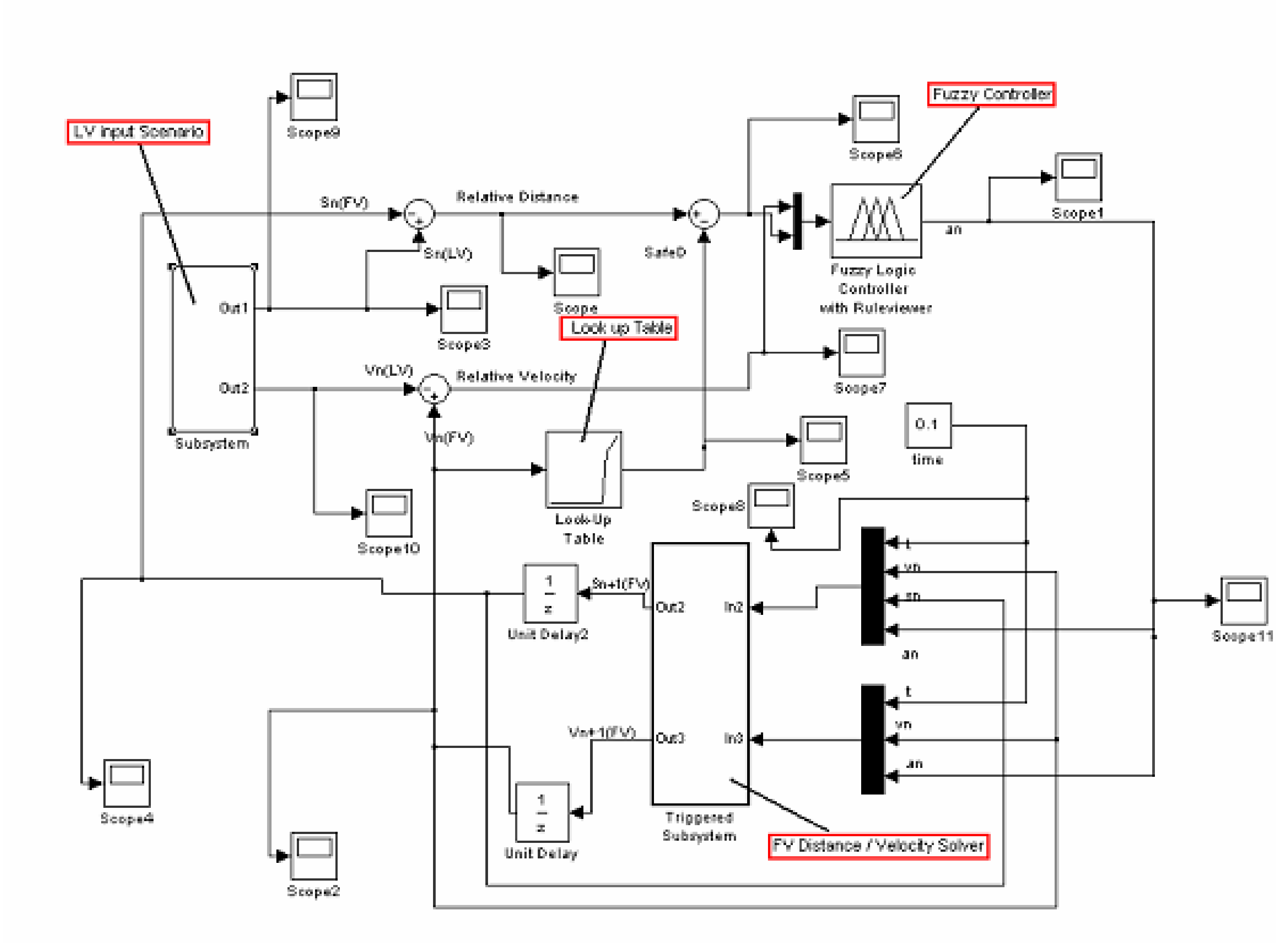


Fig. 5 The Simulink Circuit used for the simulation of the FIS and the feedback System

7. Simulation and Results

Case1: Fig.7 represents the variation of the velocity with respect to time of the FV for the scenario where the LV has constant velocity =50Km/hr, initial relative distance =30 m (<SD=37) and the initial velocity of FV =60 Km/hr and sampling period =0.1sec. This graph is obtained from Scope2. At the steady state the velocity is constant as for the time it took to reach 50.5 Km/hr steady state was 1.5 s with an error of 0.5/50.5 = 1%.

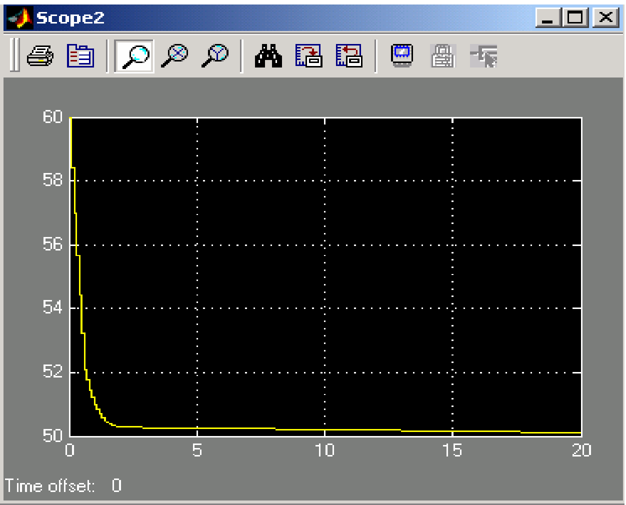


Fig. 7 FV speed versus time

Fig.8 shows the (Relative distance between the two cars – Safe Distance) for the same scenario of **Fig.7**, it is obtained from *Scope6*. It is clearly shown that the RD-SD varies between 1 and 2m at steady state. Therefore, error =2/27=7.4%, but this error is a positive 1 because RD>SD.

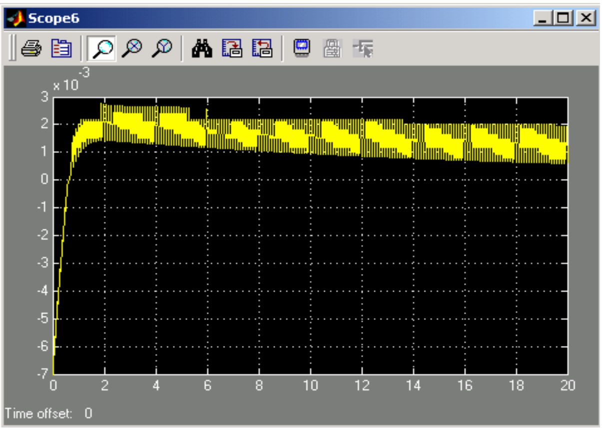


Fig. 8 RD-SD Versus time.

Case2: In this scenario LV keeps a constant velocity =65Km/hr for 2 seconds (0<t<2), then it decelerates for 2 seconds at an acceleration = -1.5m/s^2, then it accelerates at 1.5m/s^2, and finally keeps a constant velocity = 65 Km/hr. Initial relative distance =43 m (SD=43) and the initial velocity of FV =65 Km/hr and sampling period =0.1sec. Fig.9 shows the Velocity of the FV Versus time. It reached 64.5 Km/hr in 10 s, 4 seconds after LV reached its velocity 65Km/hr. Fig.10 shows the relative distance between the LV and FV all through the scenario. At t=10s, RD-SD = -0.2m, error =0.2/43=0.4%.

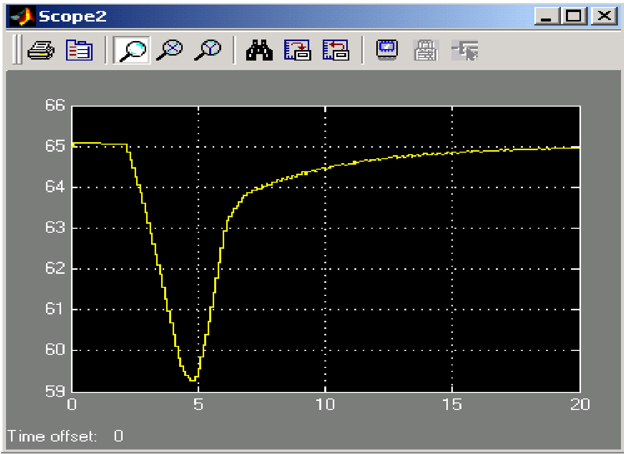


Fig. 9 Velocity versus time.

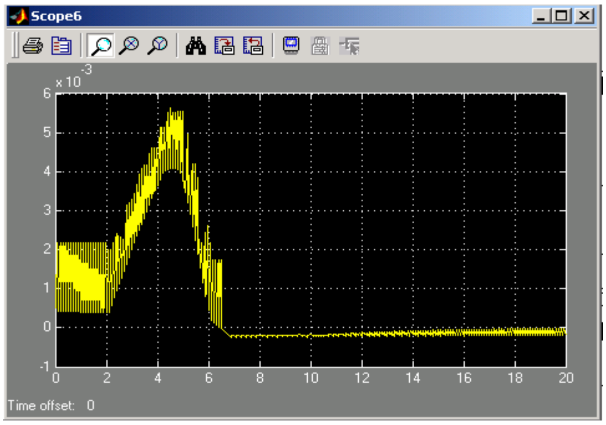


Fig. 10 RD-SD Versus time.

It can be shown from the graphs of Case 2 that we obtained, that our system reached steady state in 4 seconds whereas the system of the model [1] took more than twenty seconds for the same input. Both systems reached the objective of having RV=0 and RD=SD. We were not able to see the errors of the previous paper because its graphs do not accurately show its results.

In order to have additional checking on the effectiveness of the designed fuzzy inference system we have compared it to the FBFN system proposed by a group of engineers in Taiwan [2]. The importance of this comparison is based on the fact that the FBFN system has outperformed all previous controllers.

Thus, we are trying to measure where our controller's performance stands with respect to the FBFN which is the most recent design. The presented FBFN network can solve the oscillation problems for final relative distance between the LV and the FV and the relative speed. The required processing time for the FBFN network to achieve safe distance between the LV and FV is about 6-7sec, which is faster than those proposed by other schemes, while providing a safe, reasonable and comfortable ride. For this reason, we considered the same circumstances and tested the same situations taken in the FBFN paper and obtained the following results. The sampling period is taken at a rate of 75µs which is the same as in the paper.

Case 3: In this case the initial relative distance between the LV and the FV is equal to 40.53m. The initial speed of the FV is 48.384 Km/hr. The LV decelerates from 48.384 Km/hr to 30.186 Km/hr in 2 seconds and remains constant.

The final relative distance converges to SD regardless of the initial speeds. Fig. 11 shows the decrease of the relative distance from 43m to 15m in 8 seconds where the system reaches steady state. Both systems take about 8 seconds to converge to the desired distance and speed, but the RD converges in a smoother curve than the FBFN RD curve.

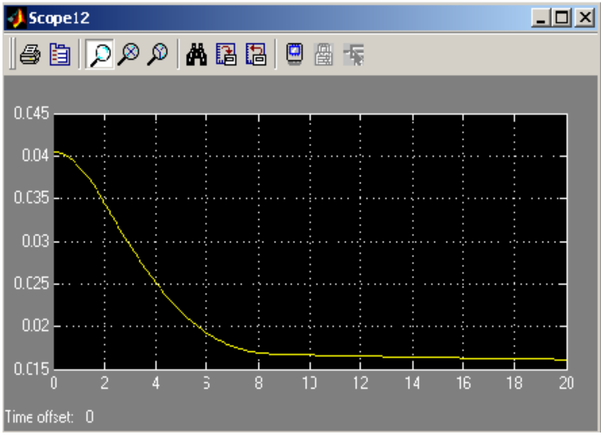
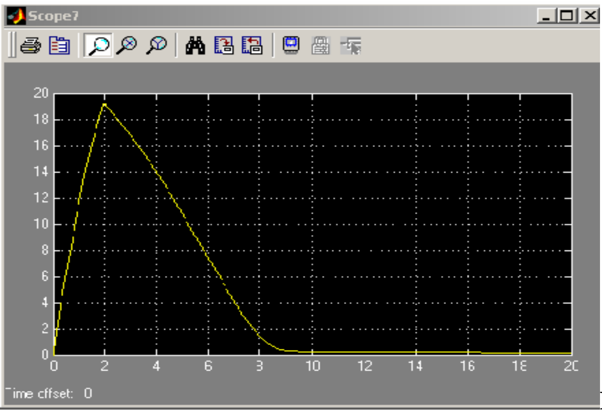


Fig. 11 RD versus time(s).

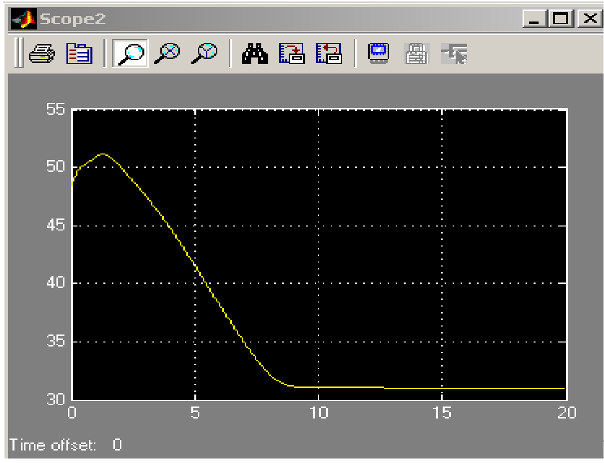


F

Fig.12 RV versus time(s).

Fig. 12 shows the relative velocity of the 2 vehicles. The convergence time is about 8 seconds and then the RV converges to 0. The overshoot in FBFN system = 25.5Km/hr where as the overshoot in this system is =19.5Km/hr which meets the smoothness criteria. It is seen that no oscillation occurs for RD, RV, and the FV velocity during the processing time and at steady state.

Case 4: In this case, the initial relative distance between the LV and the FV is equal to 28m. The initial speed of the FV is 70Km/hr. The initial speed of the LV is



F

Fig.13 FV Velocity versus time(s).

60Km/hr and remains constant. Here the FV is faster than the LV and relative distance is less than the safe distance. The graphs below show the response of the fuzzy inference system.

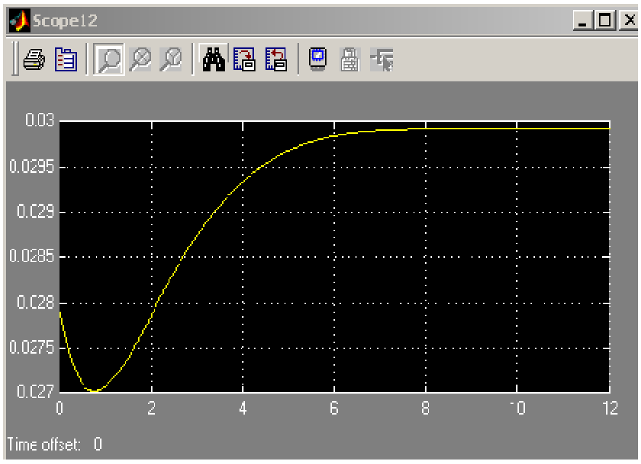


Fig.14 RD versus time(s).

Fig.14 shows the RD variation with respect to time. The main advantage of the FBFN network over the new fuzzy system is it converges in 4 sec where as the latter needs 6 sec. However, the fuzzy system is able to execute the process with no oscillations.

Fig.15 shows the RV variation with respect to time. The convergence time of both systems is approximately equal but the fuzzy system is able to remove any kind of oscillations. Also, the overshoot in this case is -2km/hr which is less than the FBFN's overshoot (-5km/hr).

In conclusion, the new design for the car following prevention controller surpasses the performance of previous proposed controllers. In this case specifically, the new design is able to achieve the smoothness and safety of the ride with an execution time.

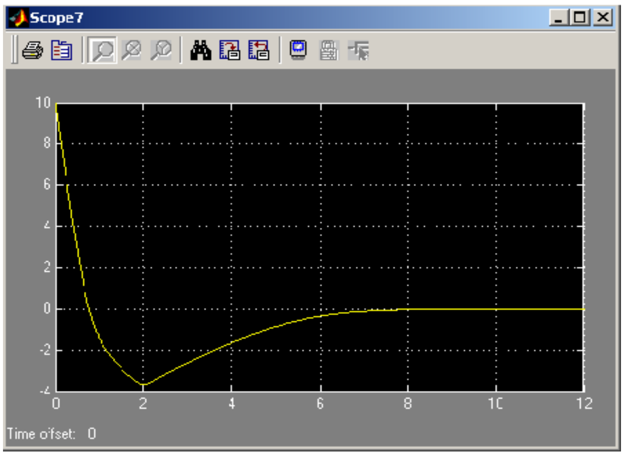


Fig.15 RV versus time(s).

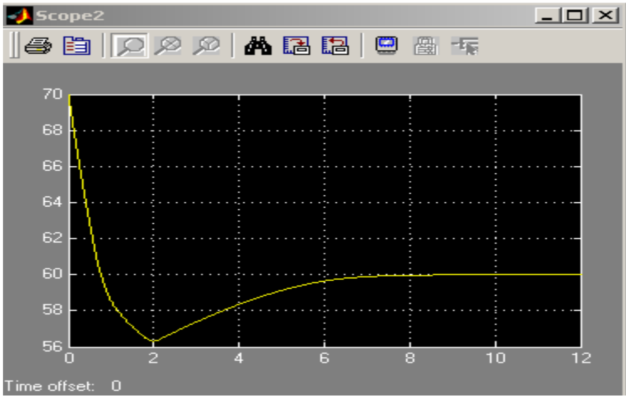


Fig.16 FV Velocity versus time(s).

8. Conclusion

In this study, a car following model was established for the estimation of the acceleration or deceleration rate using a fuzzy controller approach. The acceleration or deceleration rate is estimated using the developed model from speed and distance. Based on the simulation results, which have been shown superior over other published ones, it can be said that the developed fuzzy model can be effectively used for the car following collision prevention system so as to achieve control of vehicle separation and speed and hence smooth traffic flow on highways. Having the FV equipped with the appropriate range and speed sensors, the sensory data entered into the controller at successive time steps on-line determined the acceleration for the task at hand. This has been done irrespective of the initial cars speeds and initial distance separating them and the controller was able to maintain the stated objectives of smoothness and safety. This model can be installed in vehicles by having the output acceleration (positive or negative) translated into either braking or throttle pedal pressure for the system's operation.

Acknowledgements

We would like to thank Dr. Jean J. Saade of the Electrical and Computer Engineering Department at the American University of Beirut for his contributions that made this paper possible. Our sincere thanks to you Dr. Saade for your constant support, patience, and guidance.

References

[1] S. Kikuchi, P Chakroborty, Car-following model based on fuzzy inference system, Transportation Research` Record 1365,TRB,1993,pp 82-91

[2] Jeich Mar, Feng-Jie Lin, Hung-Ta Lin, Li-Chin Hsu, The car following collision prevention controller based on the fuzzy basis function network (2003), Fuzzy Sets and Systems Vol. 139 p.167-183.

[3] R.E. Chandler, R. Herman, E.W. Montroll, Traffic Dynamics: Studies in Car-following, Operations Research, vol. 6, 1958, pp. 165-184.

[4] R. Herman, E.W. Montroll, R.B. Potts and R.W. Rothery, Traffic dynamics, Analysis of stability in car-following, Operations Research, vol. 7, 1959, pp. 86-106.

[5] Road Markings and Stopping Distances (Australian Department of Transportation).

[6] A.Bjornberg, Autonomous Intelligent Cruise control, 44th IEEE Veh Tech Conf 1 (1994) 429-433

[7] P.Ioannou, Z. Xu,S. Eckert, D Clemons, T. Sieja, Intelligent Cruise control: theory and experiment, Proced. Of 32nd Conf. on Design and Control, San Antonio, Texas, Dec. 1993.