Integrated Type-2 Fuzzy System for Controlling Throttle and Brake in Smart Car to Implement Car Following and Stop & Go Maneuver

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Abstract
Longitudinal control of the vehicle evolved from Cruise Control (CC) to Adaptive Cruise Control (ACC) and now recently to Stop and Go (SNG). SNG is the most demanding functionality of the intelligent car. This feature allows the vehicle to move in a congested traffic, at a speed less than 30 kmph, even without the intervention of the driver. It enables the vehicle to follow the leader car during a stop-and-go scenario. For safety, the system should stop the vehicle before it reaches the critical distance and for comfort, system should keep the deceleration and jerk bounded. In the proposed paper, Integrated Type-2 Fuzzy System is developed with two inputs from the sensor namely, relative velocity and relative distance. The output of the system is the percentage throttle opening and brake torque requirement. The very obvious reason for using integrated system is because brake and throttle are not simultaneously required in any driving condition. Three diversified scenarios are effectively handled by the system namely- car following, pedestrian crossing and stop and go.
Keywords:
Car following, pedestrian crossing, stop and go (SNG), type-2 fuzzy inference system (T2FIS)

I. INTRODUCTION

AUTOMATIC vehicle speed control is presently one of the hottest research topics throughout the automotive industry as a whole and particularly in the field of intelligent transportation systems. The goal of such automation is to improve the safety of the occupants of the car by relieving the human driver of tedious tasks that could lower attention, as well as to make the traffic flow more efficient. Cruise control (CC) systems, with the capability of maintaining a user preset speed, was the first step in this direction. The next step was adaptive CC (ACC) systems, which add the capability of keeping a safe distance from the preceding vehicle to CC. Both systems are now on the market, and several cars come equipped with them. Highways are the most common scope of applicability of such systems.
The main limitation of conventional ACC systems is that they do not manage speeds under 30 km/h because only the throttle is used for this task and consequently, they are inhibited in traffic jams or urban driving.
Extensions of ACC with Stop & Go capabilities are being researched to overcome this drawback. Stop & Go driving is a typical maneuver in city streets. Throttle and brake pedal automation is needed to install this feature in a vehicle. This feature makes ACC useful in urban driving and dense traffic situations, when it is all the more necessary for preventing and averting rear-end collisions and major accidents.
The use of fuzzy logic for control systems has two main features. The first to one is that these kinds of systems do not need an exact mathematical model of the system to control. The second feature of the fuzzy control is that it does not pretend to use the mathematical representation of the systems but to emulate the behavior of the human driver and his experience, mimicking his reactions. It also permits adding to the system the subjective knowledge of the users, which is certainly a very useful characteristic for emulating the human behavior[1][11].

A. Sensor Analysis

There are two output profiles from the sensors. They are relative velocity and relative distance between two vehicles. The fig.1 shows two typical unfiltered measurement profiles from the sensor.

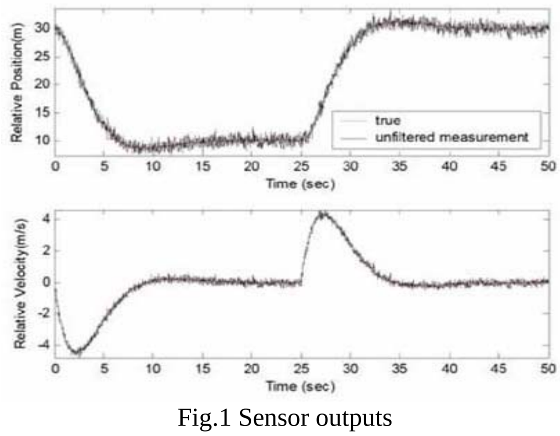

Fig.1 Sensor outputs

It can be observed that when relative velocity is positive, the distance between the vehicles' increases. The distance between the cars will keep on increasing, as long as the relative velocity is positive. When relative velocity is positive and decreasing then relative distance is increasing

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but with lesser acceleration, similarly when relative velocity is negative and increasing then relative distance is decreasing but again with lesser retardation rate. The rate of change of distance varies with the rate of change of relative velocity. When relative velocity becomes negative, the distance between the vehicles starts decreasing. Relative distance decreases as long as the relative velocity remains negative [2]

B. Safe Inter-Distance Policies-

During the last decades, the well known “safe inter-distance” has been calculated as a minimal distance to avoid a collision if the preceding vehicle were to act “unpredictably.” In fact, the safe inter-distance is calculated from the Newtonian motion equation, permitting to obtain the necessary distance to full stop without collision [3].

C. Comfort Criteria-

Some works that try to ensure comfort by imitating the human behavior. An ACC system for low speed motion, where the desired acceleration was obtained using data of a real driver’s behavior. Human perception theory is applied in order to obtain an acceptable inter-distance reference. The problem here is that reproducing such as behavior may not necessarily lead to safe operation. Therefore, human-based methods may perform over heuristic approaches [3].

In general, passenger comfort in public ground transportation is determined by the changes in motion felt in all directions, as well as by the other environmental effects. Typically, acceleration magnitude is taken as a comfort metric. However, comfort due to the motion changes in a vehicle’s longitudinal direction (the “jerk”) has been used instead. So, the jerk is important when evaluating the discomfort caused to the passengers in a vehicle [4].

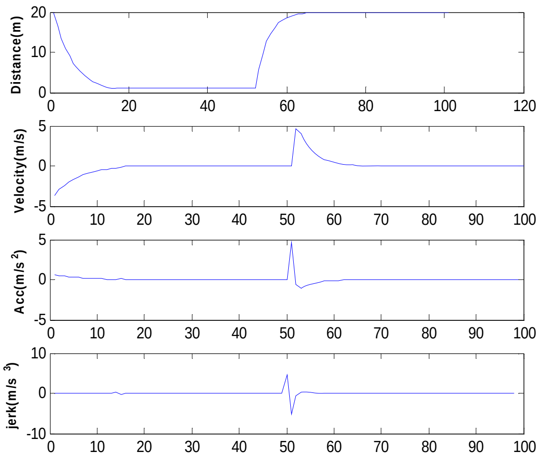

Fig.2 Inter-distance, velocity, acceleration and jerk

II. METHODOLOGY

Considering the nature of signals from sensors it can be inferred that type -1 fuzzy system will not handle the noisy signal. It is therefore decided to use type-2 fuzzy system[5][6], which can very easily handle the uncertainty in the input signal from sensors.

The fundamental reason for choosing single type-2 fuzzy systems for proposed applications are- I) input is noisy, which can be handled easily with type-2 fuzzy system. II) brake and throttle are never required simultaneously for longitudinal control of the vehicle.

A. Design of Type-2 Fuzzy Inference System (FIS)

The system has two inputs – relative velocity and relative distance, and two outputs throttle percentage and brake torque.

[System]
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Type='mamdani'
Version=2.0
NumInputs=2
NumOutputs=2
NumRules=38
AndMethod='min'
OrMethod='max'
ImpMethod='min'
AggMethod='max'
DefuzzMethod='centroid'

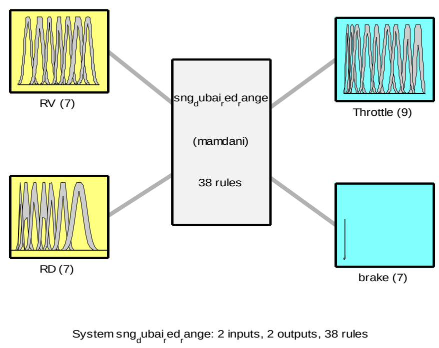

Fig.3 FIS for proposed applications

B. Input Membership Functions

i) *Relative Velocity*- vn-very negative, mn-medium negative, n-negative, nullrv-null relative velocity, p-positive, mp-medium positive, vp-very positive. The range of relative velocity is taken from -5 to +5 mph.

ii) *Relative Distance*- dd-Danger distance (1m), vvc-very very close, vc-very close, c-close, d-distant vd-very distant, vvd-very very distant .The range of distance is 0 to 20 meters.

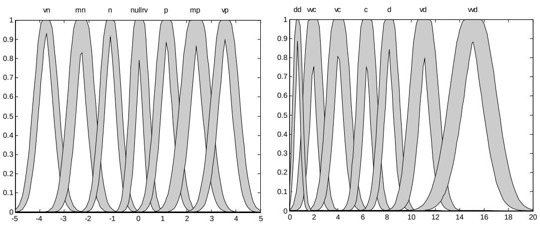

Fig.4 Relative Velocity & Relative distance

C. *Output Membership Functions*

i) Throttle Percentage- Null(0 % acceleration) dvvl-down very very low, dvl-down very low, dl-down low, d-down, uvl-up very low, uh- up high uvh-up very high, fullt- full throttle. This is taken as 0 to 20 %.

ii) Brake Torque- Nullb(0% braking), vsb-very soft brake, sb- soft brake, pb-prominent brake, shb- slightly hard brake, hb- hard brake, vhb-very hard brake. Brake torque is in between 0 to 1000 lb/ft.

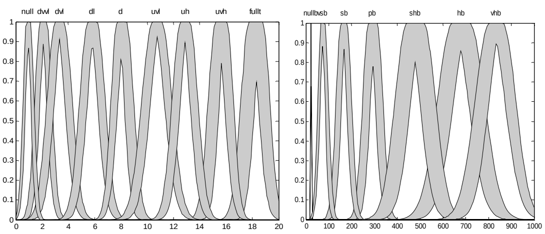

Fig.5 Throttle percentage & Brake Torque

D. *Rule Table*

Table 1.Rules of Type-2 Fuzzy System

RV/RD	dd	vvc	vc	c	d	vd	vvd
vn			shb	pb	pb	sb	
mn		shb	pb	pb	sb	sb	vsb
n	vhb	hb	shb	pb	pb		
Null	vhb	null	dvvl	dvl	dl	d	d
p	dvvl	dvvl	dvl	dl	dl	d	d
mp			dvl	dl	dl	d	uvl
vp		dvvl	dvvl	dvl	dl		

III. IMPLEMENTATION

A. *Input output data set-*

The type-2 fuzzy system with appropriate rules and membership function is then tested for standard input data set. Fig. 6 shows the graphs of relative distance, relative velocity, throttle percentage opening and brake torque output.

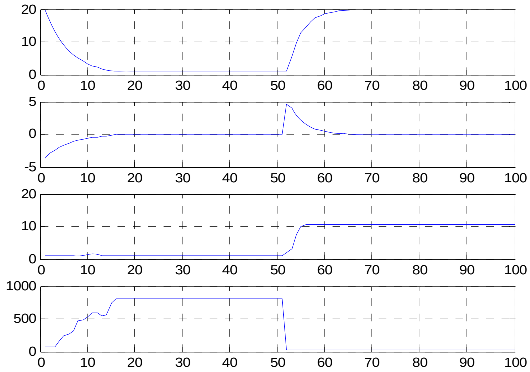
Fig.6 Input/output of T2FIS

B. *Scenarios-*

The system is then tested for three scenarios [7] i) Car following- When relative velocity is zero, and the vehicles are moving at different constant relative distances. (Car Following).

ii) Pedestrian crossing (Stopped vehicle / obstacle)- When the pedestrian was detected in front of the vehicle or when an obstacle (or stopped vehicle) appeared in front of the host vehicle. The vehicle approached with a negative relative velocity. The throttle pedal was released. The braking control system was then activated, bringing the vehicle to stop before of the pedestrian. After the pedestrian crossed the road car resumed acceleration toward the previous velocity.

iii) Stop and Go- When the vehicle moves in a traffic jam.(stop&go). This scenario simulates a traffic jam. In this scenario. The preceding vehicle moved for a period of time, then stopped completely. After a few seconds, the preceding vehicle continued to move and stop. The automated S&G system in the host vehicle controlled the throttle and brake pedals to maintain a safe distance between the host vehicle and the preceding vehicle.

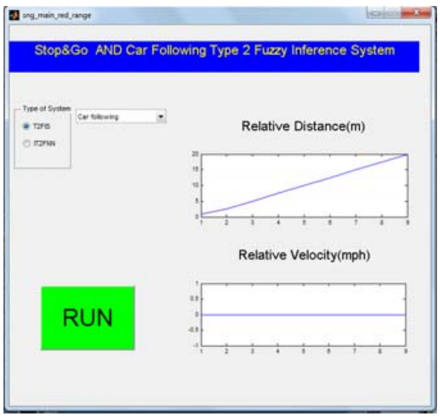

Fig. 7 Car following input

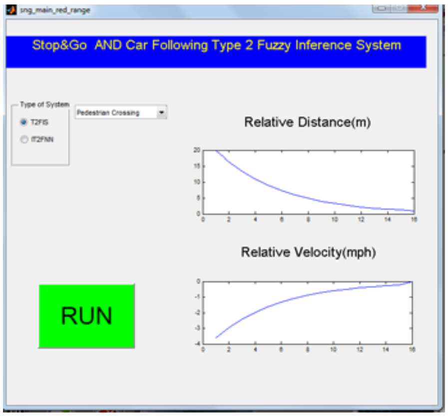

Fig. 8 Pedestrian Crossing input

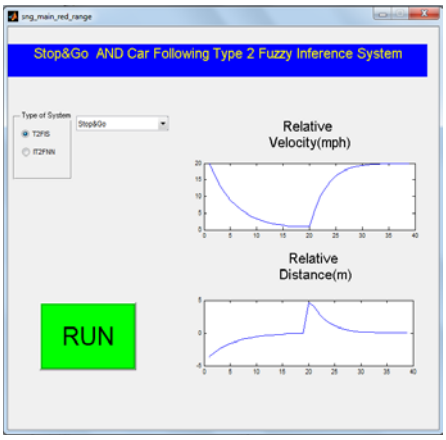

Fig. 9 Stop & Go inputs

C. *Vehicle Model with input from type-2 fuzzy system*

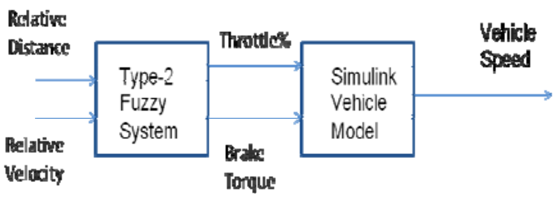

Fig.10 Block Diagram of proposed system

Fig. 10 shows the block diagram of the system which has input from sensors applied to type-2 fuzzy system, and the output of the fuzzy system is then fed to the simulink model of the vehicle which gives the speed of the test vehicle. The modeling of the vehicle's drive train and dynamics is done by mapping on the specifications of a Tyota Yaris onto a demonstration model in MATLAB[8]. The automatic drivetrain model available in SIMULINK[9] is taken as a base model for the system development. The inputs to the drive train are the throttle opening and brake torque. The engine, vehicle dynamics and the automatic transmission have been modeled using non-linear differential equations. The transmission control unit has been modeled in STATEFLOW as it involves decision making based on the current state of the vehicle.

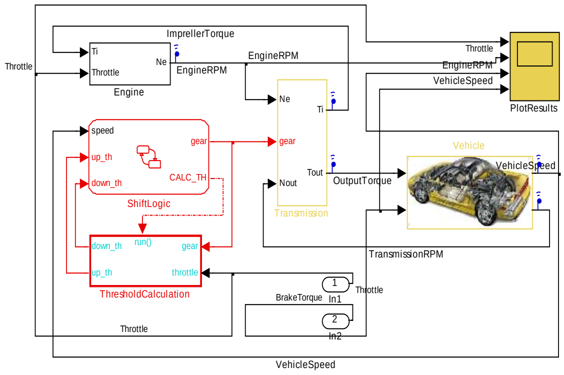

Fig. 11 Simulink model of test vehicle

IV. SIMULATION RESULTS

A. *Simulation scenarios*

Fig.12 shows relative distance, relative velocity, throttle percentage and brake torque for input output data set and engine RPM and output speed is shown in fig. 13.

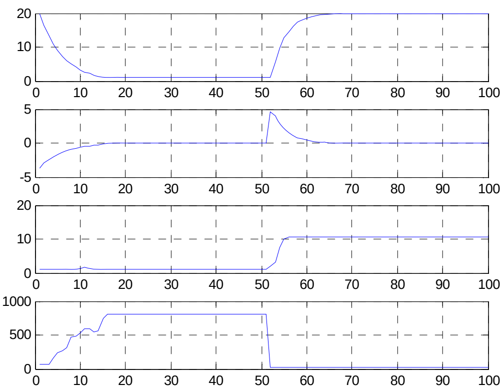

Fig.12 input/output of t2fis

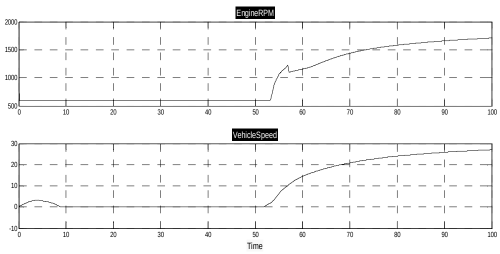

Fig.13 Simulink model output

Figures 14,15,16 shows simulation results of the car following, pedestrian crossing, stop and go respectively. Every figure consists of four graphs, in which first graph will be of throttle %, second of Engine rpm, third of vehicle speed(mph) and forth is of brake torque(lb/ft). From the simulation results of the car following shown in fig.14 it can be inferred that when relative distance is less brake is more prominent and slight application of throttle is there, whereas when relative distance is more throttle is opened more, and brake is almost negligible.

From simulation results of pedestrian crossing shown in fig.15 When relative distance is decreasing throttle is almost closed, and brake torque is gradually increasing.

Finally, from simulation of stop and go shown in fig.16. When relative velocity is negative and relative distance is decreasing throttle is almost closed, and brake is applied accordingly whereas when relative distance is increasing, and relative velocity is positive brake is released, and throttle is opened accordingly.

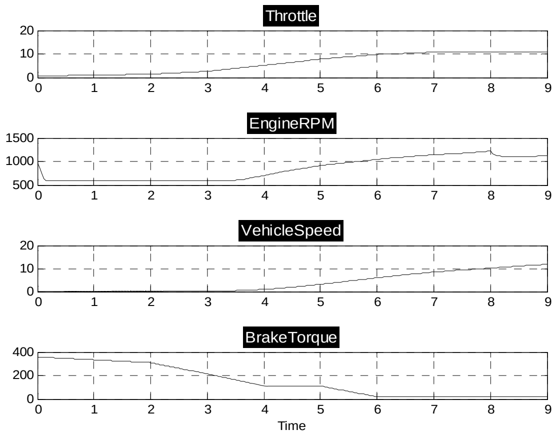

Fig.14 Car following

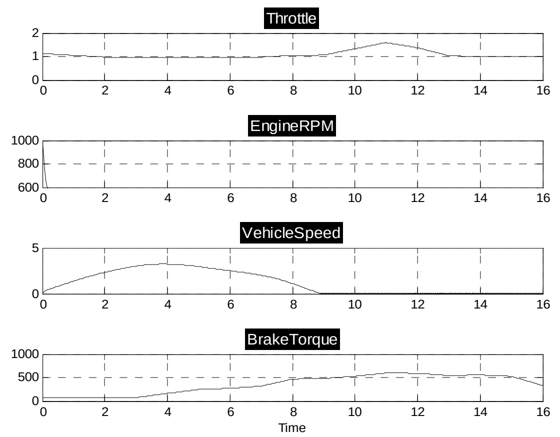

Fig.15 Pedestrian crossing

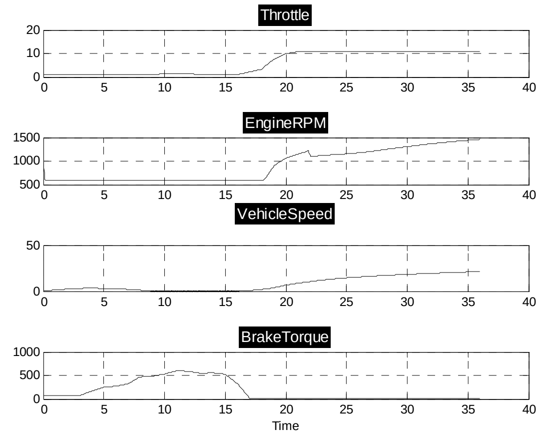

Fig.16 Stop and Go

In fig. 17, GUI, window is shown, which has T2FIS selected through a radio button and from the pop-up menu concluding simulation option is selected. When run button is pressed the axes shows relative distance, relative velocity, throttle % and brake torque(lb/ft). Fig.18. simulation showing engine rpm and vehicle speed for combined testing of all three scenarios viz., car following, pedestrian crossing and stop & go.

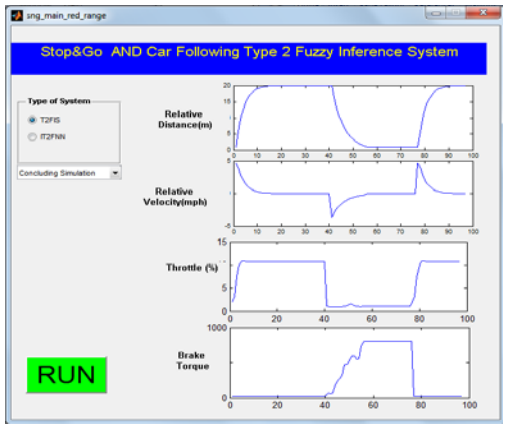

Fig.17 Go, follow and stop input

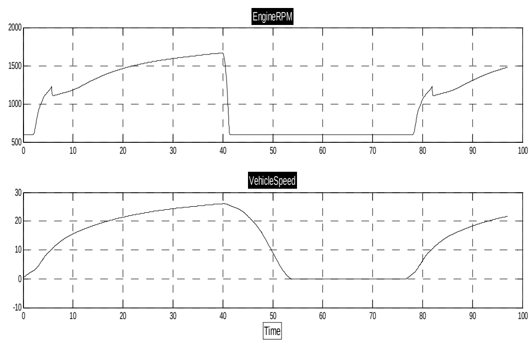

Fig. 18 Combined scenarios

B. Jerk Analysis and reduction:

Magnitude of the jerk depends upon the rate of acceleration or deceleration, which is decided by the throttle% (TP), and brake torque (BT) signals. If TP and BT are smooth, then rate of change of acceleration or deceleration would be bounded. Therefore, smoothing function shown in fig. 19 is applied at output of t2fis to smoothen the TP and BT signal and ultimately jerk can be reduced.

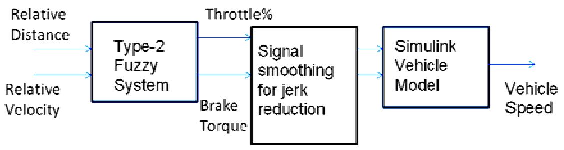

Fig.19 Modified block diagram for jerk reduction

Figs. 20,21,22. Shows throttle and brake jerk before and after smoothing. Furthermore, fig 23 shows input /output of the fuzzy system with smoothing for a typical stop, follow and go scenario and in addition, the speed output of simulink vehicle model after smoothing.

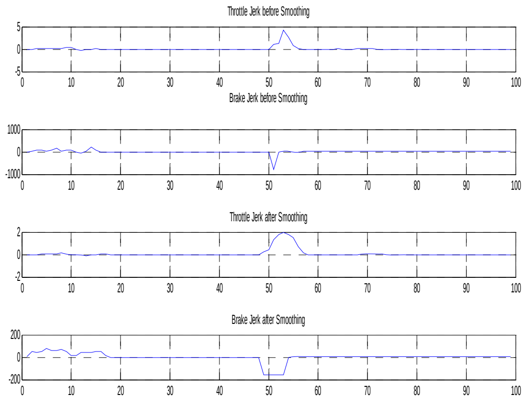

Fig.20 Input output data set simulated jerks of fig12

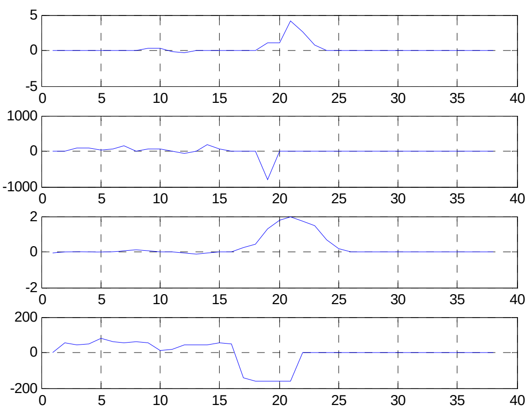

Fig 21 Jerks of Stop and Go of fig16

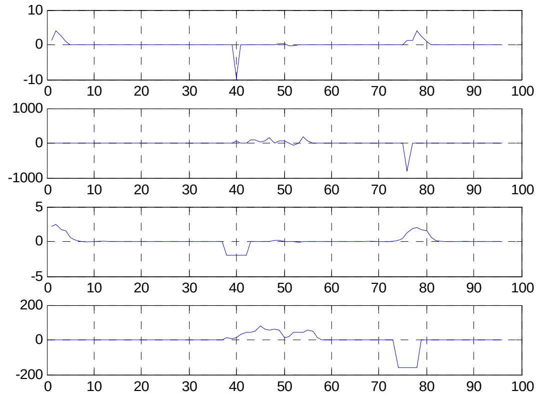

Fig 22 Jerks of Go, follow and stop input of fig17

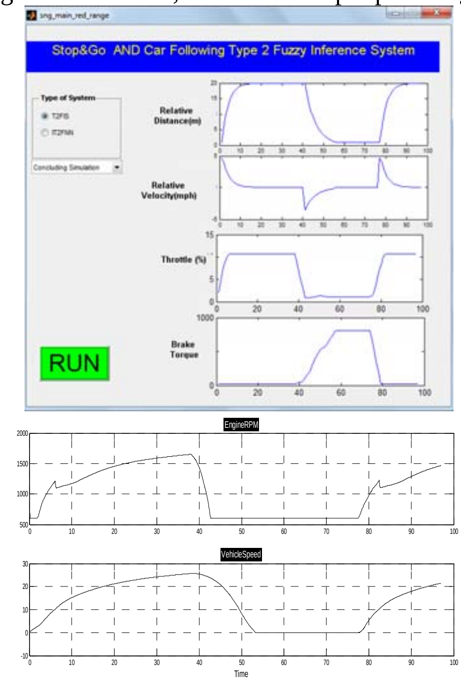

Fig. 23 Combined scenarios stop and go with smoothing

C. Safety constraint analysis

Analysis of magnitude of BT required to stop the vehicle completely before or at critical distance.
If speed is fixed at 30 kmph, and throttle is released. Then max BT limit can be increased so that time to stop the vehicle can be reduced.
Similarly, for lesser speeds considering same BT variation the stopping time would be reduced.
Assume maximum vehicle speed =30 for stop and go scenario if throttle percentage=0, then as per the following table 2 it can be inferred that when brake torque is less stopping time is more, so safety constraint is violated. Whereas, if brake torque is very high, then jerk will be increased, so suitable value of brake torque can be selected keeping safety on high priority.
Table 2. BT and Time to stop vehicle completely

Magnitude of B T (lb/ft)	Stopping time of vehicle (samples)
340	20
400	14
500	12
600	10
1000	9
2500	7

D. Simulink 3D animation model Simulation

The simulink 3D animation model (Skoda Octavia) available in MATLAB is taken for real time 3D visualization of the system implementation. Fig.24 shows simulink 3D animation model of the vehicle, in which In1 and In2 are the outputs of type-2 fuzzy system. VR sink and VR signal expandar blocks are taken from the virtual reality library of MATLAB[10]. Fig.25 shows the 3D animation view of the vehicle (Skoda Octavia) available in MATLAB. Fig. 27 shows the simulation output of the animated vehicle model for 420secs for which the input is as shown in fig. 26 (1000 secs). The inputs show the variation in throttle% and brake torque corresponding to variation in relative velocity and relative distance at various time intervals. The output of the model is vehicle speed and engine RPM, which shows apparent changes in speed for a typical stop follows and goes situation in the urban or congested traffic environment.

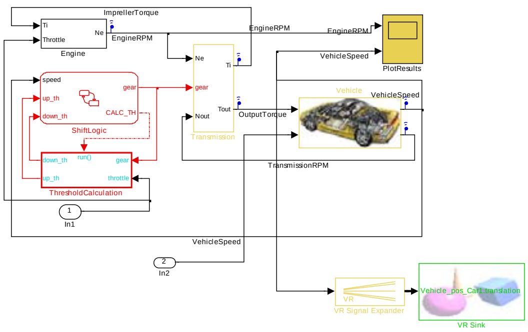

Fig.24 Simulink 3D Animation model of vehicle

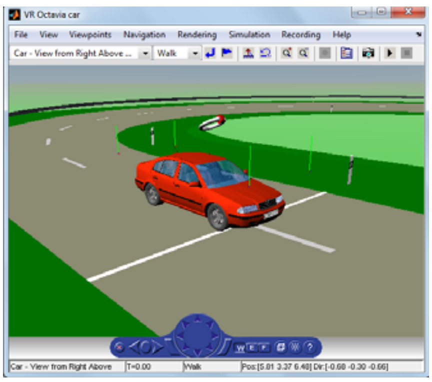

Fig.25 3D Animation view in VRML

Fig .26 Congested traffic situation simulation input (GUI Window)

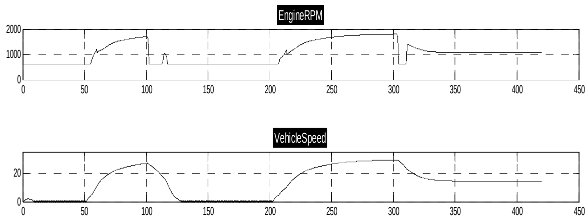

Fig .27 Congested traffic situation simulation outputs

V. CONCLUSION AND FUTURE SCOPE

The proposed application is designed using type-2 fuzzy system having relative distance and relative velocity as input and throttle and brake position as output. It is apparently observed that only one fuzzy system is capable of handling both output as they are not required simultaneously.

Moreover, two major concern of the system are safety and comfort; so far, as safety is concerned the vehicle should stop before a critical distance which is well observed in the simulations, and comfort, rate of change of acceleration (jerk), is not vital for the safety. Jerk can only play a role in case of hard stop where safety is a major concern as against comfort. Jerk can only be reduced by proper mechanical design of the vehicle and to some extent, by smoothing throttle and brake signals of the fuzzy system. The throttle and brake signals can be smoothly applied in order to minimize jerk. Hence signal smoothing block is inserted in the design which ensures the bounded jerk.

The vehicle is very smoothly accelerated by the system to a maximum speed of 30mph when a relative distance between the vehicles is 20m. Whereas vehicle is comfortably stopped before the critical distance by appropriate braking applied from the fuzzy system. When relative velocity is zero and relative distance is maximum the speed is maintained to follow the leader vehicle and when relative velocity is zero and relative distance is 1m the vehicle comes to complete stop until the time relative distance and relative velocity increases.

The type-2 fuzzy system can be hybridized with neural network, which will perfectly tune the membership functions of fuzzy sets. This would ensure the immediate release of the brake pedal when the throttle is about to open. The 3D traffic environment will be further requires several external variables such as detection of traffic lights, pedestrians, intersections along with the movement of the vehicle in the congested traffic. These conditions should have two vehicles leader and follower. The speed of the leader vehicle should be controlled by the user and speed of the follower vehicle by the system. This will make the actual real-time traffic environment for visualization and presentation.

The fuzzy logic system must be able to incorporate the environmental conditions when the vehicle is moving in the above 3D model. The VRML realm builder along with the virtual reality toolbox allows the connection of the fuzzy system to the 3D system. This will make testing of the system more realistic.

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