Intelligent control design of car following behavior based on fuzzy logic control

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Abstract—A reference model based control approach for improving the behavior of following car is proposed in this paper. The reference model is nonlinear and provides dynamic solutions consistent with safety constraints and comfort specifications. A robust fuzzy logic based control strategy is proposed in this paper. A set of simulation results showing the suitability of the proposed technique for various demanding scenarios is also included in this paper.

Key words Reference model, Longitudinal Control, fuzzy logic.

I. Introduction

Adaptive cruise control (ACC) and stop-and-go control systems have been thoroughly studied in recent years (see [1],[2]). Some of such research papers may be examples of problems relating to longitudinal control. Some others may concern the inter-distance control in highways where the vehicle velocity remains mainly constant. Whereas others may deal with the vehicle circulating in towns with frequent stops and accelerations. In all situations, safety and comfort are often the main goals but most often oppose each other [3],[4].

The main contribution of this paper consists in finding a fuzzy control algorithm that leads to the expected reference speeds and acceleration of the backward vehicle, while keeping a reference distance with the vehicle in front.

The paper is organized as follows. After giving a concise introduction to the problem, the dynamic inter-distance model will be presented in section II. The implementation of a fuzzy controller will be detailed in Section III. This technique will be further evaluated under a simulation environment and the results will be discussed in section IV, where disturbance robustness, comfort and safety will be compared. Finally, some concluding remarks will be given in section V.

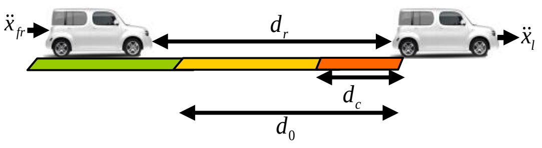

Fig.1 The inter-distance reference model.

II. DYNAMIC INTER-DISTANCE GENERATION

The inter-distance reference model as shown in Figure 1 describes a virtual vehicle dynamics which is positioned at a distance d_r (the reference distance) from the leader vehicle. The reference model's dynamics are given by :

$$\ddot{d}_r = \ddot{x}_l - \ddot{x}_{fr} \qquad (1)$$

$$\ddot{x}_{fr} = u_r\left(d_r, \dot{d}_r\right) \qquad (2)$$

where $\ddot{x}_l$,is the front vehicle acceleration and $\ddot{x}_{fr}$ is the following vehicle's acceleration, which is a nonlinear function of the inter-distance and its time derivative.

Introducing $\tilde{d} = d_0 - d_r$ in Eq. 2, where d_0 is the safe nominal inter-distance, the control problem would be then to find a suitable feed-forward control u_r , when $\tilde{d} > 0$, such that all the solutions of the dynamics (Eq. 2) fulfill the following comfort and safety constraints:

- $d_r \geq d_c$, with d_c the minimal inter- distance.
- $\|\ddot{x}_r\| \leq \gamma_{\max}$,where $\gamma_{\max}$ is the maximum attainable longitudinal acceleration.
- $\|\ddot{x}_r\| \leq J_{\max}$, with $J_{\max}$ a bound on the driver desired jerk.

In [5], the authors proposed the use of a nonlinear damper/spring model $u_r = -c\left|\tilde{d}\right|\dot{\tilde{d}}$, which can be introduced in the dynamics of Eq. (2) to give:

$$\ddot{\tilde{d}} = -c\left|\tilde{d}\right|\dot{\tilde{d}} - \ddot{x}_l \qquad (3)$$

The previous equation may be analytically integrated and expressed backwards in terms of d_r as follows:

$$\begin{aligned} \dot{d}_r &= \frac{c}{2}\left(d_0 - d_r\right)^2 + \dot{x}_l(t) - \beta \\ \beta &= \dot{x}_{f_r}(0) + \frac{c}{2}\left(d_0 - d_r(0)\right)^2 \end{aligned} \qquad (4)$$

Note that this reference inter-distance depends upon the leading vehicle, distance d_0 and parameter c, which is, in turn, an algebraic function of safe and comfort parameters d_c , $V_{\max}$, $\gamma_{\max}$ and $J_{\max}$.

$$\begin{aligned} & d_0 = \sqrt{\left(\frac{16}{27}\right)\frac{V_{\max}^2}{\beta_{\max}}} + d_c \qquad c = \frac{27\beta_{\max}^2}{8V_{\max}^3} \\ & \left|\dddot{x}_f^r(t)\right| \leq \max\left\{\frac{27}{8}\frac{V_{\max}^2}{\beta_{\max}}, 2.6\frac{V_{\max}}{\beta_{\max}}\gamma\right\} \end{aligned} \qquad (5)$$

Finally, the feed-forward control law –or the follower acceleration- yields from Eq. 3:

$$\ddot{x}_{f_r} = u_r = -c\left|d_0 - d_r\right|\dot{d}_r \qquad (6)$$

where the inter-distance evolution comes from the numerical integration of Eq. 4.

III. FUZZY LOGIC CONTROLLER

This section proposes a fuzzy logic algorithm to control the host vehicle. The distance and the relative velocity between the host vehicle are the inputs of the fuzzy controller (see e.g [6],[7],[8]). The output variables are used for the control of the brake and velocity [9].

Figure (2, 3 and 4) show the normalized membership functions for fuzzification of the controller inputs and defuzzification of the controller output.

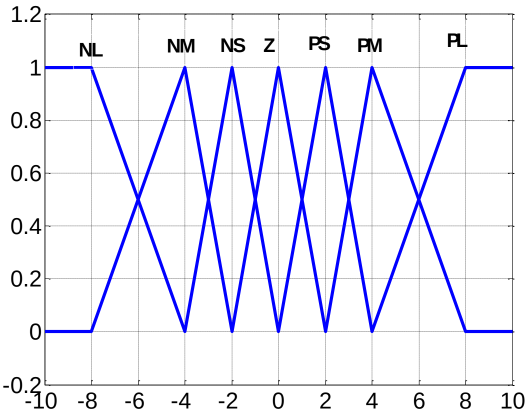

Fig. 2 Membership functions of distance error

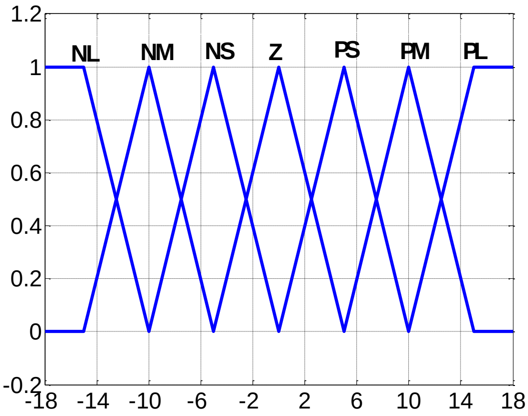

Fig. 3 Membership functions of relative velocity

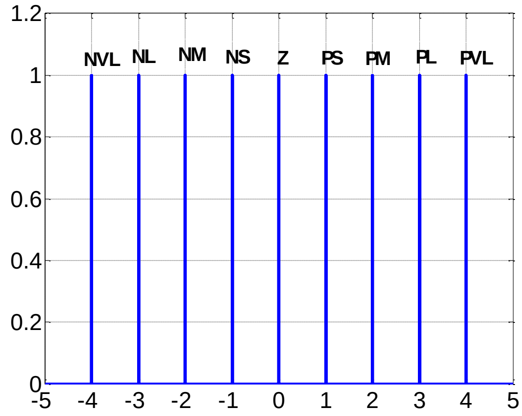

Fig. 4 Membership functions of output command

Each linguistic variable contains seven terms. The meanings of each input variable are as follows :

NL : negative large PS : positive small
NM: negative medium PM : positive medium
NS : negative small PL : positive large
Z : zero

The outputs are divided into two sides, the negative one which represents the braking command and the positive side which represents the velocity ratio command.

NVL : negative very large PS : positive small
NL : negative large PM : positive medium
NM : negative medium PL : positive large
NS : negative small PVL : positive very large
Z : zero

TABLE I. THE FUZZY RULE OF OUTPUT COMMAND

Output		**Distance Error**						
		NL	**N M**	**NS**	**Z**	**PS**	**PM**	**PL**
Relative Velocity	**NM**	NVL	NL	NM	NM	NS	NS	Z
	NS	NL	NM	NS	NS	NS	Z	Z
	Z	NM	NS	Z	NS	Z	PS	PS
	PS	NM	Z	Z	Z	Z	PM	PL
	PM	NS	Z	Z	PS	PM	PL	PVL
	PL	NS	Z	Z	PS	PL	PVL	PVL

IV. SIMULATION RESULTS

The leading and follower cars will be initially running at different speed, $\dot{x}_l(0) = 9m/s$ and $\dot{x}_f(0) = 0m/s$. Besides, the inter-distance dynamic model is parameterized to provide a maximum speed $V_{\max} = 30m/s^2$, a maximum acceleration $B_{\max} = 8m/s^2$ and a minimum inter-distance $d_c = 5m$.

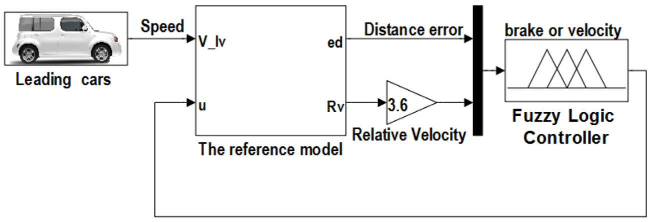

Fig. 5 The simulation model in Matlab

a A Car-following with a change in the leading vehicle velocity (Fig .6 to 9) :

When the follower vehicle comes near to the leading vehicle, the velocity is adapted with comfortable deceleration and the reference vehicle is positioned at a safe distance.

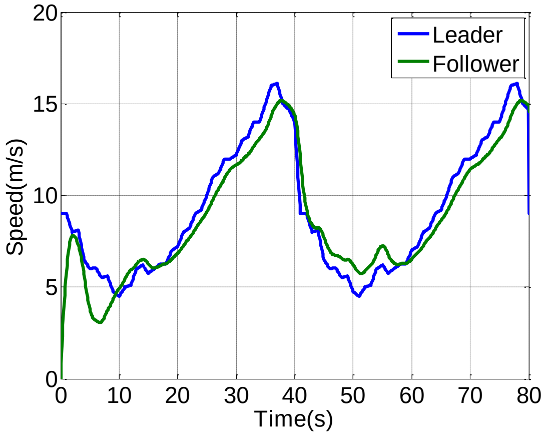

Fig. 6 Velocities for leading and follower cars

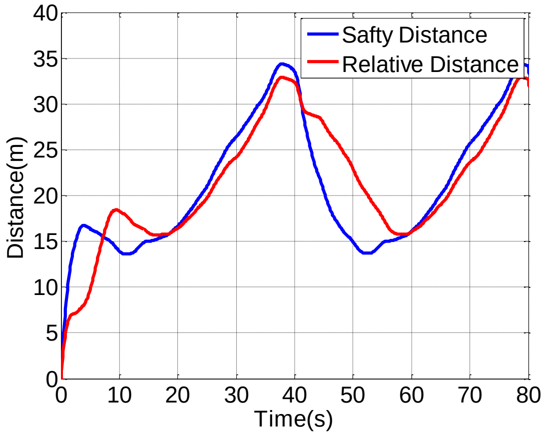

Fig. 7 Safety distance, Relative distance

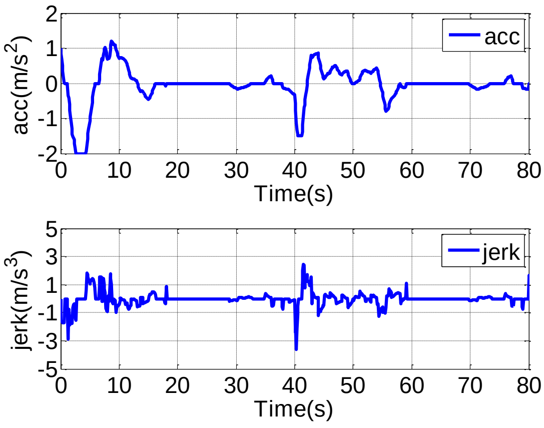

Fig.8 Accelerations and Jerk for follower car

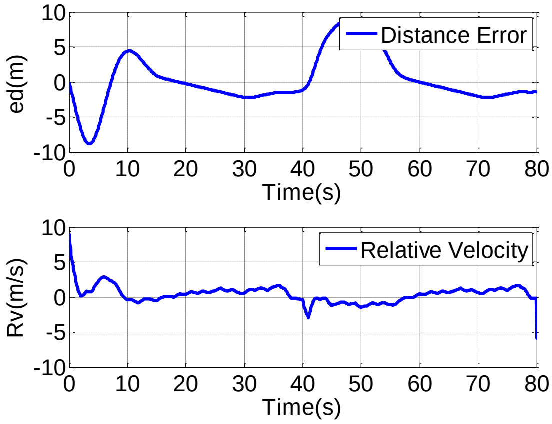

Fig. 9 Distance error and Relative velocity

b. A Stop-and-go scenario (Fig 10 to 13)

At (20s,40s) and (70s,80s) the leading vehicle is accelerated and decelerated (stop-and-go) and the following vehicle is maintained to a safe distance and with bounded jerk .

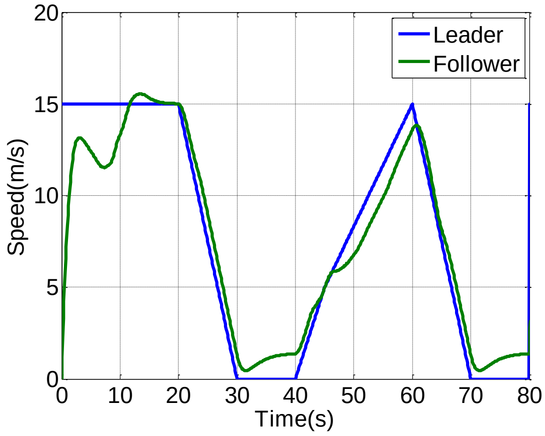

Fig. 10 Velocities for leading and follower cars

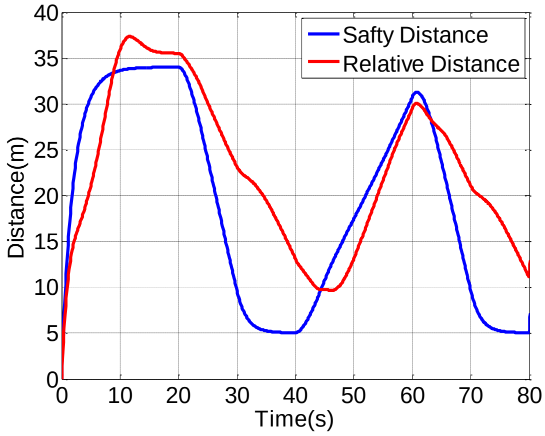

Fig. 11 Safety distance, Relative distance

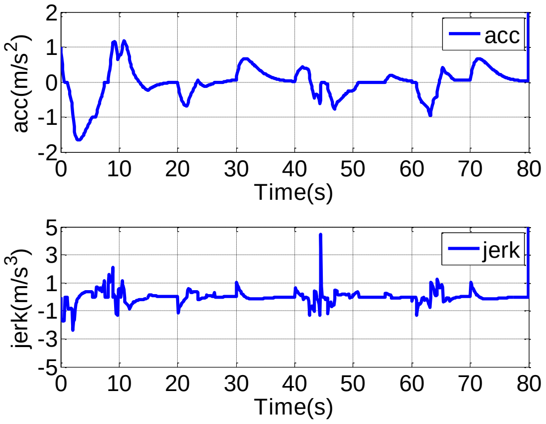

Fig. 12 Accelerations and Jerk for follower car

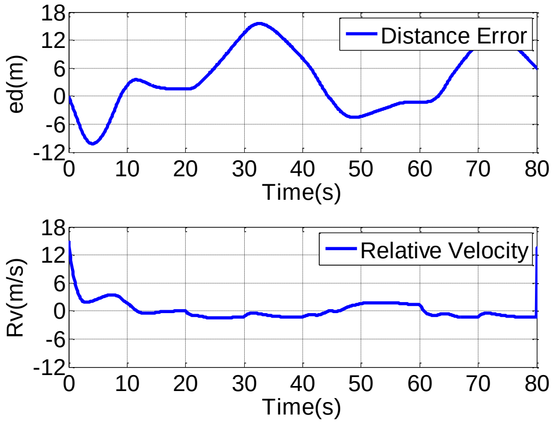

Fig. 13 Distance error and Relative velocity

c. A Car-following with Hard stop scenario (Fig 14 to 17) :

At t = 30s the leading vehicle stops with a high braking value while the follower vehicle comes to a complete stop before the critical distance $d_c = 5m$ with lower braking.

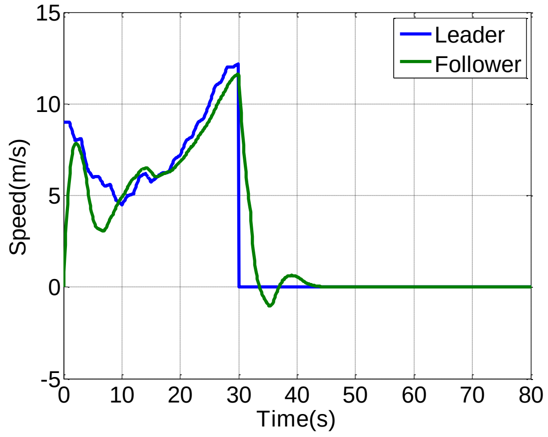

Fig. 14 Velocities for leading and follower cars

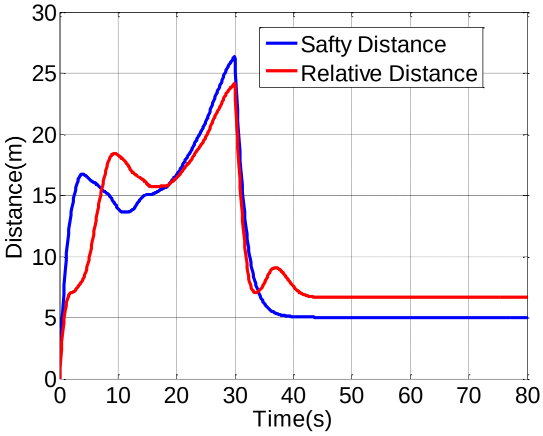

Fig. 15 Safety distance, Relative distance

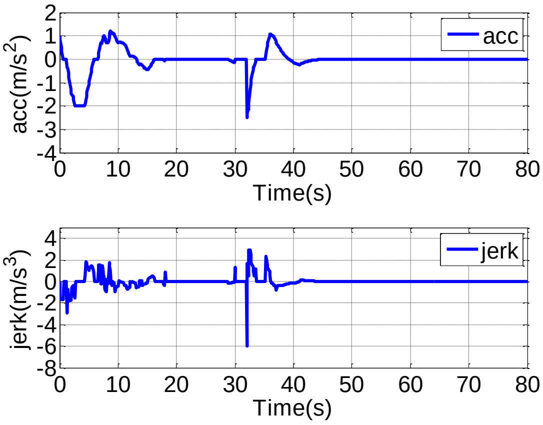

Fig. 16 Accelerations and Jerk for follower car

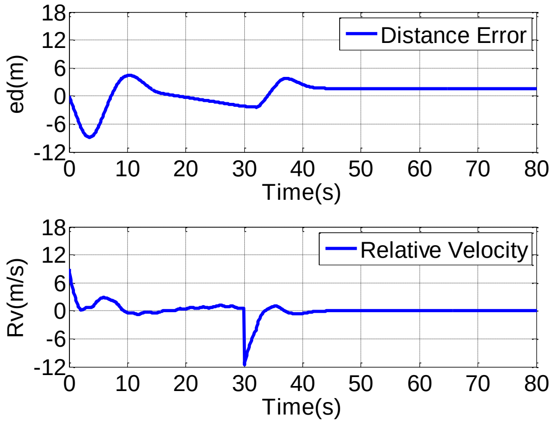

Fig. 17 Distance error and Relative velocity

d. CONCLUSION

In this paper, a reference model based control approach for longitudinal control for a vehicle has been presented. The proposed structure combines a reference model in which the former will be to verify the safety and comfort constraints, while the latter will be in charge of the model-tracking.

In this paper, the distance controller uses fuzzy algorithm in which the inputs are the distance and relative velocity whereas the outputs from the controller are separated into two groups. The first one is the command to accelerate the vehicle and the other output is the command to decelerate the vehicle in case of braking command.

The simulation results included in this paper show that the system which is developed for the AIT intelligent vehicle is able not only to control the vehicle to run at a desired velocity when operated in velocity control mode but also maintain efficiently the distance between the host vehicle and the obstacle vehicle.

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