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Fuzzy control of anticipation and evaluation behaviour in real traffic flow

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***Abstract*—Through recent studies, effects of lane change on the car following models have been relatively less studied. This effect is a transient state in car following behaviour during which the Follower Vehicle (FV) considerably deviates from conventional car following models for a limited time. This paper aims to control the behaviour of FV during exiting of Lane Changer (LC) according to the anticipation and evaluation behaviour. According to the latent nature of human driving decisions, data of real drivers is used to design a fuzzy controller for the behaviour vehicle route guidance. Exact inputs are employed to achieve accurate output which is the acceleration of FV. The method is evaluated via simulation experiments, and data of real drivers, which allows to demonstrate the effectiveness of the developed methodology and to highlight the improvement in comfortable drive, safety, and homogenous traffic flow with shorter traffic queues.**

***Index Terms*—anticipation and evaluation behaviour, fuzzy controller, car following behaviour, lane changing behaviour.**

I. INTRODUCTION

Among the traffic flow modellings [1], the car following models are increasingly being used to evaluate new Intelligent Transport System (ITS) applications. These models aim to describe the longitudinal movement of a driver following other vehicles and trying to maintain a safe distance to the Leading Vehicle (LV) [2]. One of the substantial restitution of temporary car following models is of these models to anticipation and evaluation as transient states. The FV diverges from usual car following models to accommodate the LC throughout evaluation and anticipation [3], [4]. These two subjects happen before and after the lane change maneuver for FV. Furthermore, LC informs FV about intention in changing lanes by signalling before lane changing maneuver. Hence, FV reacts to LC by decelerating the relative distance to get ready for lane change maneuver. This behaviour which is started earlier than lane change maneuver is called anticipation. According to Fig. 1, the FV suddenly faces a huge spacing with LV when the LC exits the target lane. It is time

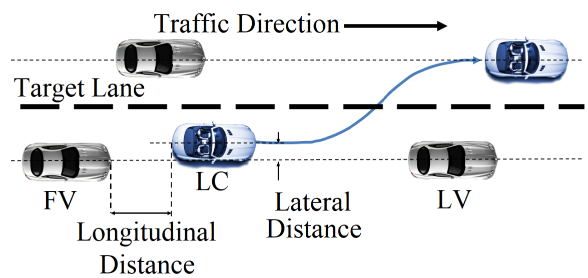

Fig. 1: Anticipation and evaluation maneuver [7].

consuming for the driver to set desired distance for the current speed [5]. This state begins with the response of FV is called evaluation [6]. Evaluation is a non-linear behaviour throughout the time of which FV does not follow common car following models. Therefore, this state should be studied individually. In sum, anticipation and evaluation behaviour of FV are actually transient states between two car following maneuvers. They also occur due to the lane changing of LC. Despite of the significant effect of this temporary state on behaviour of the FV, anticipation and evaluation have not been characterized yet. Thus, this paper studies the behaviour of FV in case, LC exits the target lane. The rest of paper is structured as follows: Section II provides the literature review on anticipation and evaluation behaviour. Design of intelligent controller based on fuzzy solution and its performances are explored in section III. Section IV offers discussion of findings. Finally, conclusions are discussed in section V.

II. LITERATURE REVIEW

A. A brief review of studies on anticipation and evaluation behaviour

Firstly, smith [8] presented, in a lane changing maneuver the behaviour of FV is affected for the first 20 or 30 seconds after lane changing. In addition, other papers reported the

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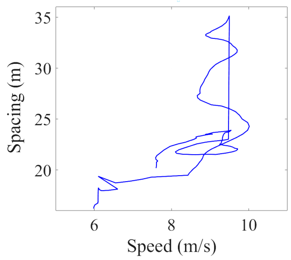
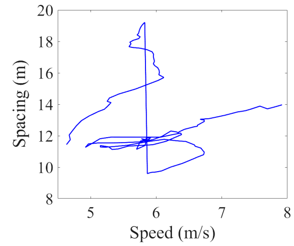


(a)



(b)

Fig. 2: Spacing-speed relation during car following maneuver. (a) Test vehicle one, (b)Test vehicle two.

duration of relaxation state with the average time of 15 seconds ([8], [9]). The LL (Lava and Leclercq) model, which captures evaluation state for LCs by employing macroscopic theory of lane change maneuver was defined with Lava and Leclercq [10] using extension of Newell theory [11] validated experimentally. Afterwards, Leclercq et al. [12] proved the results of LL model microscopically. Duret et al. [9] employed passing rate to explore both anticipation and relaxation behaviour for the FV, which drives in the target lane. Anticipation is described by a deviation from immediate car following models before lane change maneuver to adapt with the LC ahead [13]. According to this report, Duret's model of relaxation behaviour can be used to represent anticipation and relaxation phenomenon with desirable accuracy. Recently, Ghaffari, et al. [14] studies behaviour of FV introducing relaxation behaviour, using human factors, while LV is entering the FV's lane. But, behaviour of FV in presence of exiting LV is missed, investigated as follow.

B. Anticipation and evaluation behaviour

Anticipation and evaluation behaviour are inherently complex behaviours, which make it difficult to define inception, and ending of the behaviour. Zuduo et al. [13] specified the inception of anticipation and the end point of transient state using the simplified Newell car following theory which declares that the time–space trajectory of FV is similar to that of the preceding trajectory vehicle, except for shifts in time and space [11]. In the paper, space is denoted as relative longitudinal distance between FV, and its front vehicle. To evaluate the hypothesis of linearity between spacing and speed of FV in real traffic flow, these trajectories for two test vehicles are depicted in Fig. 2, using the data-set introduced in [15]. According to this figure, the spacing-speed trajectory during departure of LC is not linear. Thus, Zuduo's method of determining the inception of anticipation and the end point of evaluation behaviour is not applicable for this traffic data, and a new approach should be superseded. Addressing the inherent non-linearity in behaviour of human drivers, determining the precise time at which drivers decide to execute a maneuver, is considerably sophisticated. Based on the behaviour of drivers in real traffic flow, Ghaffari, et al. [7] presented an innovative method to determine the inception of anticipation and end point of evaluation behaviour. Determination of the beginning and ending point of anticipation and evaluation for a test vehicle, based on the mentioned criteria, is summarized in Fig. 3. According to Fig. 3(a), the attack signal from LC as a stimulation for the start point of anticipation of FV is specified. The attack happens when the lateral velocity of any vehicle exceeds 0.05 m/s [7]. Therefore, FV responds to this stimulation signal by not following the acceleration of its leader. The time at which total acceleration of the FV becomes zero for the first time after attack is assumed as the inception of anticipation, shown in Fig. 3(b). Fig. 3(c) shows the start point of evaluation state during which the relative lateral distance of the two vehicles (FV, and LC) excesses y_{safe} after the anticipation state [7]. In real driving maneuver and during lane changing, FV keeps a safe lateral distance with LC to observe the behaviour of both LV and LC at the same time to ensure accuracy of anticipation and prevent collision with LC. This safe lateral distance is named as y_{safe} [7] and described as following.

$$y_{safe} = -0.2716\, e^{Distance} + 0.0116\, sin\,(V_{ave}) + 0.1585\, sin\,(a_{LC} - a_{FV})\,, \quad (1)$$

The ending point of evaluation, as depicted in Fig. 3(d), is the time at which longitudinal distance between FV and LV decreases to the value of modified pipe's law. Although anticipation behaviour does not have a definite ending point because follower constantly predicts the behaviour of LC before lane change and LV after lane change, the end point of anticipation is assumed as the time which lane change maneuver is completely done. At the end, comparison of acceleration between LC and FV is shown in Fig. 3(e). The idea of controlling anticipation and evaluation behaviour is motivated to help the driver to come over the complicated transient state, which is the main objective of this paper, and discussed in section III.

III. Fuzzy controller

There is uncertainty and human logic in control [16]–[18] of vehicle as well as the non-linear nature of traffic flow, the use of new tools and capabilities to be the cause. Among these tools, intelligent control is designed based on soft computing techniques such as fuzzy logic and Neural Network [19], [20]. Hence, a fuzzy controller is used to control the anticipation and evaluation behaviour [21], [22]. To design a FIS controller, a data-set includes anticipation and evaluation behaviour is substantial. 44 data-sets consist anticipation and evaluation behaviour, introduced in [7], are employed to train and test the controller. As sake of validation data-set, second data subset, is not employed in the development of the controller. This data-set is applied to assess the performance of the trained controller. In this paper, 75% of the master data-set (33 data-sets of anticipation and evaluation maneuver) was used for training purposes, and the remaining 25% (11 datasets of anticipation and evaluation maneuver) was set aside for controller validation.

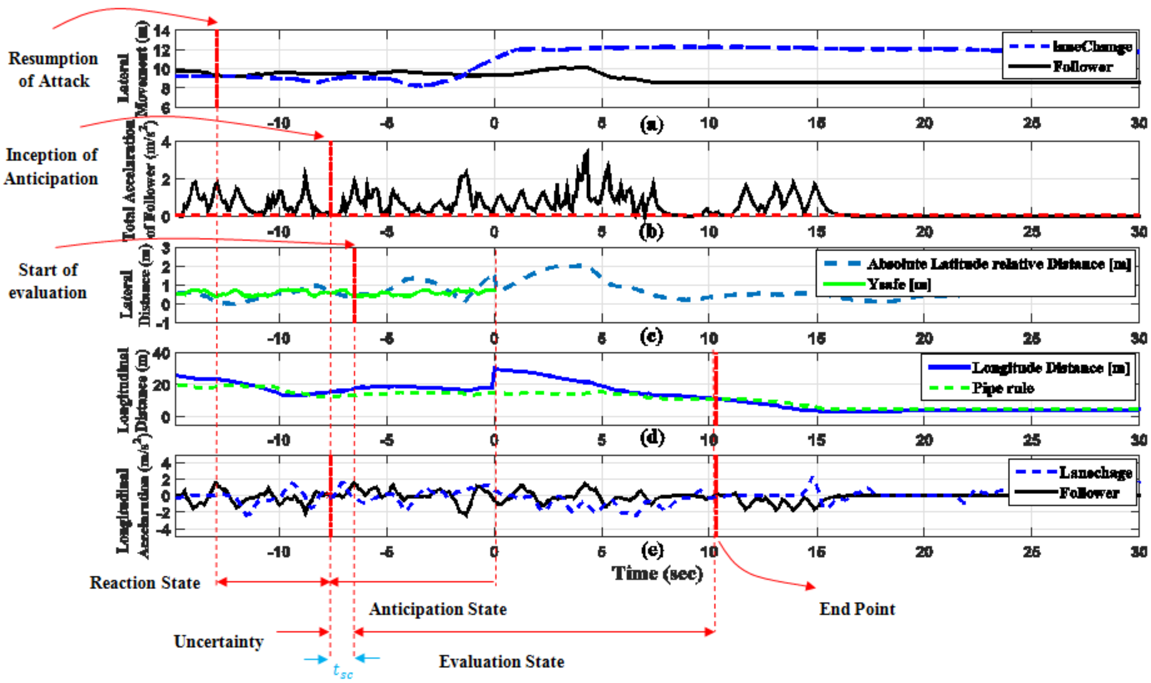


Fig. 3: Hierarchy of determining anticipation and evaluation state [7].

The main purpose of controlling is steering the FV in the desired direction which is similar to the selection of a human driver. Due to this purpose, the first step in designing fuzzy controller is determining the exact inputs and outputs for the controller. In general, acceleration is the only parameter which can be directly affected using changing the gas pedal or brake. As the FV has mainly longitudinal movement, the control system can modify the variable to get the car in the desired direction. The control inputs of the factors that influence the behaviour anticipation and evaluation will be determined during the actual driver behaviour. In fact, with regard to the real drivers and also check the results of various parameters, the most appropriate inputs to the controller are selected. According to the results, relative lateral distance of FV with front vehicle, relative velocity of FV with front vehicle and velocity of FV are measurable inputs of controller and duration of uncertainty state is intended as an unmeasurable input to the controller as shown in Fig. 4. The last input which is called t_{sc} indicates the degree of wariness and environmental conditions for drivers [7]. The longer t_{sc} takes, the more careful the driver is, i.e. the vehicles respond earlier to the exiting vehicle and gradually relax to more spacing. Hence, t_{sc} is added as an input to the aforementioned controller to investigate the effects of human driving behaviour on the anticipation and evaluation states. To determine the usefulness of t_{sc} on performance of controller a second controller is designed in a same way but without t_{sc}. The inputs and output of the first fuzzy controller is shown in Fig. 4. After reviewing the performance of the controllers with different membership functions, three Gaussian membership functions for each input are used. In Fig. 5(a) the membership functions for velocity

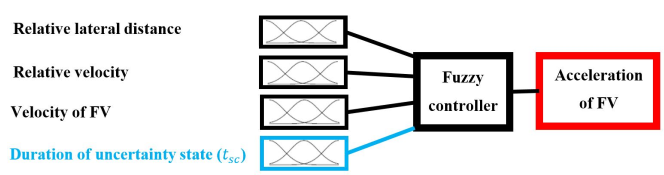


Fig. 4: Structure of fuzzy controller for anticipation and evaluation behaviour.

of FV is shown. In drawing this inference, Takagy- Sugeno controller is used. Fuzzy control rules are selected based on two criteria. The control system aims to replicate behaviour of real driver to an acceptable level. It also guarantees safer and more comfortable drive for passengers. Subject to these two points, the controller obtained 81 fuzzy rules. Some of the rules are shown in Fig. 5(b), in which the design of the center area is used as defuzzification-maker. In Fig. 6 the level of control achieved by the acceleration of FV as output of the system is shown. As shown in this figure, the flatness levels achieved steady, represents the perfect design phase relationships.

IV. Experimental results

To investigate the usefulness of fuzzy controllers, their function within a closed-loop system is checked. This control system is shown in Fig. 7. In this closed-loop system, a_{FV}, V_{FV} and X_{FV} are respectively acceleration, velocity and position of FV. As shown in the figure, the duration of the uncertainty state, relative position and relative velocity of LC are imported as inputs of the first controller and a

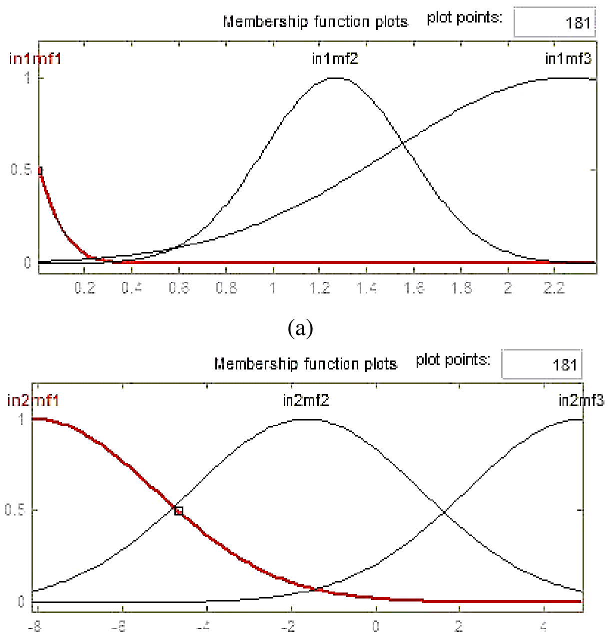


Fig. 5: Gaussian membership function, (a) Distance, (b) Velocity of FV.

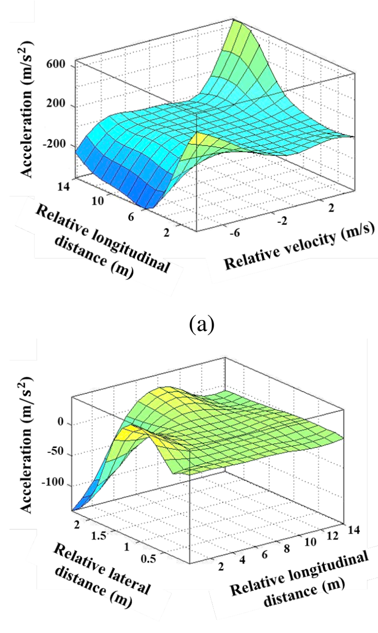


Fig. 6: Fuzzy surfaces for the fuzzy controller, (a) Acceleration of controller as output, based on relative longitudinal distance, and relative velocity, (b) Acceleration of controller as output, based on relative lateral distance, and relative longitudinal distance.

second controller is designed without t_{sc}. This data, and the data produced with feedback of control system, generate the inputs of fuzzy controller. In the system, t_{sc} is estimated online according to an estimator which can express t_{sc} due to dynamical features and condition of traffic flow. The controller sets correct control signals on the system using the inputs in the anticipation and evaluation behaviour. According to the structure of control system, shown in the Fig. 8, t_{sc} is estimated based on velocity and position of FV and LC which is one of the inputs of fuzzy controller. As mentioned before, a closed-loop control system is used to study performance of the controller and to simulate the FV with a linear model. This has been shown in Fig. 9. Input of the system is acceleration of FV. Thus, traveled distance of FV is obtained with double integration of acceleration according to the state space which indicated in (1) [23]. In this equation, x_1 is velocity of FV, x_2 is position of FV and u_1 is acceleration of FV.

$$\begin{cases} \begin{bmatrix} \dot{x_1} \\ \dot{x_2} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 1 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u \\ y = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \end{cases} \tag{2}$$

The main objective of this paper is designing a controller which refines acceleration and velocity of FV in a way that replicates the real driver performance to guarantee safe and comfort for the passengers. Thus, not only must the controller produce the real driver's position path, but also have smoother trajectories of velocity and acceleration to prevent sudden movement of vehicle. In what follows, the mentioned

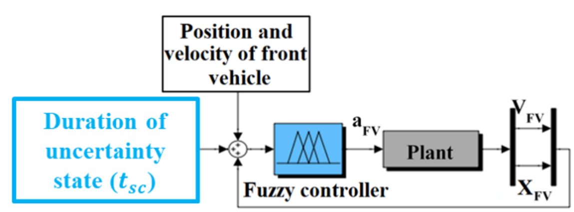


Fig. 7: Control diagram for anticipation and evaluation behaviour.

goals will study separately. The first purpose of controller is replicating a path direction as same as a real driver during the behaviour. To study the first goal, the path trajectory of the two controllers is drawn in Fig. 10, in comparison with real drivers. According to this figure, the performance of both controllers are approximately similar to real drivers. The second goal is control of velocity and acceleration of the FV. Fig. 11 indicates a comparison between velocity of controllers and real driver: therefore, it can be inferred that velocity of controllers are smoother than the real driver. In addition the claim is validated by calculating variance of the velocity data for the controllers and real driver. According to the Table I, variance of velocity data for controllers is less than the driver's data and it endorses the smoother drive of the controllers in comparison with real driver. Smoother velocity trajectory results in less fuel consumption and more comfort for passengers.

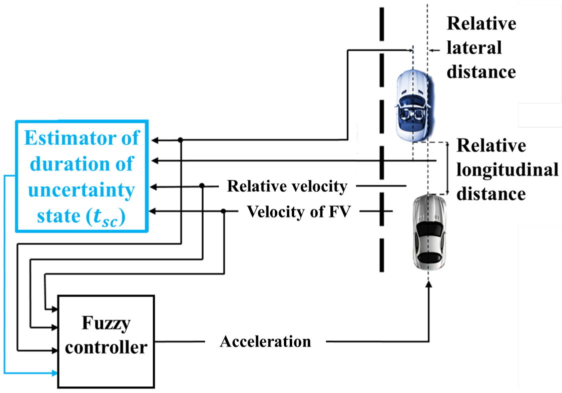


Fig. 8: Structure of closed-loop system.

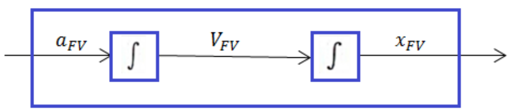


Fig. 9: Model of FV.

Another profound purpose of the paper is quality of acceleration which is expected to be smoother in comparison with real driver. To validate the goal, the acceleration of both controllers and real driver are drawn in Fig .12. According to this figure, the generated acceleration of controllers is not only in range of real driver's acceleration but also is smoother than driver based on Table I. In the table, variance of the data of acceleration shows that both controllers have less dispersion than real driver. Thus, the controllers guarantee more comfort of ride for passengers with less movements. As a result, the performance of both controllers is more desirable than real driver. To compare the output of controllers with each other, pipe's law is used to express which controller is faster due to

TABLE I: Results of calculated variance of velocity and acceleration of FV

	Velocity $\frac{m}{s}$	Acceleration $\frac{m}{s^2}$
Controller with t_{sc}	0.3049	0.3099
Controller without t_{sc}	0.6705	0.0621
Real driver	1.6262	0.6705

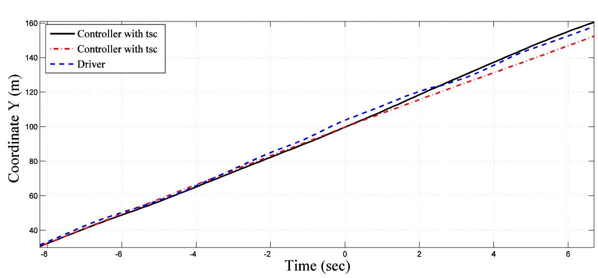


Fig. 10: Current position performances of controllers and real driver.

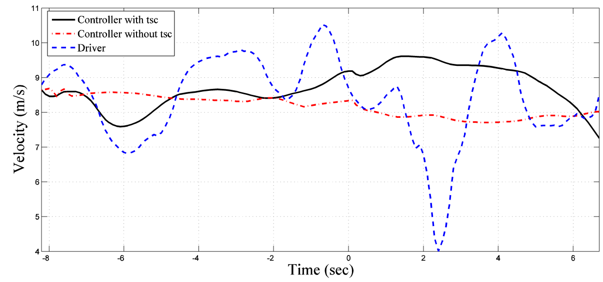


Fig. 11: Velocity performances of controllers and real driver.

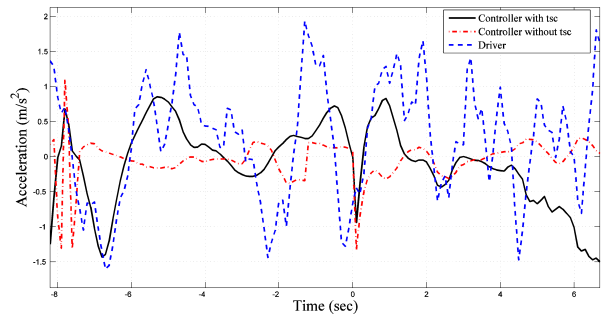


Fig. 12: Acceleration performances of controllers and real driver.

being safer than real driver. As a matter of fact, pipe's law or modified pipe's law [7] suggests an online safe longitudinal distance to drivers and how close to this criteria indicates suitable drive. In what follows, the longitudinal distance of controllers and real drivers, pipe's law and modified pipe's law are drawn in Fig. 13. Based on the figure, the controller trained with t_{sc} has closest distance to modified pipe's law and it can be inferred, this controller not only makes safer and more comfortable drive based on the variance data of velocity and acceleration, but also reduces traffic queues fuel consumption, and time of travel. To clarify the selection of the controller trained with t_{sc} as the best controller, online error of longitudinal distance for driver and every controller and driver with modified pipe's law are mapped in Fig. 14. As shown in this figure, the fuzzy controller which designed with t_{sc} has less errors with the modified Pipe's law.

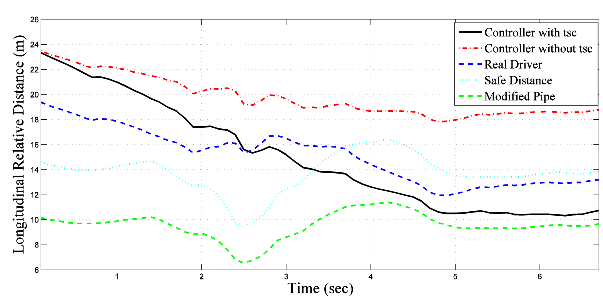


Fig. 13: Comparison of relative longitudinal distance performances of controllers and real drier with safe distance criteria.

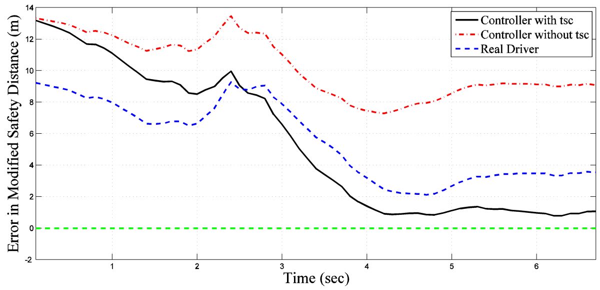


Fig. 14: Error of relative longitudinal distance performances of controllers and real driver with safe distance criterion.

V. Conclusion

Two temporary states in car following maneuver which happen due to the lane change of FV are Anticipation and evaluation. Although many studies have been carried out on driving behaviours, analysis of anticipation and evaluation behaviour have relatively been neglected because of the latent and complex nature of these transient states. This paper aims to control the behaviour of FV during exiting of LC, according to the anticipation and evaluation behaviour. Based on, latent nature of human driving decisions, data of real drivers of NGSim data-sets is used to design a fuzzy controller for the behaviour. To validate the fuzzy controller, the actual driver behaviour is compared with fuzzy controller performance. Results show the intelligent controller recommends safer longitudinal distance and more comfortable drive than real drivers. It also aims to homogenous traffic flow with shorter traffic queues. We are currently investigating stability properties of the controller and feasibility of the controller in real environment, as well as producing further experiments through a test-bed to investigate robustness to parameter choices, which are going to appear in a future publication.

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