A New Model of Car Following Behavior Based on Lane Change Effects using Anticipation and Evaluation Idea

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This paper aims to investigate a new and intricate behavior of immediate follower during the lane change of leader vehicle. Accordingly, the mentioned situation is a tran[**]sient state in car following behavior during which the follower vehicle considerably deviates from conventional car following models for a limited time, which is a complex state including lateral and longitudinal movement simultaneously. Based on closer inspection of microstructure behavior of real drivers, this transient state is divided into two stages of anticipation and evaluation. Afterwards, a novel adaptive neuro-fuzzy model considering human driving factors is proposed to simulate the behavior of real drivers. Comparison of model results and real traffic data shows that the proposed model can describe anticipation and evaluation behavior during a car following behavior with acceptable errors which leads to enhancement of car following applications like driving assistant and collision avoidance systems.

Keywords: evaluation; car following; intelligent model; ANFIS; human driving factors

1 Introduction

Nowadays, intelligent transportation systems (ITS) plays an important role in transportation industry. The prominent aspect of these systems is their ability to increase safety and improve the traffic flow [1-2]. ITS achieves these goals by incorporating up-to-date information technologies of all kinds in the transportation field [3].

Among the microscopic traffic flow modeling, car following models are increasingly being used to evaluate new intelligent transport system 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 [1].

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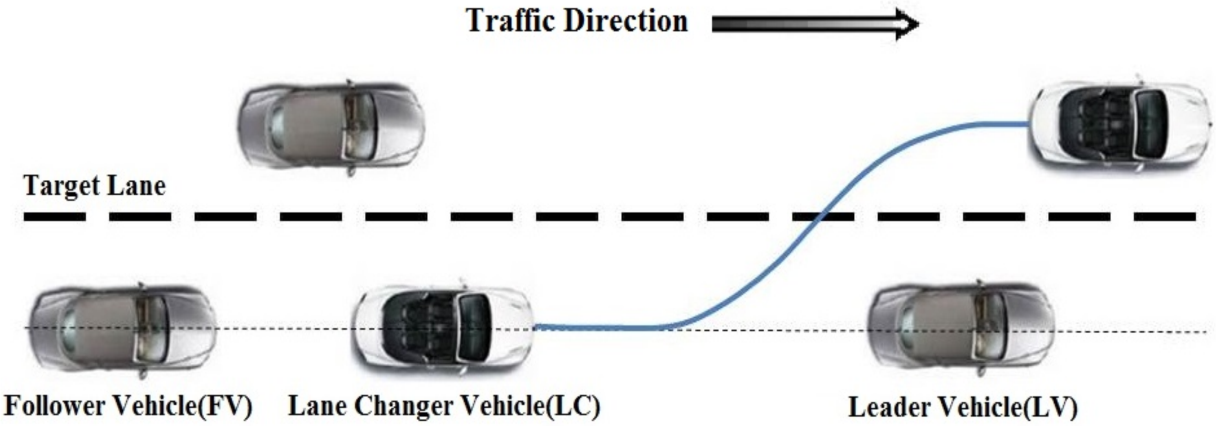


Figure 1 Anticipation and evaluation maneuver.

Lane change behavior suggests the vehicle is adjacent to the next line so that in addition to the latitudinal, longitudinal movement of vehicles also affects their behavior.

An important problem of current car following models is that they do not capture anticipation and evaluation behavior. The anticipation and evaluation are two transient states which occur before and after lane change maneuver for following vehicle [4].

According to figure (1), when lane changer (LC) exits the target lane, the follower vehicle (FV) unexpectedly has a huge spacing and it may takes several seconds for this driver to adjust to his/her desired spacing for the given speed [5]. This transient state is called evaluation which is really nonlinear behavior that does not imitate common car following models. During evaluation, the observed behavior of follower deviates from common car following models and should be investigated separately. In addition, before lane change maneuver, follower informs lane changer about his/her plan in changing lanes rather by signaling. Hence, follower responds to lane changer by decelerating the relative distance to become ready for lane change maneuver. This behavior, which occurs before lane change maneuver, is called anticipation.

Over all, as mentioned before, anticipation and evaluation behavior for follower is a transient state between two cars following maneuvers that happen due to the lane change of new leader. In spite of its vital importance, the anticipation and evaluation has not been meticulously investigated yet when lane changer exits the target. Therefore, it is chosen as the object behavior in this study and novel adaptive neuro-fuzzy inference models are proposed for this behavior. The rest of the paper is organized as follows: Section II summarizes literature review on anticipation and evaluation behavior. Design of intelligent model based on ANFIS is presented in section III. Section IV offers discussion of findings. Eventually conclusions are discussed in section V.

2 A brief review of studies on anticipation and evaluation behavior

Previously equation-based models were used to simulate human's driving behavior that their parameters were determined with the average amount of real experimental data. While these parameters depend on many factors, such as driver, vehicle, path of driving and obviously time. As a matter of fact, results of these models are reliable just in domain of laboratory. Thus in our modeling, the parameters will be variable instead of being constant [6]. Going on, some papers about driving behavior will be discussed briefly.

Smith [7] first reported that vehicles involved in a lane change maneuver accept short spacing during the first 20 or 30 seconds, gradually attaining more desirable spacing. Other reports corroborated the evaluation phenomenon with the average time of 15 seconds [7], [8] and [9]. Laval and Leclercq [10] proposed a microscopic framework (the LL model hereafter) based on extension of Newell simplified car following theory [11]. The LL model captures the evaluation phenomenon for the LCs by using macroscopic theory of lane change maneuver. Empirical data was used to verify this model. Afterwards, Leclercq et al. [8] corroborated the results of LL model microscopically.

Since the parameters of LL model were not easy to calibrate, Duret et al. reformulated the LL model by using passing rate. Passing rate is the rate at which the flow passes through the kinematic wave. This variable is continuous in time and space and can be easily measured from trajectory data [9]. Duret analyzed this model for both LC and immediate follower after the lane change maneuver. Calibration results based on vehicle trajectories from NGSIM dataset indicated that the revised evaluation model was acceptably consistent with real traffic data. Zuduo et al. used passing rate to study both anticipation and evaluation phenomena for immediate follower in the target lane.

Anticipation is characterized by a deviation from common car following models before lane change maneuver to accommodate the LC ahead [12]. This report declared that Duret’s model of evaluation phenomenon can be extended to represent both anticipation and evaluation behavior with acceptable accuracy. According to the literature review, all of the proposed models for anticipation and evaluation behavior are equation based models. These models are explained based on choosing appropriate variables and parameters. As these parameters are obtained by the average of experiment values, results of these models are only matched to the test cases and are not reliable [13]. System modeling based on mathematical equations is not well suited for dealing with ill-defined and uncertain systems [14]. Input-output models, on the contrary, are trained based on real traffic data and can capture the highly nonlinear nature of driving behaviors thoroughly. Intelligent algorithms, as an input-output approach, can deal with structural and parametric uncertainties in the anticipation and evaluation behavior. One of the powerful intelligent methods, FIS, is used in this paper. A FIS employing fuzzy if-then rules can model the qualitative aspects of human knowledge and reasoning processes without employing precise quantitative analyses [14].

Accordingly, Kazemi [15] proposed an Evolving Local Linear Neuro-Fuzzy Model for modeling and identification of nonlinear time-variant systems which change their nature and character over time. The evolution process is managed by a distance-based extended hierarchical binary tree algorithm including normal car-following behavior, velocities close to zero, and full stop due to heavy traffic congestions. Furthermore, Asaithambi [16] focused on evaluation of different vehicle-following models under mixed traffic conditions. The car-following models such as Gipps, Intelligent Driver Model (IDM), Krauss Model and Das and Asundi were selected for this study. The results showed the promise of some measures based on vehicle class, namely, the exclusion of auto rickshaws or auto rickshaws and heavy vehicles. Although, the previous studies have studied designed carfollowing behavior, none of them explored carfollowing behavior by presence of exiting of LC. Thus, this paper focuses on designing an innovative model for FV based on anticipation and evaluation states.

3 Design a new anfis model for follower vehicle behavior

3.1 An innovative method for determination of anticipation and evaluation behavior

Anticipation and evaluation behavior are inherently complex behavior which should be fully investigated to design a comprehensive input– output model.

Accordingly, the start point of anticipation and the end point of evaluation should be determined. This novel method is based on human driving behavior which is discussed in the following section. Zuduo et al. [12] used the Newell [11] simplified car-following theory to specify the start point of anticipation and the end point of evaluation. Based on the Newell theory, in congested traffic on a homogeneous highway, the time–space trajectory of the FV is similar to that of the preceding trajectory vehicle, except for shifts in time and space.

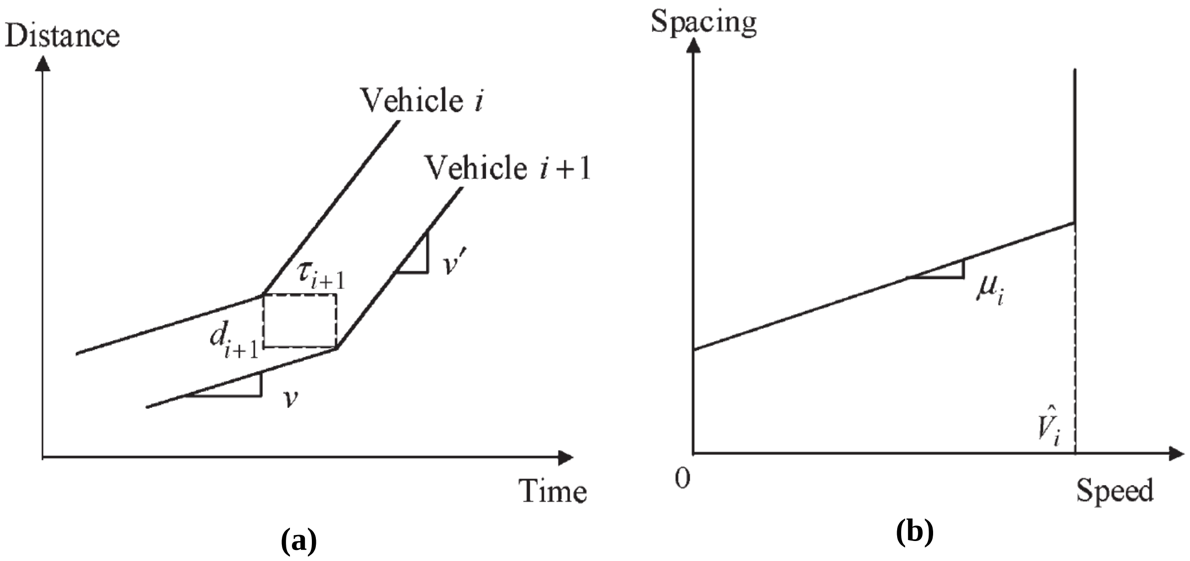
Suppose that vehicle $i+1$ is following vehicle i in congested traffic on a homogeneous highway, as shown in figure (2-a). First, vehicle i travels at speed v and then accelerates to v'. According to the Newell theory, the FV also travels at v until the spacing between this vehicle and the leader becomes sufficiently large to accelerate to v', which causes a time shift τ_{i+1} and a space shift d_{i+1}.

Zuduo et al. specified the start point of anticipation by intersecting the theoretical trajectory of the FV from the Newell theory with its actual trajectory before changing lanes. In the same way, the end point of evaluation behavior is obtained by intersection of the theoretical and actual trajectories of the FV after the lane-changing maneuver.

This specification is based on the hypothesis that the spacing–speed relation for a given vehicle is linear during a car-following maneuver, as shown in figure (2-b), but that the anticipation and evaluation phenomena cause the FV to deviate from the theoretical trajectory of the Newell model. In this figure, μ_i is the slope of the linear curve and $\hat{V}_i$ is the speed at which the FV ceases car following. To evaluate this hypothesis, the spacing–speed relations for two test vehicles of real data are depicted in figure (3).

According to this figure, the spacing–speed relation during a car-following maneuver is not exactly linear. Therefore, an innovative method for determination of the start point of anticipation behavior and the end point of evaluation behavior seems necessary, and this is proposed hereafter.

Generally, because of the latent nature of human driving decisions, determination of the exact time at which anticipation behavior starts or evaluation behavior ends is very complicated. In this paper, a novel idea for determination of the start point of anticipation and the end point of evaluation is proposed by considering the behaviors of real drivers during these phenomena.



(a) (b)

Figure 2 Illustration of Newell's car following theory [8]: (a) Linear approximation to vehicle trajectories. (b) Linear relation between spacing and speed for an individual vehicle.

In this paper, the data of relative acceleration of FV with LC and relative distance of FV with its front vehicle are used to determine the inception of anticipation behavior. This means that at the moment before the happening of lane change, the relative distance between FV and LC vehicle is going to be increased and the increase happens when the amplitude and frequency of relative acceleration between FV and LC vehicle are intensified. This state is determined as the inception of anticipation behavior. According to figure (4), that the confines of the desire behavior is marked with two purple lines, the relative distance started to be increased about 2.5 seconds before completing the action of lane changing. This shows that the follower is predicting the action of lane change. In addition, the end of the reaction state has been considered for a moment that the FV mimics the velocity of LV instead of LC (17th second), and relative distance between FV and LV is adapted with Pipe's law [22] as in Eq. (1).

$$S = L\left(1+\frac{V_{FL}}{4.47}\right) \tag{1}$$

Where L is length of the vehicle,$V_{FL}$is velocity of follower and S is safe distance.When the LC exits the target lane, the spacing between the Leader and the FV is quite large. Based on this solution, when the spacing between the LC and the FV intersects with the Pipes law, this time is considered as the end point of evaluation.

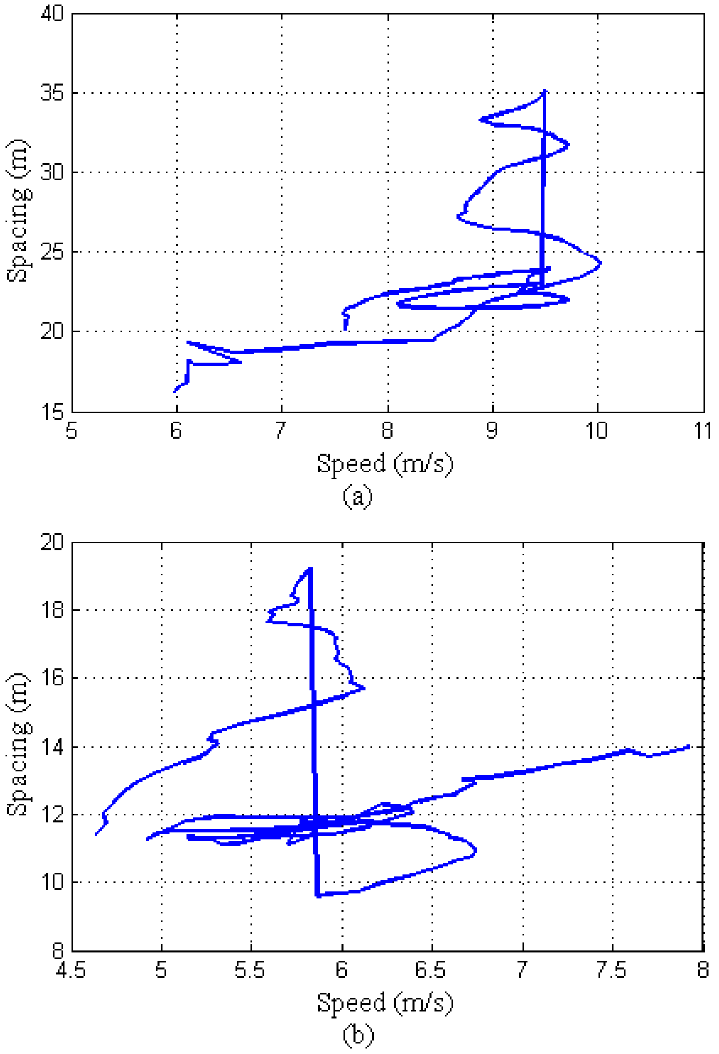


Figure 3 Spacing-speed relation during car following maneuver: (a) First test FV. (b) Second test FV.

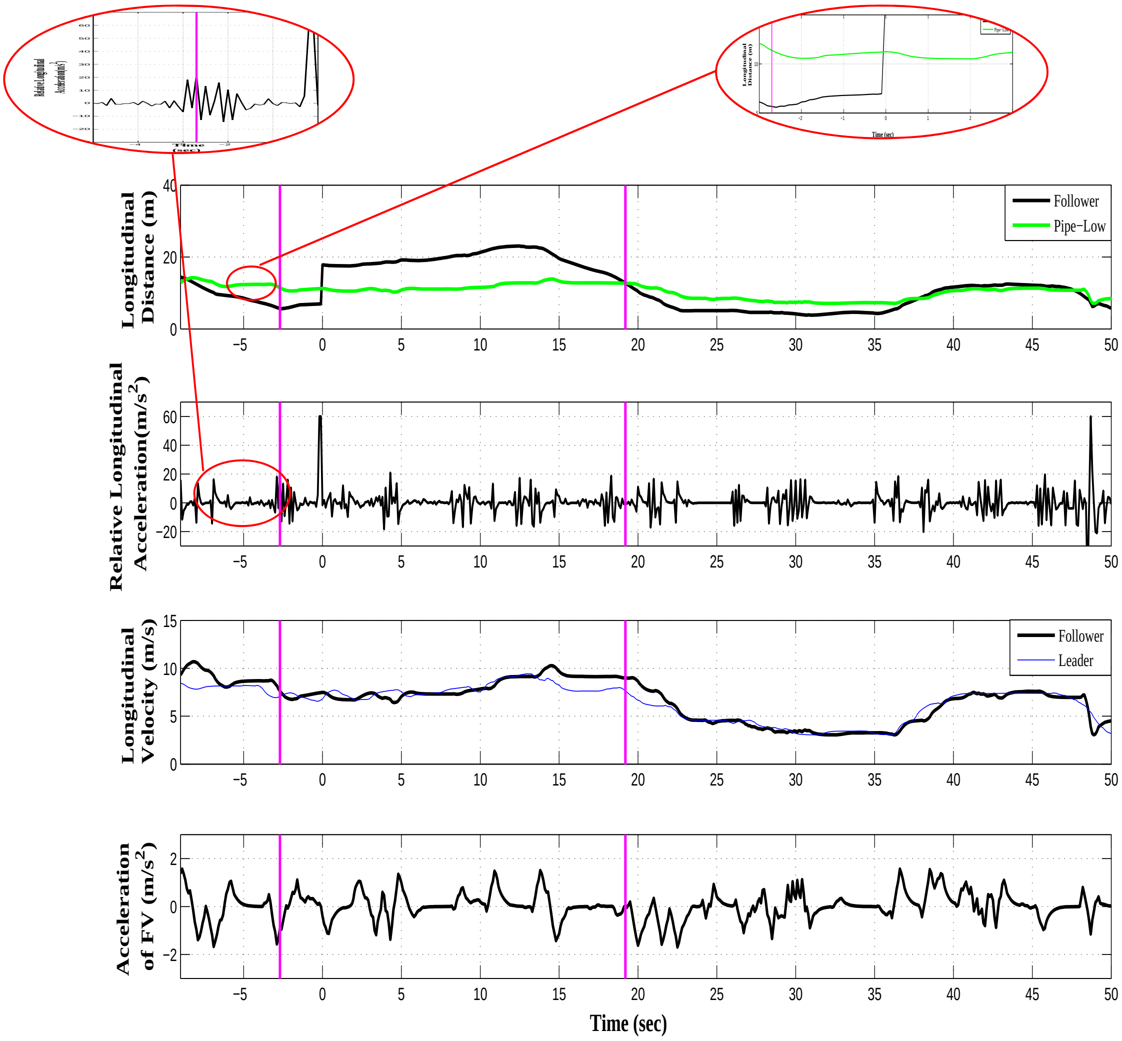


Figure 4 Start and end of anticipation and evaluation for a lane changing maneuver, a) Relative Longitudinal Distane between Follower and its front vehicle, b) Relative Longitudinal Acceleration between Follower and its front vehicle, c) Longitudinal Velocity of Follower and Leader, d) Acceleration of Follower Vehicle.

3.2 Design of ANFIS model for follower vehicle behavior

Since ANFIS is the basis of this design, this section starts with a brief review on ANFIS. Next, the datasets used for the design of theses model are explained. In order to have a smooth car following trajectory, some conditions are defined and the car following data are extracted according to these conditions. At the end of this section, the structure of the models is described. Since in this research type-3 ANIS is used for modeling the car following behavior, in this section ANFIS structure is explained briefly. More information about ANFIS is available in [17]. ANFIS networks can learn to make human-like decisions.

Since ANFIS structure is made of the combination of the neural network and fuzzy logic, using ANFIS for non-liner systems leads to good results [18]. The if-then fuzzy rules used in ANFIS are Takagi-Sugeno's type, and a recursive least square (RLS) is the basis of the learning procedure. In order to design the prediction models, datasets of real lane change behaviors are needed. So, real data from US Federal Highway Administration's NGSIM dataset is used to train the ANFIS prediction models [19].

In June (2005), a dataset of trajectory data of 6101 vehicles travelling during the morning peak period on a segment of Interstate 101 highway in Emeryville, California, as shown in figure (5), has been made using eight cameras on top of the 154m tall 10 Universal City Plaza next to the Hollywood Freeway US-101. On a road section of 640m, vehicle trajectories have been recorded in three consecutive 15- minute intervals. This dataset has been published as the .US- 101 Dataset.. The dataset consists of the detailed vehicle trajectory data on a merge section of eastbound US-101. The data is collected in 0.1 second intervals. Any measured sample in this dataset has 18 features of each driver-vehicle unit in any sample time, such as longitudinal and lateral position, velocity, acceleration, time, number of road, vehicle class, front vehicle and etc.

However, this dataset seem to be unfiltered and have some noise artifacts. Thus, the NGSIM dataset is filtered as earlier studies [20] and [21]. A moving average filter has been designed and applied to all data before any further data analysis. Comparison of the unfiltered and filtered data of the acceleration is shown in figure (6).

At first, data of vehicles that have anticipation and evaluation behavior are separated from others to design an ANFIS model. The main purpose of designing this model is to find a system that can simulate the acceleration of follower during anticipation and evaluation behavior as same as a real driver.

Determining inputs and output is one of the most important step to design an ANFIS model. Apart from latitude movement of follower vehicle, the only parameter that driver can directly affect is acceleration of the vehicle. Indeed, the changes in pressure of the gas pedal or brake, driver can adjust the acceleration. As a result, the acceleration of follower vehicle is considered as output of the model.

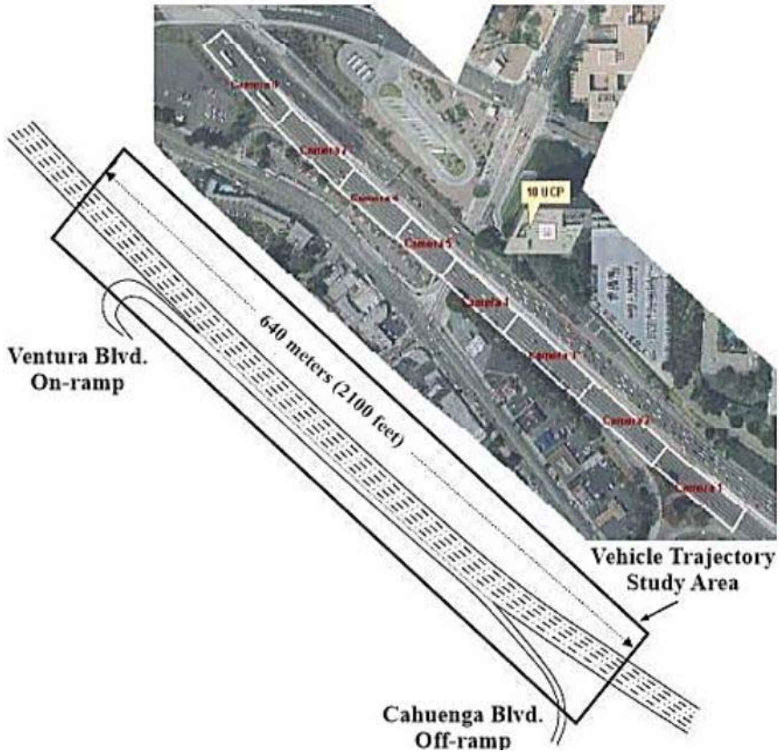


Figure 5 A segment of Interstate 101 highway in Emeryville, California [19].

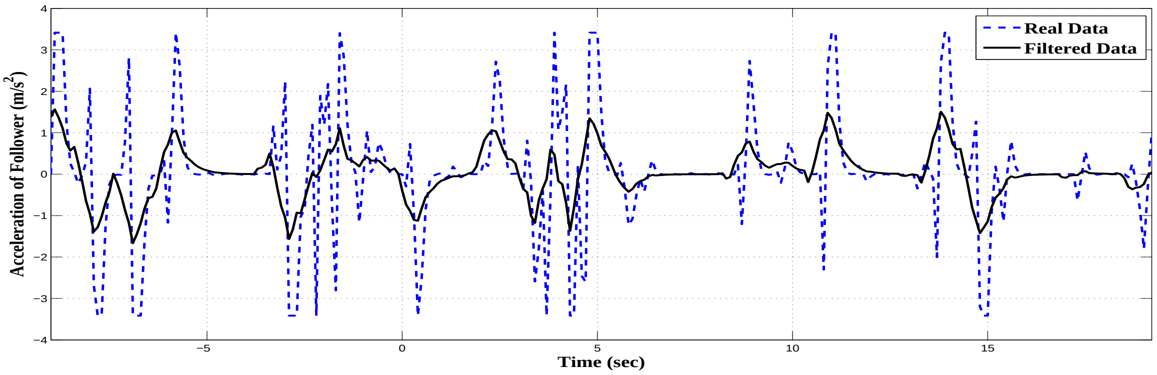


Figure 6 Comparison of filtered and unfiltered data for acceleration of a sample vehicle.

The appropriate inputs to design the ANFIS model are discovered by a trial and error procedure. The four inputs are the distance between follower and front vehicle, the relative acceleration of these two vehicles, the velocity of follower and the acceleration of follower in previous step. The structure of this model is shown in figure (7).

Three Gaussian membership functions for each input are determined. In development of the ANFIS model, the available data is usually divide in to two randomly selected subset. The first subset, which is known as the training dataset, is used to develop and calibrate the model. The validation dataset, second data subset, is not used in the development of the model. This data set is applied to validate the performance of the trained model.

In this paper, 75% of the master dataset was used for training purposes, and the remaining 25% was set aside for model validation [13].

4 Discussion and results

According to the previous discussion, which is explained, and taking these criteria into consideration for determining the start and end of anticipation and reaction, suitable data were separated from raw data.

By using ANFIS toolbox in MATLAB, A model for FV was designed. The performance of this model on four test and real vehicles is shown in figure (8). It can be seen that the designed model for the test vehicle, can model the nonlinear human’s behavior well.

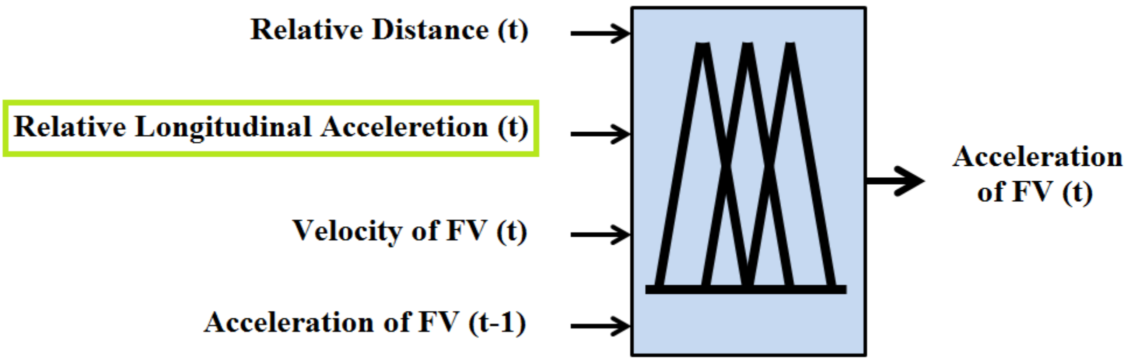


Figure 7 Input-output of ANFIS model

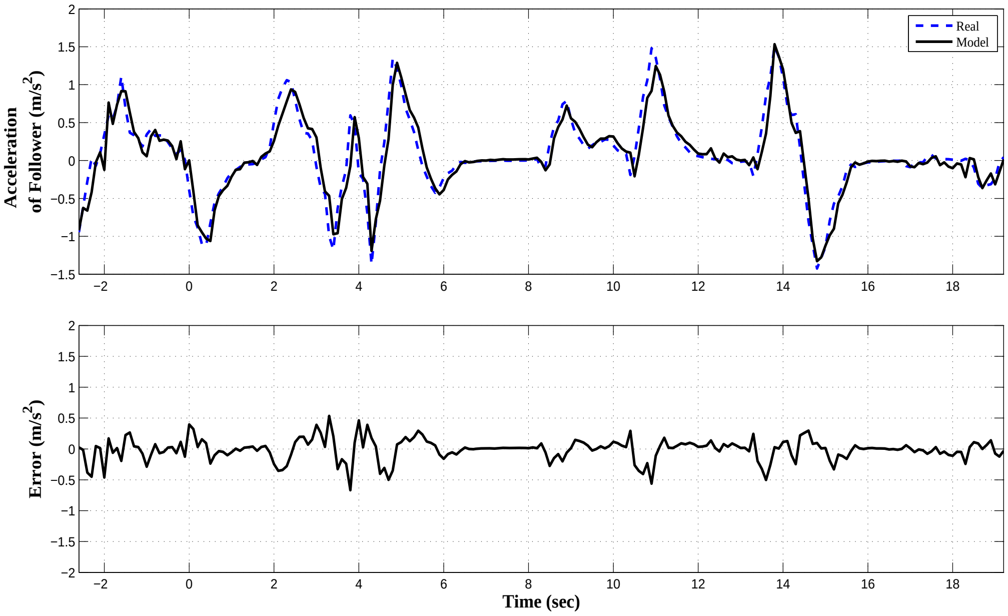


Figure 8 Result of performance comparison between ANFIS model with real driver.

To examine the performance of ANFIS models, various criteria are used to calculate errors. The criterion mean absolute percentage error (MAPE), according to Eq. (2), is considered to model risk for its usages in real-world conditions. The root mean square error (RMSE), according to Eq. (3), is a criterion to compare error dimension. Correlation coefficient (R^2), according to Eq. (4), is another criterion that provides a measure of how well the real data are replicated. In these equations, x_i shows the real value of variable (observed data), $\hat{x}_i$ denotes the value of variable modeled by anticipation and evaluation model, $\bar{x}$ is the mean value of variable and N is the number of test observations.

The aforementioned equations are given as follows:

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\frac{|x_i - \hat{x}_i|}{x_i} \tag{2}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \hat{x}_i)^2} \tag{3}$$

$$R^2 = \frac{\left[\sum_{i=1}^{N}(\hat{x}_i - \bar{\hat{x}})(x_i - \bar{x})\right]^2}{\sum_{i=1}^{N}(\hat{x}_i - \bar{\hat{x}})^2 \times \sum_{i=1}^{N}(x_i - \bar{x})^2} \tag{4}$$

Table 1 Result of error for model.

Vehicle ID	$MAPE$	$RMSE$	R^2
1	1.0588	0.3396	0.5315
2	0.9418	0.8817	0.1859
3	0.9305	0.3033	0.4749

Errors of MAPE, RMSE and R^2 are summarized in table (1). According to this table, the low value of errors for MAPE and RMSE and the proximity of R^2 to one show that the proposed ANFIS model is capable to model anticipation and evaluation behavior for follower vehicle. In addition, to validate the results, errors of this model are comparable with [15] in RMSE criteria. The average RMSE criteria of acceleration of first case in [15] is 1.16 while it is about 0.5 for the novel model of this paper which shows that intelligent model of this paper is well improved and manipulate behavior of LC with allowable performances.

5 Conclusion

This paper developed an innovative adaptive neuro-fuzzy model to investigate a new and intricate behavior of immediate follower during the lane change of leader vehicle which is a transient state in car following behavior during which the follower vehicle considerably deviates from conventional car following models for a limited time. Furthermore, the behavior is a complex state including lateral and longitudinal movement simultaneously. As explored, the start point of anticipation and end point of evaluation is determined, due to some measureable variables of both FV and LC.

Afterwards, in this paper a novel adaptive neuro-fuzzy model for anticipation and evaluation behavior based on real traffic data is proposed. Unlike previous studies, this input-output model can capture highly nonlinear nature of driving behaviors. The simulation results show that the ANFIS model has reasonable performance in comparison with real data. The proposed model can be used in analyzing driver's behaviors, driver assistant devices, collision avoidance systems and other ITS applications.

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Nomenclature

LC : Lane Changer vehicle
FV : Follower Vehicle
LV : Leader Vehicle
v : Speed of vehicle
τ : Time shift
d : Space shift slope of the linear curve
μ : Slope of the linear curve
S : Safe distance of Pipe’s law
V_{FL} : Velocity of follower
$\hat{x}_i$: Value of variable modeled by anticipation and evaluation model
$\bar{x}$: Mean value of variable
N : Number of test observations
R^2 : Correlation coefficient
MAPE : Mean Absolute Percentage Error
RMSE : Root Mean Square Error

چکیده

امروزه خودرو به عنوان اصلی‌ترین وسیله‌ی حمل و نقل در زندگی انسان محسوب می‌شود. از این رو، توجه ویژه‌ای از سوی جوامع علمی، تحقیقاتی و صنعتی به مدیریت و کنترل سیستم‌های همیار رانندگی معطوف شده است. یکی از راه‌های بهبود سیستم‌های موجود، به‌کارگیری اتوماسیون و روش‌های کنترل هوشمند در زیرساخت‌های کنار جاده و خودروهاست تا علاوه بر افزایش امنیت خودرو از شرایط غیر ایمن، از ناپایداری کلی خودرو اجتناب شود. درچند دهه اخیر فعالیت‌های زیادی در زمینه کنترل هوشمند خودروها صورت گرفته است و نتایج قابل‌ملاحظه‌ای پیرامون رفتار تعقیب خودرو و رفتار تغییر خط به دست‌آمده است. اما در مورد اثر رفتار تغییر خط بر رفتار تعقیب خودرو پژوهش‌های کمی صورت گرفته است.

این تأثیر به‌صورت یک حالت گذرا در رفتار تعقیب خودرو ظاهر می‌شود و باعث می‌شود خودروی تعقیب‌گر برای زمان محدودی از مدل تعقیب خودرو خارج شود. هدف اصلی این مقاله، مدل‌سازی رفتار پیش‌بینی و ارزیابی رانندگان، با در نظرگرفتن رفتار ریزساختار آن‌ها است. با توجه به غیرخطی بودن رفتارهای رانندگی، برای مدل‌سازی، از داده‌های واقعی رانندگان استفاده شده است و با انتخاب ورودی‌های مناسب برای مدل رفتار پیش‌بینی و ارزیابی، شتاب خودروی تعقیب‌گر در هرلحظه به‌دست‌آمده است. در ادامه برای بررسی عملکرد مدل حاصل‌شده، نتایج خروجی مدل با رفتار واقعی رانندگان مقایسه و مقادیر خطای آن حساب شده است. نتایج نشان می‌دهند که مدل پیش‌بینی و ارزیابی به‌خوبی می‌تواند رفتار رانندگان واقعی را مدل نماید.