Research on Adaptive Cruise Control Car-following Model Based on Dynamic Spacing in V2X Scenario

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Abstract. In the adaptive cruise control (ACC) car-following model, the constant spacing strategy cannot adapt to complex and variable deceleration and acceleration situations. When the preceding car decelerates or accelerates suddenly, considering the safety and adaptability, the desire spacing should be larger or smaller, so the desire spacing is not only related to the speed of the two cars, but also to the speed change of the preceding car. For this problem of the deficiency, which the desire spacing existed, an adaptive cruise control car-following model based on dynamic headway strategy is proposed in this paper. In order to achieve more real-time and more accurate information transmission, this paper uses the v2v communication in v2x environment to obtain the preceding car information. MATLAB/Simulink is used to simulation modelling for verification and analysis. The experimental results show that, under the same simulation conditions, the dynamic spacing strategy proposed in this paper have a larger desire spacing for safety when preceding car decelerates, and a smaller desire spacing for comfort and road dynamic utilization when preceding car accelerates. So, the dynamic spacing strategy proposed in this paper shows different improvement effects for different acceleration and deceleration conditions.

1. Introduction

Car-following theory is a very important part of microscopic traffic flow theory. It is one of the most basic simulation models used in traffic simulation, and an indispensable theoretical cornerstone for understanding the formation and development of microscopic traffic flow. The study of car-following theory has a very important practical significance [1-3], which can help traffic organization and management and reduce traffic congestion. In the course of decades of development, there are many kinds of research on car-following theory. ACC system is a kind of auxiliary driving system, which senses and controls the distance ahead more accurately and quickly than the driver. It greatly improves car safety, reduces the occurrence of traffic accidents, and has great research and development potential in comfort and active safety of car.

For the study of ACC car-following theory, a lot of research results have been achieved. Kesting et al. [4] proposed an ACC strategy considering acceleration characteristics, the driving style automatically adapts to different traffic situations. The experimental results show that the ACC cars improve the traffic stability and the dynamic road capacity. Chen et al. [5] proposed an ACC strategy based on MPC algorithm for the cut-in scenarios, and established a safety distance model of the cut-in car. So that the ACC car can respond in advance and quickly switch the following target to the cut-in car when facing the cut-in car.
The improvement and perfection of the model of optimal desire spacing in car-following condition has always been the focus of research. In the car collision avoidance system, the determination of the safe distance completely depends on the desire spacing model. Therefore, whether the desire spacing model is reasonable or not is of great significance to improve the reliability and effectiveness of the collision avoidance system.

The follow-up arrangement of this paper is as follows: the second chapter briefly introduces the insufficiency of the original model, the third chapter puts forward the improved model and briefly introduces the related concepts used in this paper, and the fourth chapter carries on the simulation modelling of the proposed model. through comparative experiments for verification and analysis, the fifth chapter makes a comprehensive summary.

2. Insufficiency of classic ACC car-following model

The ACC car-following model based on constant headway is currently the most widely used model. It was first proposed by PATH Laboratory of University of California, Berkeley. Its model structure is simple and the model parameters have clear physical meanings, which is also the reason why the model is widely used. The ACC car-following model is as follows:

\[ v_{n}(t) = k_{v}[v_{n+1}(t) - v_{n}(t)] + k_{d}(x_{c}(t) - Tv_{n}(t) - l - s_{0}) \]  

(1)

Where \( v_{n}(t) \) is the output acceleration of car \( n \) at time \( t \); \( v_{n+1}(t) \) is the speed of the preceding car \( n+1 \) at time \( t \); \( v_{n}(t) \) is the speed of the preceding car \( n \) at time \( t \); \( x_{c}(t) \) is the headway of car \( n \) at time \( t \); \( T \) is the desire spacing; \( l \) is the length of the car; \( s_{0} \) is the minimum safety distance; \( k_{v} \) and \( k_{d} \) are the control coefficients of the model.

It can be seen from the equation that the desire headway distance equation based on the constant headway \( T \) is a linear function of speed. The value of \( T \) is fixed. The desire spacing \( x_{d}(t) \) is only related to the speed of car \( n \), and it changes linearly with the change of speed \( v_{n} \). However, in actual car driving application scenarios, there will be complicated and changeable situations of acceleration and deceleration of the preceding car. When the preceding car decelerates rapidly, the car speed drops rapidly, and the desire spacing to decrease accordingly. However, in actual application scenarios, the speed of the preceding car drops sharply, and the desire spacing between the self-car and the preceding car decreases rapidly. In order to maintain the car-following behaviour when the preceding car accelerates, the speed of car \( n \) is also adjusted and increased rapidly. The desire spacing between the self-car and the preceding car is rapidly increased under linear conditions, but a too far spacing between cars not only has the risk of being inserted into the car, but also reduces the utilization rate of the road.

The ACC car relies on the on-board sensing equipment to detect the driving state of the preceding car, and then optimize the output acceleration at the next time according to its current driving speed and other information, so as to achieve the purpose of car-following \[7\]. However, the accuracy of the information obtained by this way of obtaining the driving state information of the preceding car is limited, and the sensing equipment takes a certain time from detecting the running state of the preceding car to analysing and calculating the feedback results. Therefore, the ACC system control will also have a certain time delay.

3. Proposal based on improved dynamic headway strategy

According to the insufficiency of the constant headway model mentioned in the previous chapter, based on the original model and considering the factors of emergency acceleration or deceleration of the car in preceding, this paper will propose an improved dynamic headway strategy, and the equation is as follows:
\[ x_d(t) = t_h v + l + s_0 + k_a a_{n+1}^2(t) \]  

(3)

Among them,

\[ t_h = t_0 - c_v [v_{n+1}(t) - v_n(t)] \]  

(4)

\( t_0, c_v \) is a constant coefficient greater than zero. In view of the desired effect of the model in this paper, the acceleration and deceleration of the preceding car should be discussed separately. Therefore, equation (4) can be expressed as:

\[ \Delta x_d(t) = \begin{cases} 
 t_h v + l + s_0 - k_a a_{n+1}^2(t) & a_{n+1} \geq 0 \\
 t_h v + l + s_0 + k_a a_{n+1}^2(t) & a_{n+1} < 0 
\end{cases} \]  

(5)

Where, \( k_o, k_1, k_2 \) are model coefficients, and \( k_1, k_2 \) are positive numbers. The ACC car following model with dynamic spacing established in this paper can be more adaptive to the complex and changeable acceleration and deceleration of the preceding car.

Aiming at the way of ACC detecting external environment information, this paper proposes to obtain the driving state information of the preceding car based on V2X. ‘V’ represents the car, ‘X’ represents any object interacting with the car and it mainly includes car, people, traffic roadside infrastructure and network. In short, it is the car wireless communication technology. Compared with the camera or lidar commonly used in automatic driving technology, V2X technology has the ability to break through the visual dead angle and obtain information across obstructions. At the same time, it can also share real-time driving status information with other cars and facilities. In this way, the obtained information directly obtains the real-time and accurate information of the driving status of the car in preceding, with stronger real-time and accuracy. As shown in figure 1, it is car-following in V2X scenario.

Figure 1. Car-following in v2x scenario.

Figure 2. Partial Simulink model.

4. Analysis of experimental results

In order to verify the feasibility of the dynamic spacing strategy proposed in this paper, the ACC car following model is established by using MATLAB /Simulink, as shown in figure 2. The dynamic
spacing strategy and the original spacing strategy proposed in this paper are verified and analysed in two car following scenarios. This paper will carry out simulation verification for two car following scenarios: rapid deceleration and rapid acceleration of the preceding car. Table 1 shows the parameters required by the model in the experiment.

| Parameter | Value |
|-----------|-------|
| $k_v$ | 0.4 |
| $k_d$ | 0.23 |
| $T$ | 1.1 |
| $t_o$ | 1.1 |
| $l$ | 2 |
| $s_0$ | 5 |
| $k_1$ | 0.1 |
| $k_2$ | 0.4 |

4.1. Preceding car deceleration scene

In the scene of car following, the preceding car may have various driving state changes. When the preceding car slows down, especially in the case of rapid deceleration, it is most likely to collide with the car in preceding and cause traffic accidents. Therefore, in this case, when the current car suddenly slows down, if the desire spacing is larger, the car speed will be adjusted and reduced quickly, and then the spacing from the preceding car will be opened quickly, which can effectively avoid traffic accidents. The speed of the preceding car is $25\text{ m/s}$, the speed of the rear car is $25\text{ m/s}$, and the spacing between the two cars is 35 meters. When the current car decelerates rapidly and finally reaches $20\text{ m/s}$, keep driving at a constant speed, as shown in figure 3~6, which is the effect of the dynamic spacing strategy and the original spacing strategy proposed in this paper. As can be seen from the figure, when the preceding car decelerates rapidly, the spacing is shortened rapidly, and the rear car starts to adjust its own speed and decelerate rapidly in order to delay the shortening of the spacing. In comparison, the dynamic spacing strategy proposed in this paper is larger than the desire spacing of the original spacing strategy, which effectively ensures the safety of the rear car. On the premise of ensuring safety, when the spacing reaches the shortest time and starts to open the spacing, the rear car speed under the dynamic spacing strategy proposed in this paper has a gentler change trend.

4.2. Preceding car acceleration scene

In the scene of car following, the rapid acceleration of the car ahead is also a common driving state. The car in preceding suddenly accelerates and quickly opens the spacing from the car. At this time, it is not only easy to be inserted, but also reduces the road occupancy rate. Therefore, in this case, when the current car suddenly accelerates rapidly, it is desire that the spacing should be smaller, the car speed will increase rapidly, and then narrow the spacing from the preceding car to maintain the following state. The speed of the preceding car is $20\text{ m/s}$, the speed of the rear car is $18\text{ m/s}$, and the spacing between the two cars is 30 meters. When the current car accelerates rapidly and finally reaches $25\text{ m/s}$, keep driving at a constant speed, as shown in figure 7~10, which is the effect of the dynamic spacing strategy and the original spacing strategy proposed in this paper. As can be seen from the figure, when the preceding car accelerates rapidly, the spacing continues to expand, and the rear car begins to adjust its own speed and decelerate rapidly in order to delay the speed of spacing expansion. In comparison, the dynamic spacing strategy proposed in this paper is smaller than the desire spacing of the original spacing strategy, which effectively ensures the car following behaviour and avoids being interrupted. When the spacing reaches the maximum, it begins to gradually reduce the spacing. The rear car speed under the dynamic spacing strategy proposed in this paper shows a gentler change trend. The maximum speed difference is also lower than the original spacing strategy. It effectively improves the driver's comfort.
Figure 3. Desire spacing corresponding curve.

Figure 4. Actual spacing corresponding curve.

Figure 5. Acceleration corresponding curve.

Figure 6. Speed corresponding curve.

Figure 7. Desire spacing corresponding curve.

Figure 8. Actual spacing corresponding curve.
5. Conclusion
The shortcomings of ACC car following model are discussed, and the dynamic headway strategy is established based on the original model. A simple car-following model is built by using MATLAB/Simulink simulation environment. According to the analysis of the simulation results, it can be proved that the dynamic spacing strategy proposed in this paper reflects different improvement effects for different acceleration and deceleration conditions, under the same simulation conditions. It is more adaptive to the scene of acceleration and deceleration of the preceding car, so the dynamic spacing strategy proposed in this paper is feasible and effective.

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