Research on Adaptive Cruise Control Based on Curve Radius Prediction

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***Abstract*—The process of ACC vehicle running in the curve is divided into three kinds of working conditions: Enter the Curve, In the Curve and Come off the Curve. Based on the prediction of lane radius, the ACC system operating mode switching logic is designed, and vehicle track radius is used to identify the target vehicle in the front. The feasibility of curve target recognition algorithm and switching logic is verified by simulation.**

Keywords-adaptive cruise control; curve radius prediction; target recognition; mode switch

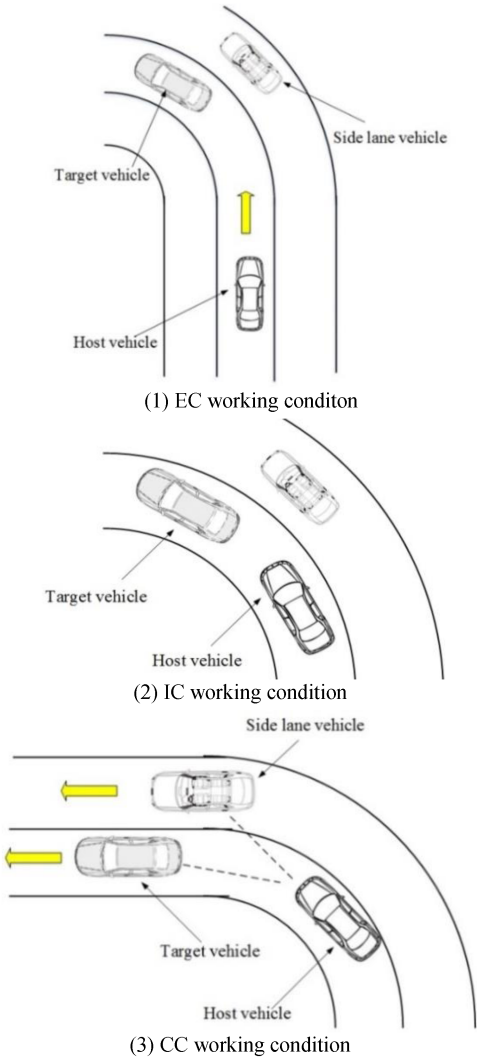
I. INTRODUCTION

With the development of Adaptive Cruise Control (ACC) system, more and more automobile manufacturers launch with adaptive cruise function models and put them on market, gained the favor of consumers [1, 2]. However, in some special conditions, like turns and changes of lane, the solution adopted in adaptive cruise control is not mature and worthy of further research and exploration [3]. The current research on the curve condition is mainly focused on the target recognition, path planning and other fields, in order to improve the safety and stability of vehicles in the curve [4].

US official survey shows that the traffic accidents occurred in the curved road section are 8 times that of other road conditions, and vehicles through the curved section occur easily in the lane departure, vehicle collision or sideslip even rolling-over [5]. The research of adaptive cruise control under curve conditions is the key to improve the automatic driving technology [6, 7]. In this paper, the curve radius is predicted and the reasonable trajectory planning is carried out by using radar to detect vehicles in front. The process of vehicle running in curve is divided into three stages: Enter the Curve, In the Curve and Come off the Curve. By switching the mode of operation in a timely and reasonable manner, the ACC vehicle can better identify the target vehicle and pass the curve.

II. WORKING CONDITION CLASSIFICATION AND DECISION LAYER FRAMEWORK

How to distinguish between the target vehicle and the side lane vehicle is the key of achieving adaptive cruise control [8]. In order to improve the tracking ability, the process of vehicle running in curve is divided into three phase: Enter the Curve (EC), In the Curve (IC) and Come off the Curve (CC). While the front vehicle (the target vehicle) has entered the curve, ACC vehicle is still in the straight road. We define this situation as EC. When the front vehicle and ACC vehicle are in the curve, we define it as IC. When the front vehicle has already come off the curve, ACC vehicle is still in the curve. We define it as CC. The three cases correspond to (1), (2) and (3), respectively, in the Figure 1.



(1) EC working conditon

(2) IC working condition

(3) CC working condition

Figure 1. Three work conditions of curve

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As shown in Figure 1, vehicles in the outer lane will interfere with the target recognition. How to make the ACC vehicle identify the front vehicle in the same lane and how to get accurate speed and distance information of the front vehicle? These will be the key of Adaptive Cruise Control in the curve road [9, 10].

Corresponding to the above three conditions, set up three working modes: Enter the Curve Mode (ECM), In the Curve Mode (ICM) and Come the Curve Mode (CCM). In the curve road, setting a virtual front vehicle, make the ACC vehicle switch work mode from ECM to CCM. Through the coordination of the three modes of operation, ACC vehicles can smoothly through the curved road. Figure 2 is the ACC system decision framework.

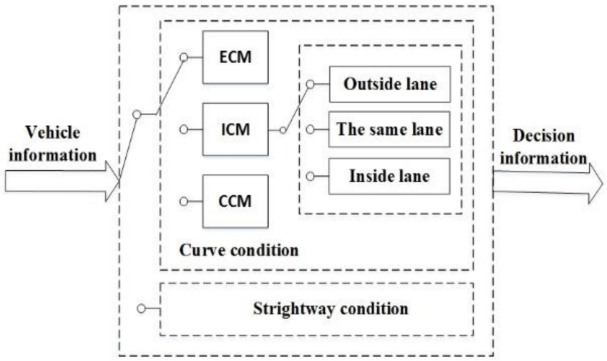


Figure 2. Decision layer framework

III. CURVED TARGET RECOGNITION ALGORITHM BASED ON ROAD PREDICTION

A. Simplified Model of Curved Road Section

According to *The Highway Route Design Rules*, the planar lines of expressway consist of straight lines, circular curves, and convolution curves [11, 12]. In this paper, we simplify the curve section into a model, which consist of straight lines and circular curves.

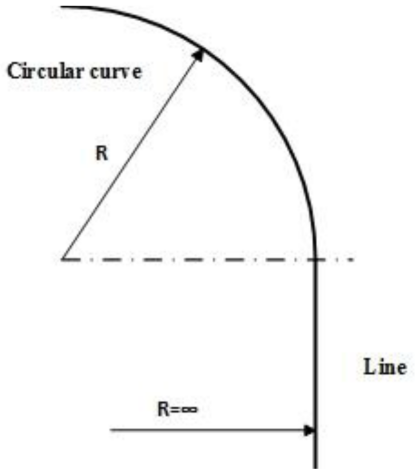


Figure 3. Simplified model of curved section

B. Curve Radius Prediction

Three points can determine a circle so we can use coordinates of three points to predict the curve radius. Set the center coordinates for (X_0, Y_0), radius R, so the equation of the circle can be expressed as:

$$(X_i - X_0)^2 + (Y_i - Y_0)^2 = R^2 \quad (1)$$

We can solve the equation by three points: (X_1, Y_1), (X_2, Y_2), (X_3, Y_3). Through the calculation and fitting of N points, we can get the radius of the vehicle track.

C. Target Recognition Algorithm in Curve Condition

Based on the simplified curve section model in Section A, the trajectories of vehicles, in the curve, can be simplified into a circle. When the host vehicle is in the EC working condition, the trajectory of front vehicle is a circle and the trajectory of host vehicle is a line. When the host vehicle is in IC working condition, the trajectories of front vehicle and host vehicle are circles. When the host vehicle is in the CC working condition, the trajectory is a line and the trajectory of the host vehicle is a circle. According to the Mathematical axiom, the radius of a circle is a constant, however, the radius of line is close to zero. So we can distinguish the straight line and the circle by the difference of the radius value.

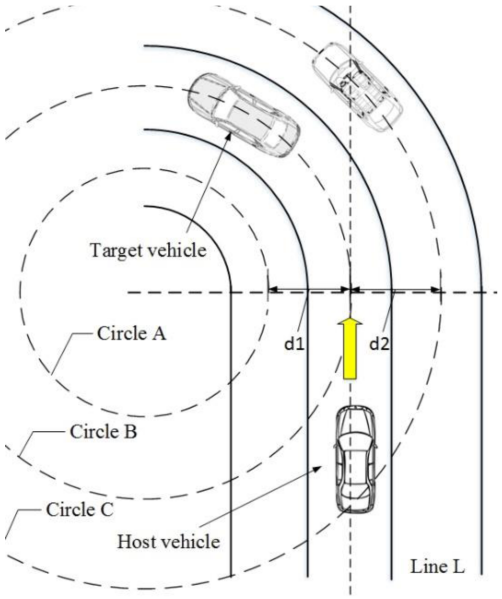


Figure 4. Sketch map of vehicles' trajectories

When the host vehicle is in IC working condition, the trajectories of front vehicle and host vehicle are circles. We can judge the relative position by comparing the radius of the front vehicle track and the host vehicle track. When the difference between the radii of the two circles is less than 1.5m, we define it as two vehicles in the same lane. For example, only when $|R_1-R_2|<1.5$m, can we define the front vehicle as the target vehicle, shown in the Figure 5.

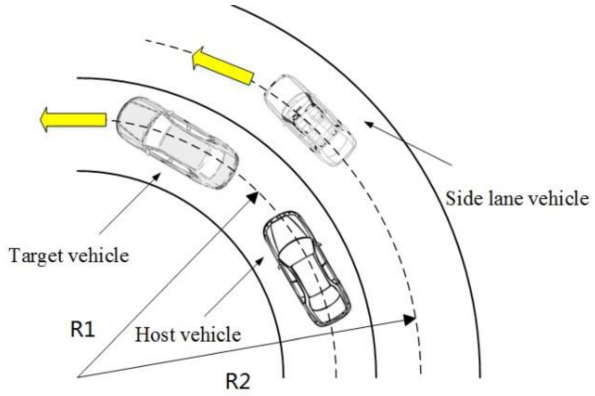


Figure 5. Sketch map of lane identification under the IC condition

After identifying the target vehicle, it is an urgent problem to estimate the distance between the two vehicles. In the EC/CC working condition, the actual distance between the two vehicles is the sum of the straight distance S_1 and the arc length S_2. In the IC working condition, the actual distance between the two vehicles is the value of the arc length in the middle of the two vehicles.

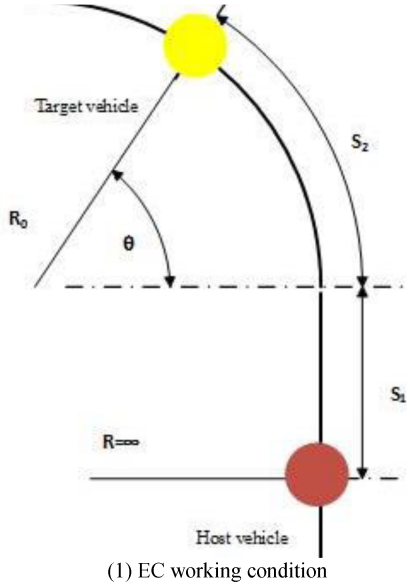
The radius of the curvature is R_0, and the center angle of the arc length is θ (radian). In the EC/CC working condition, the true distance of vehicles is:

$$S = S_1 + S_2 \tag{2}$$

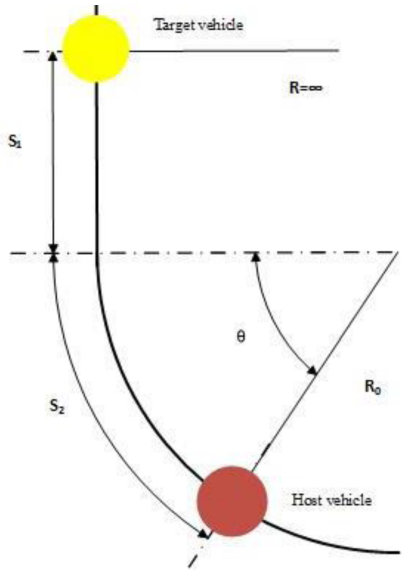
$$S_2 = \theta R_0 \tag{3}$$

In the IC working condition, the true distance of vehicles is:

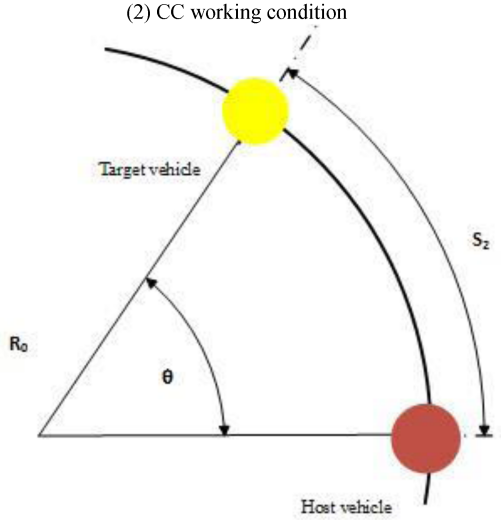
$$S = \theta R_0 \tag{4}$$



(1) EC working condition



(2) CC working condition



(3) IC working condition

Figure 6. Actual distance calculation model

IV. Simulation Experiment

Through the simulation experiments of three kinds of curve conditions, including EC, IC and CC, the target recognition algorithm based on curve radius prediction is verified in this paper. The MATLAB/Simulink software is used to build the radius prediction algorithm, in the simulation. Through the input of vehicles' position information, calculate the radius of the curve, judge the working condition of vehicles and select the appropriate working mode.

A. The Identification of Straight Condition

The straight condition refers to the front vehicle and the host vehicle traveling in the straight road, vehicles' track radii approach infinity. Curve road condition is the front vehicle or host vehicle at least one in the curve.

In the straight working condition, the vehicle track is preset to a straight line, and the radius predicted by system approaches infinity. The simulation results are as follows:

TABLE I. SIMULATION RESULTS OF STRAIGHT WORKING CONDITION

Module	Result
Vehicle radius	Not a number
Straightway module	1
Other modules	0

The system identifies the working condition of the vehicle as a straight line. Curve working condition simulation experiment is divided into three groups, and we will discuss it in the next Section.

B. The Identification of Curve Condition

The curve working condition is divided into three stages: EC, IC and CC. We set A, B, C three groups of experiments to verify the above three conditions.

In the A group, we set the track radius of the front vehicle to 70m, and the host vehicle is traveling in the straight lane. In the C group, we set the track radius of the host vehicle to 70m, and the front vehicle is traveling in the straight lane. In these two groups of experiments, the system has successfully identified EC and CC conditions, respectively. The simulation results are as shown in the following tables.

TABLE II. SIMULATION RESULTS OF EC WORKING CONDITION

Module(A group)	Result
Front vehicle radius	70.04m
Host vehicle radius	Not a number
EC module	1
Other modules	0

TABLE III. SIMULATION RESULTS OF CC WORKING CONDITION

Module(C group)	Result
Front vehicle radius	Not a number
Host vehicle radius	70.05m
CC module	1
Other modules	0

In the B group, both the front and the host vehicles were in the curved road, and we divide this group into three cases: B_1, B_2 and B_3. In the B group, we don't only identify the IC working condition, but also judge the mutual position relationship between vehicles.

In the B_1 group, the track radius of front the vehicle and the host vehicle is set to 70m and 65m, respectively. The system successfully identifies the vehicle being in the IC working condition, and judges that the front vehicle is in the outer lane of the host vehicle. In the B_2 group, the track radii of the front vehicle and host vehicle are set to 70m. The system successfully identifies the host vehicle being in the IC working condition, and judges that the front vehicle is in the same lane with the host vehicle. In the B_3 group, the track radius of the front vehicle is set to 65m，while the track radius of the host vehicle is set to 70m. The system identifies the front vehicle is in the inner lane of the host vehicle.

The simulation results of B group are as follows:

TABLE IV. SIMULATION RESULTS OF IC WORKING CONDITION

Module(B_1)	Result
Front vehicle radius	69.25m
Host vehicle radius	64.94m
IC module	1
Outside lane module	1
Other modules	0
Module(B_2)	**Result**
Front vehicle radius	70.05m
Host vehicle radius	70.53m
IC module	1
The same lane module	1
Other modules	0
Module(B_3)	**Result**
Front vehicle radius	64.94m
Host vehicle radius	70.88m
IC module	1
Inside lane module	1
Other modules	0

Additional instructions: In the above tables, 1 indicates that the module is activated, and 0 indicates that the module is not activated.

V. CONCLUSION

In this paper, based on the state of the ACC vehicle in the process of entering the curve, a switching mode of ACC system under the condition of curve is designed. The main conclusions are as follows:

1) According to the different stages of the host vehicle passing through the curve, the curve condition is divided into EC, IC and CC. This division scheme covers all the aspects of the ACC system under the curve condition, improving the performance of the ACC system in the curved road section.

2) The system can successfully identify the different working conditions of the host vehicle, and select appropriate mode of operation.

3) In the IC working condition, based on the prediction of vehicle track radius, ACC system can identify the lane of the front vehicle and judge whether the front vehicle and the host vehicle are in the same lane. Curved target recognition algorithm, based on road radius prediction, successfully solve the interference of the vehicles in the next lane on the target recognition.

In the next work, we will continue to study the distance compensation algorithm and improve the performance of the ACC system in the curve road.

REFERENCES

[1] Guocheng Ma. Research on the Adaptive Cruise Control Tracking System Applied for Motor Vehicles [D]. Beijing Institute of Technology ,2014.

[2] Shifeng Geng. Research on Target Object Selection for ACC System Based on Analysis of Vehicle Trajectories [D]. Jilin University, 2015.

[3] Lei Zhang. A Vehicle Longitudinal Driving Assistance System Based on Self-Learning Method of Driver Characteristics [D]. Tsinghua University, 2009.

[4] Lilong Gong. Research on Algorithm of Adaptive Cruise Control System [D]. Zhejiang University,2012.

[5] Zhonghai Liu. Adaptive Cruise Control: Design and Simulation [D]. Tsinghua University,2005.

[6] Wei Yan. Study on Adaptive Cruise Control Algorithms Imitating Car-following Behaviors of Drivers [D]. Jilin University, 2016.

[7] Rongrong Gu . Summarization of Typical Scenarios of Adaptive CruiseControl Based on Natural Drive Condition [A]. State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body Hunan University.Proceedings of The 11th International Forum of Automotive Traffic Safety−SESSION IV: Active Safety Technology and V2x[C].State Key Laboratory of Advanced Design and Manufacturing for Vehicle Body Hunan University:,2014:7.

[8] Xingda Chen. Research on Relevant Target Seltecion Algorithm of Adaptive Cruise Control System [D]. Jilin University, 2011.

[9] Zhenhai Gao, Wei Yan, Hongjian Li, Zhencheng Hu.Adaptive Cruise Control Algorithm Based on Simulated Driver Multi-objective Decision [J].

[10] Xiaohan Li, Research on Fuzzy Control Strategy of Vehicle Adaptive Cruise Control System [J]; Journal of Beijing Institute of Technology, 2015.

[11] Zhenhai Gao, Wei Yan, Hongjian Li, Zhencheng Hu.Adaptive Cruise Control Algorithm Based on Simulated Driver Multi-objective Decision [J].

[12] Ping Li, Research on the Fuzzy Control and Simulation of Automobile Cruise System based on the City Traffic, [D]. Liaoning University of Technology, 2014.