

A New Method for Target Object Selection for ACC System Based on Analysis of Vehicle Trajectories

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ABSTRACT

The trajectory variation of preceding objects with changing road curvature and uncertain driving behaviors of both host and preceding cars make it difficult for conventional radar-based Adaptive Cruise Control (ACC) system to effectively select its valid target object, which is mainly caused by the deficient judgment about the preceding curves and the behaviors of preceding cars. Through analysis of the trajectories that host and preceding objects generate, the new proposed method can differentiate the operating conditions of each car, either in straight lane, on curve or in lane-change, thus front path prediction and host vehicle's future lane estimation can be precisely fulfilled.

From radar and host car's information a coordinate that changes under several criteria can be established, and based on this coordinate the trajectories of preceding and host car can be recorded and analyzed, some mathematics methods are adopted to reach the qualitative conclusion.

The new method can find the valid target for ACC system and enable the system to conquer some typical drawbacks of conventional ACC, such as the confusion between lane-change and curve-enter of a preceding car, and also the speed of a preceding object can be modified as soon as it enters a curve. Simulations have been conducted to validate the method, and the results show that the proposed method could exactly judge the operating condition and find correct target for ACC system.

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INTRODUCTION

For the first time a great part of driver's tasks can be fulfilled by an automatic system, ACC system was introduced in Japanese auto market nearly 20 years ago, the research of ACC system is still in process nowadays, and it also becomes a significant issue of intelligent vehicle (IV) [1]. Besides the conventional cruise control function, ACC system obtains environmental information using frontal radar or maybe some visual sensors to find the possible target vehicle, and from information such as relative velocity and range between the target and host vehicle, the system will maintain a desired distance between cars [2].

Besides the utilization rate and cost problem, target selection is a special challenge of ACC system. Since the cars do not always drive straightly with the change of lane's curvature, and

vehicle-borne radar cannot measure the change of road by itself, confusions of valid target sometimes occur when preceding objects enter or exit curves (Fig.1, b). Two methods were mainly introduced to make up for this drawback [3], using yaw rate or steering angle sensor of host vehicle to determine the road curvature is the first and the common method, but the approach is only efficacious while the curvature is a constant. As another method, added visual sensors are adopted to detect lane markers, however, these sensors work unsatisfactorily under bad weather or at night, and also, it further increases the cost of ACC system. Besides, it's difficult for the system to distinguish the curve-entry and lane change of a preceding car (Fig.1, a), since general methods seldom care about the car's operating condition.

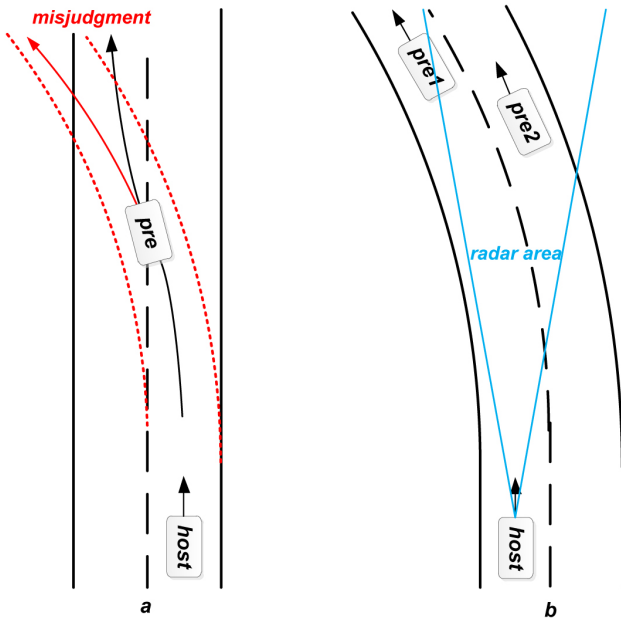


Figure 1. Two typical conditions in which general target selection methods are prone to fail, 'pre' and 'host' mean preceding and host car respectively.

Actually, the trajectory of any vehicle on a certain road can depict the geometrical shape of the road on some level, thus when there exists one or more preceding cars, the trajectories of them can be obtained with frontal radar on host car. For example, if the system acquires that there is a frontal curve and the curvature of it when the host vehicle is in straight road, the host vehicle's future lane estimation can be fulfilled accurately. In this paper, two main problems will be solved:

1. Usually, the analysis of trajectory is based on apparatus like GPS/INS, which could establish a standard geodetic coordinate to help record trajectories. With the new method, the establishment of the coordinate used to record and analyze trajectory is based on some data from host car (yaw rate and velocity) and the radar, the coordinate will be updated intermittently to guarantee the accuracy, and it's always approximately parallel to a part of straight path that the host have passed by.
2. Qualitative analysis of trajectories of host and preceding cars will be done, that is to say, the analysis should tell the operating condition of each car (in straight lane, on curve or in lane-change). Though under the influences of uncertain driving behaviors (i.e. the car in a straight path doesn't always drive a perfect line), different driving habits (i.e. the start moment of making the wheels steer when enter a curve) and different driving speed, there still exist conspicuous discrepancies between the trajectories of different operating conditions, thus some mathematics methods can be used to differentiate them.

Details of the new method are presented in [Section 3](#) of the paper, and general target object selection methods are also briefly described in [Section 2](#). Finally [Section 4](#) shows the result of HIL simulation.

GENERAL TARGET OBJECT SELECTION METHOD FOR ACC

The process of selecting a valid target object can be divided into steps which are showed in [Fig.2](#).

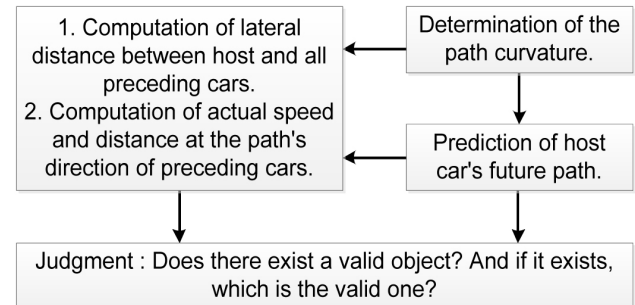


Figure 2. General steps of valid target selection system.

A common hypothesis that general methods employ is that the current curvature of host will be retained [3], and the curvature can be calculated from yaw rate, lateral acceleration or steering wheel angle, etc. Apparently the computation and prediction in [Fig.2](#) work effectively under this hypothesis only when host and preceding cars are on the road of same curvature. For instance, in [Fig.3](#), while the curvature is calculated from host yaw rate via [Eqs.1](#), a predictive segment of circular arc which is tangent to the current driving direction can be acquired as the green arc showed in [Fig.3](#), the predictive arc is regarded as the center line of host car's future path, and with an estimated path width or so-called driving corridor, as the follow yellow area showed, the path prediction can be finished.

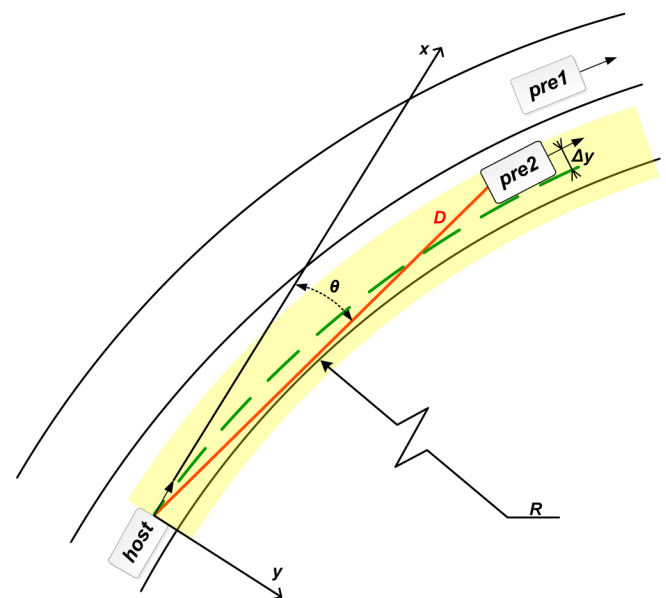


Figure 3. The condition in which general method works well.

D is the relative distance between host and preceding car, the distance along the predictive arc L can be calculated by [Eqs.2](#), and with [Eqs.3](#) the lateral distance between preceding car and predicted center line could be acquired, θ represents azimuth

angle acquired from radar. Finally the judgment could be done by comparing L to the desired safe distance and Δy to driving corridor.

$$\kappa = \omega / v \quad (1)$$

$$L = \frac{2}{\kappa} \arcsin\left(\frac{\kappa D}{2}\right) \quad (2)$$

$$\Delta y = \frac{\kappa}{2} (D \cos \theta)^2 - D \sin \theta \quad (3)$$

The approach is badly prone to incorrectly lose valid target or select a wrong one when preceding cars enter (Fig.1, b) or exit curves, lane-change of host car could be regarded as entering a bend, and the condition of clothoid transition curve is also disregarded.

Excellent researches about differentiating curve enter/exit and lane-change of preceding cars have been done for radar-based ACC in [4] and [5] which provide good references, but the work seems to have made too much assumptions and didn't take the changes of host operating condition into consideration.

PROPOSED NEW METHOD

In the method, operating condition (OC) of host and preceding cars can always be identified as one of the following.

1. In straight line (inS): the car is believed to drive in a straight carriageway, though the trajectory of it may not be a perfect line. When the host car is inS, the preceding inS car can easily be judged as a target or not, invalid target will be classified into cars in left roads (LR) or in right roads (RR), and HR means the carriageway of host vehicle. If a car is in LR, the average lateral distance between it and the host should be calculated and updated as the system acquires enough new data.
2. On curve (onC): the car is believed to drive on a bending carriageway, which means the car is driving on a curve with constant (circular arc) or continuous changing (transition curve) radius. If a car is onC, the curvature of it should be acquired using some average data and should be updated intermittently.
3. In lane-change (inLC): the car is believed to change lane, this is an interim condition that usually takes about 4~8 seconds [6]. The lane-change on curve also needs to be recognized.

First we may assume that the OCs of all cars are known, for example in Fig.4, the change of frontal path curvature is also acquired from the information of preceding car 1 (Pre 1), thus the lane prediction of host car can be also made as a

combination of straight line and curve, and with the curvature, distance and velocity of preceding objects could be modified from radar information. Even without Pre 1, the prediction can also be made by modifying the curvature of preceding car 2 (Pre 2) with the average lateral distance measured before Pre 2 enters the curve.

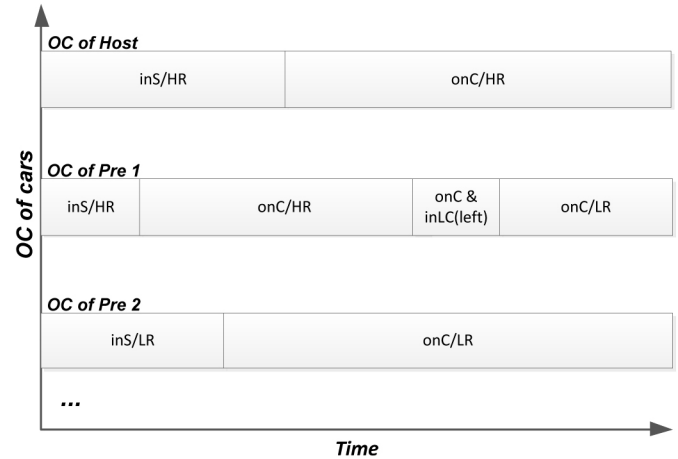


Figure 4. An example of cars' OCs change over time.

Three parts are designed to finish the differentiation of OCs: establishment of coordinate, the pre-judgment and the judgment.

The Establishment of Coordinates

Since the pre-judgment and the judgment we designed about operating condition are both based on analysis of vehicle trajectories, the coordinate should be established at the first, and in fact, the variation of coordinate changes the coordinate figures of points which constitute trajectories. The judgment about inLC and onC in the method is prone to be influenced by the coordinate, so x axis of it should try to be parallel to a segment of straight lane that the host car have passed by, and if possible, it should be updated as soon as possible to guarantee the accuracy.

For initialization, the points (X, Y) of host car's trajectory can be described as follow:

$$\begin{aligned} \theta_0 &= \omega_0 t_s \\ \theta_i &= \theta_{i-1} + \omega_i t_s \\ (X_0, Y_0) &= (0, 0) \\ (X_i, Y_i) &= v_{i-1} t_s (\cos \theta_{i-1}, \sin \theta_{i-1}) + (X_{i-1}, Y_{i-1}) \\ \text{and, } i &= 1, 2 \dots n_c \end{aligned} \quad (4)$$

In Eqs.4, ω_i means the yaw rate of host vehicle at the i th sampling point, θ_i represents the angle between x axis and the line that point i and $i + 1$ link, t_s is the sample time and the n_c th point is the last point before updating the coordinate. Besides