Advanced Adaptive Cruise Control Considering Reaction Time of Following Driver

Hanwool Woo
dept. Intelligent Mechatronics
Akita Pref. Univ./The Univ. Tokyo
Akita/Tokyo, Japan
woo@akita-pu.ac.jp

Hirokazu Madokoro
dept. Intelligent Mechatronics
Akita Prefectural University
Akita, Japan
madokoro@akita-pu.ac.jp

Kazuhito Sato
dept. Intelligent Mechatronics
Akita Prefectural University
Akita, Japan
ksato@akita-pu.ac.jp

Yusuke Tamura
inst. Engineering Innovation
The University of Tokyo
Tokyo, Japan
tamura@robot.t.u-tokyo.ac.jp

Atsushi Yamashita
dept. Precision Engineering
The University of Tokyo
Tokyo, Japan
yamashita@robot.t.u-tokyo.ac.jp

Hajime Asama
dept. Precision Engineering
The University of Tokyo
Tokyo, Japan
asama@robot.t.u-tokyo.ac.jp

***Abstract*—In this paper, we propose a novel method for advanced adaptive cruise control considering the reaction time of the following driver. Our research group has developed a system to anticipate future positions of adjacent vehicles. Based on the prediction results, our system plans its path to avoid a collision. However, it can conversely cause an accident when the ego vehicle excessively accelerates or decelerates, particularly the following driver. The proposed method controls the inter-vehicular distance to adjacent vehicles while considering the reaction time of drivers. It is demonstrated that the proposed method is able to decrease collision risks and improve driving safety.**

***Index Terms*—Adaptive cruise control, Trajectory prediction, Reaction time**

I. Introduction

Recently, autonomous driving has been focused as a solution to improve driving safety. However, it is anticipated that human drivers and autonomous vehicles coexist on the way to the society where autonomous vehicles completely replace all human drivers. Our research group has constructed a framework for the trajectory prediction of human drivers around the ego vehicle, and the control method to avoid collisions was proposed [1]. This method predicts lane changes of surrounding vehicles and controls a maneuver based on the prediction result. However, it can conversely cause an accident when applying an excessive acceleration (deceleration), particularly the following driver. Human drivers take time to react unlike a self-driving car, therefore, it is strongly required to consider the reaction time of human drivers for the co-existence. However, most of the previous methods do not take account of this characteristic [2]. According to the previous study, the reaction time with respect to objects, which suddenly move into the driver's path, was between 0.92 s and 1.94 s [3]. Considering the report, the control method of ego vehicle should consider the reaction time of human drivers at least 2 s.

In this paper, the proposed method controls the inter-vehicular distance to adjacent vehicles while considering the reaction time of drivers. ACC (adaptive cruise control), which drives behind the lead vehicle while automatically adjusting its speed and keeping a safe distance, is already commercialized; however, it does not take into account the following vehicle. The proposed method generates a path that minimizes the collision risk with not only the lead vehicle but also the following vehicle. This paper presents a state-of-the-art technique for the ACC, and it is demonstrated that the proposed method significantly improves driving safety.

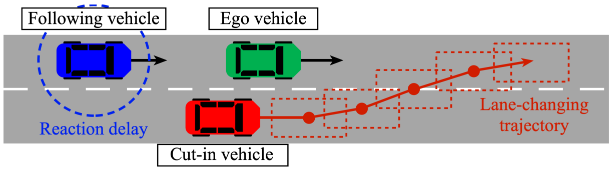

Fig. 1. Problem formulation.

II. Problem Formulation

In this paper, it is assumed that the ego vehicle drives on a straight highway. There are two lanes in the same direction as shown in Fig. 1. Measurement devices such as a position sensor and laser scanners are installed to the ego vehicle, hence, movements of adjacent vehicles can be acquired. This study assumes that one surrounding vehicle, indicated using a red color, changes a lane and enter to the front space of the ego vehicle. The lane-changing vehicle is defined as the *cut-in* vehicle. There is the *following* vehicle, indicating a blue color, behind the ego vehicle, and the vehicle is operated by a human driver. If the ego vehicle immediately decelerates to maintain a sufficient distance from the *cut-in* vehicle, an accident would occur with the *following* vehicle. All measurements and calculations are conducted within 0.1 s. Moreover, only position data of the three vehicles is used in the proposed method.

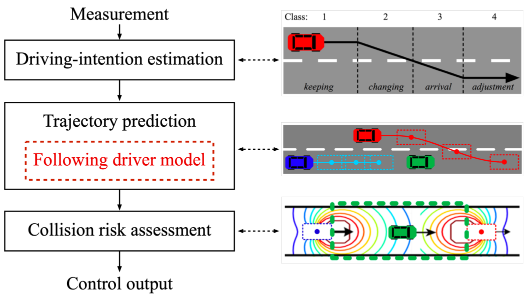

Fig. 2. Schematic of proposed method.

III. Proposed Method

A. Overview

The key point of the proposed method is to anticipate future positions of the *following* vehicle when the ego vehicle changes its speed. Fig. 2 shows the schematic of the proposed method, which consists of three parts: driving-intention estimation, trajectory prediction, and collision risk assessment. The position of the three vehicles are input to the framework, and the output is the control command of ego vehicle.

In our previous paper, it has been proposed to avoid a collision with respect to the lane-changing vehicle, which cuts in the front space of the ego vehicle [1]. However, the method assumed that the *following* driver is immediately able to react to a deceleration of the ego vehicle. In this study, the reaction time of the *following* driver is considered, therefore, a more realistic control method can be constructed than the previous one. How to take into account the reaction time of drivers is described in the next subsection. Details of the other parts are described in our previous work [1]. The future position of *following* vehicle is predicted, and the ego vehicle is controlled to avoid the collision even if the operation of *following* driver is delayed.

B. Following Driver Model

The following driver model describes how a driver reacts to the speed of preceding vehicle. Although various models have been proposed, General Motor's model is commonly used among them [4]. It was reported that this model shows a good correlation to the real traffic data.

A driver's following behavior can be developed as below. At any time steps t, let the position of the n^{th} vehicle be represented by x_n^t.

$$a_f^t = \left[\frac{\alpha_{l,m}(v_f^t)^m}{(x_e^{t-\Delta T} - x_f^{t-\Delta T})^l}\right](v_e^{t-\Delta T} - v_f^{t-\Delta T}), \qquad (1)$$

where v_e^t represents the velocity of the ego vehicle, and x_e^t is the position of the ego vehicle at time step t. At the same way, v_f^t represents the velocity, x_f^t is the position, and a_f^t is the acceleration of the *following* vehicle. ΔT is the reaction time of human driver, and $\alpha_{l,m}$ is a coefficient which represents the sensitivity of the *following* driver. l and m are also parameters to explain the driving characteristics.

TABLE I
Comparison of collision risk.

	Human	Previous [1]	Proposed
Collision risk [J]	1.52	1.27	0.74

The position $x_f^{t+\Delta t}$ and the velocity $v_f^{t+\Delta t}$ of the *following* vehicle at the next time step are updated based on Eq.(1). As described in Section I, the reaction time ΔT should be set at least 2 s. The proposed method calculates the future position of *following* vehicle, then, it finds an optimal position between the *cut-in* and *following* vehicles to minimize the risk.

IV. Evaluation

For training and testing of the proposed framework, real traffic data were used [5]. Among data from 5,678 vehicles including lane-keeping events, 747 lane-changing events were used for the evaluation. An evaluation period of 5 s was defined based on the moment at which the *cut-in* vehicle crosses the lane marking. The collision risk between the ego and the *following* vehicles was calculated during this period at each time step.

As the metric to evaluate the collision risk, the repulsive potential energy from the *cut-in* and the *following* vehicles was used [1]. This potential energy can evaluate the relative velocity and the relative distance to the two vehicles simultaneously. Table I shows the average of repulsive energy using the entire testing data. To confirm the performance, our previous method was compared, which does not consider the reaction time of *following* driver. It can be confirmed that the proposed method is able to decrease the collision risk dramatically. Based on this result, the effectiveness of the proposed method was demonstrated.

V. Conclusion

This paper presented a novel method to improve driving safety by considering the reaction time of surrounding drivers. The proposed method predicts the future position of the following vehicle while considering the operation delay of a human driver, then, it controls a maneuver to avoid a collision. It was demonstrated that the proposed method can decrease the collision risk compared than the method without the consideration of reaction time.

References

[1] H. Woo, Y. Ji, Y. Tamura, Y. Kuroda, T. Sugano, Y. Yamamoto, A. Yamashita and H. Asama, "Advanced adaptive cruise control based on collision risk assessment," Proceedings of the 21th IEEE International Conference on Intelligent Transportation Systems, pp.939–944, 2018.

[2] M. P. Heyes and R. Ashworth, "Further research on car-following models," Transportation Research, vol.6, no.3, pp.287–291, 1972.

[3] M. Green, "How long does it take to stop? methodological analysis of driver perception-brake times," Transportation Human Factors, vol.2, no.3, pp.195–216, 2000.

[4] T. V. Mathew, "Transportation Systems Engineering," 2014.

[5] The Federal Highway Administration, "Next generation simulation," https://ops.fhwa.dot.gov/trafficanalysistools/ngsim.htm (accessed:3 April 2019).