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東京大学
THE UNIVERSITY OF TOKYO

Lane-Change Detection Based on Individual Driving Style and Correlation with Adjacent Vehicles

（個人の運転スタイルおよび周辺車両との関係を考慮した車線変更検知）

Supervisor:　Assoc. Prof. Atsushi Yamashita

山下 淳 准教授

Department of Precision Engineering

The University of Tokyo

Hanwool Woo

禹　ハンウル

Even though traffic accident rates have been decreasing, they still remain a major cause of mortality. Over 90 % of car crashes are caused by human errors, and late cognition occupies almost half of it. Based on this situation, autonomous driving technologies and advanced driver-assistance systems have been attracting considerable attention as solutions to prevent car crashes. Implementation of intelligent technologies to assist drivers in recognizing such situations around their own vehicle can be expected to decrease the accident rate.

Car crashes often occur when traffic participants try to change lanes. Even though a driver safely operates his own vehicle, when other drivers surrounding him dangerously change lanes, there is a risk of traffic accident occurs. Furthermore, low concentration makes it difficult for drivers to react to behaviors of other traffic participants immediately. If the driver assistance system of a vehicle can detect lane changes before other vehicles cross the centerline, the accident rate can be significantly decreased.

Considerable research to detect lane changes of other vehicles has also been proposed and established in theoretically. However, their performance is still not sufficient for implementation on a driver assistance system. The performance in lane-change detection can be evaluated by two indices - accuracy and early detection. Previous methods have the problem of frequent false alarms, and this can result in the distrust of the driver assistant system, which is dangerous.

Furthermore, the method should detect a lane change as soon as possible at the moment lane changing starts. If it is impossible to warn the primary driver with sufficient time margin to react to a lane change, the method cannot be implemented even though it achieves the great accuracy. However, there is normally a trade-off between the accuracy and the early detection. Therefore, it is quite difficult to improve both performances simultaneously. To overcome these limitations, there is a strong need for new approaches to make a breakthrough.

In order to solve these problems and construct a safe, reliable, and feasible driving assistance system, which can detect dangerous situations and relay alarms to the primary driver, the following points can be discussed as challenges:

- Description of general lane-changing conditions: if it is possible to describe conditions under that drivers generally consider a lane change, it should be effective to improve a detection performance.
- Prediction of target's movement: since a lane change is a continuous process, it would be able to predict movements of a lane-changing vehicle based on the relationship with adjacent vehicles. The predicted movement gives valuable information for lane-change detection, and it can contribute performance improvement.
- Consideration of personal driving style: each driver has an own driving style and shows a different driving pattern. If the driving style of a driver can be estimated, driver-assistance sytems can be adaptive to personal characteristics. As compared to previous methods, it can be expected to achieve a great performance.

In this thesis, techniques are proposed to achieve the above challenges.

Many methods have been proposed to achieve better detection performance, however, they still need to be improved for implementation on real driver assistance systems. The objective of this thesis is to improve both performances by considering the relationship with adjacent vehicles. Due to development of measurement devices, it has been possible to accurately measure the surrounding situation, as the result, the detection performances can be improved by utilizing these useful information.

More detailed summaries for each step are as follows.

In Chapter 2, a new feature to describe the characteristic of lane changing is proposed. The proposed method uses an artificial potential method to consider the relationship to adjacent vehicles. Drivers may consider the relative distance and the relative velocity with respect to adjacent vehicles at the moment a lane change is attempted. By this feature, accuracy and early detection can be improved. In this thesis, the lane-changing process is defined as consisting of four driving intentions: *keeping*, *changing*, *arrival*, and *adjustment*. The proposed method uses a machine learning technique and estimates which intention the target driver may have at each time step. This estimation method of driving intentions proposed is also used as a basic model in later methods in Chapter 3 and Chapter 5.

In Chapter 3, a method to decrease the number of false alarms by using trajectory prediction is proposed. The trajectory prediction method adopts the result of driving intention estimation in Chapter 2. Generally, drivers execute different strategies with different driving intentions. The proposed method uses the potential field method for trajectory planning and avoiding contact with surrounding vehicles. The goal, side-lines, and surrounding vehicles that generate potential energy are determined by following the driving intention. After planning, a collision check is conducted. If a collision with a surrounding vehicle occurs, the trajectory is re-planned. Such re-planning can be explained in a practical scenario as the abortion of a lane change due to the presence of adjacent vehicles. This re-planning in the driving-intention estimation can be expected to decrease false alarms. It is demonstrated that the proposed method outperforms previous methods using real traffic data.

In Chapter 4, driving style recognition based on risk taking of the target driver is discussed. The scene is assumed that the target vehicle follows the preceding vehicle. The driving style is categorized into three levels: *cautious*, *normal*, and *aggressive*, and the proposed method determines the type of driving style of the target among the three given levels. In this Chapter, a new feature is proposed using a dynamic potential field method wherein the distribution changes depending on the relative number of adjacent vehicles. A more appropriate description of driving risk is obtained compared to other indices. The proposed method is validated through experimental results using a driving simulator.

In Chapter 5, a technique to predict lane changes considering personal driving styles is proposed. The proposed method evaluates the probability performing lane changes based on the gap acceptance model, and it is integrated with the result in Chapter 2. First, the critical gaps with respect to vehicles on the next lane are derived based on the recognition result of driving styles by the method in Chapter 4. This approach makes the fast detection possible. Second, the integration of two methods based on gap acceptance and driving intention estimation is proposed. As the result, it is demonstrated that the proposed method improves the early detection without the loss of accuracy.

Finally, Chapter 6 gives conclusions of this thesis.