Autonomous Lane-Changing System at Congested Merging Area

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ABSTRACT

This paper proposes an autonomous lane-changing system at a congested merging area. It is expected that manual and autonomous vehicles co-exist until all vehicles are replaced to autonomous ones. Therefore, the interaction between humans and autonomous driving system should be discussed. This paper assumes a scene in which an autonomous vehicle performs a lane change into the congested main lane where all vehicles are manual. The proposed system estimates the acceptability of the vehicles on the main lane with respect to the lane-changing of the autonomous vehicle. Then, our method judges whether a lane change can be safely performed according to the estimated acceptability level. This enables a more flexible decision making for various driving characteristics of the drivers on the main lane.

INTRODUCTION

In the future, it is expected that all vehicles on the road will be replaced by autonomous vehicles to realize much safer driving than humans. However, it is practically difficult to replace all vehicles from manual to autonomous driving vehicles at once. Therefore, it is expected that manual and autonomous vehicles will co-exist during the transitional period. One example is a lane change from the merging lane to the main lane at an express merging area. As shown in Figure 1, when the main lane is congested, the merging vehicle needs to estimate whether drivers on the main lane side are willing to give way to the merging vehicle. However, current autonomous driving technology does not provide sufficient discussion for situations in which manual and autonomous driving vehicles co-exist.

The gap acceptance model has been proposed as a representative method for determining whether a lane change to the main lane can be performed without collisions. This method evaluates the possibility of a lane change by calculating the critical gap, which is the minimum distance required for a safe lane change.

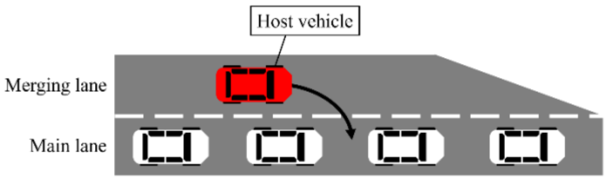

Fig.1 Lane change to congested main lane

However, the critical gap is calculated by predetermined parameters which represents the driving characteristics of human drivers. Thus, it is difficult to deal with various driving characteristics.

Based on the above limitation, we propose an autonomous lane-changing system to change lanes from the merging lane to the congested main lane at express merging area. The proposed system estimates the acceptability of the vehicles on the main lane with respect to the lane-changing of the autonomous vehicle. The acceptability levels of the main lane drivers are classified as five levels, and our method judges whether a lane change can be safely performed according to the estimated level. This enables a more flexible decision making for various driver characteristics of the main lane drivers. For the construction of the proposed method, experiments using a driving simulator (DS) are conducted to measure how human drivers make a decision in various situations. Then, our decision model is constructed based on the imitation of human drivers.

PROPOSED METHOD

This research consists of three parts: data acquisition of human drivers' behaviors using a DS, model construction for the lane-changing decision, and evaluation of the proposed method.

In the data acquisition of human drivers' behaviors, subjects operate a merging vehicle and change a lane into the congested main lane. In the real world, there are drivers who willingly accept a lane change from the merging lane, while there are also drivers who reject the lane change. In order to consider this variety of driving characteristics, we generate driving scenes by dividing the acceptability level of the main lane drivers into five levels from zero to four. Subjects are asked to perform multiple trials, and the acceptability level is randomly determined for each trial. Subjects make a decision to perform a lane change based on the behaviors of vehicles on the main lane. The positions and speeds of all vehicles are recorded.

For the model construction of lane-changing decision, DS experiment data that performed safe lane changes are selected. The maximum deceleration of the rear vehicle on the main lane is used as an index for the selection. Using the selected data, the time headway and vehicle gap between the merging and rear vehicles are extracted with respect to each acceptability level. Then, the distribution of them are modeled based on the Gaussian probability density function. The proposed method estimates the acceptability level from the situation in the main lane. Then, the possibility of lane-changing is calculated with the Gaussian probability density function of the estimated acceptability level. When the lane change can be safely performed, the lane-changing trajectory is generated through the sinusoidal model and adaptive cruise control algorithm (ACC).

To evaluate the effectiveness of the proposed method, simulation is conducted. The proposed method is implemented to the merging vehicle, and the vehicles on the main lane are controlled based on the ACC algorithm. The parameters, which represent driving characteristics of the main lane drivers, are determined randomly. By repeating trials, the safety of lane changes performed by the proposed is evaluated.

EXPERIMENTS

The data acquisition was conducted by recreating a congested merge in a simulated environment on a DS. 24 vehicles were placed on the main lane, and the acceptability level was determined randomly on each trial. At the acceptability level 0, the vehicles on the main lane kept a distance of at least one car length, and the subjects changed a lane to an available space. At the acceptability levels 1 to 3, the distance between the vehicles on the main lane was less than one car length. When the predetermined time elapsed after the subjects turned on a winker to change a lane, the rear vehicle increased the distance from the lead vehicle and gave way. Moreover, when the subject vehicle came closer to the center line, the rear vehicle gave way regardless of the elapsed time. Finally, at the acceptability level 4, the vehicles on the main lane did not give way even the subjects turned on the winker. Only the moment when the subject vehicle crossed the center line, the rear vehicle increased the distance from the lead vehicle to avoid a collision with the subject vehicle. Seven subjects participated in the experiment. Three trials were conducted for each acceptability level.

Figure 2 shows the time headway between the

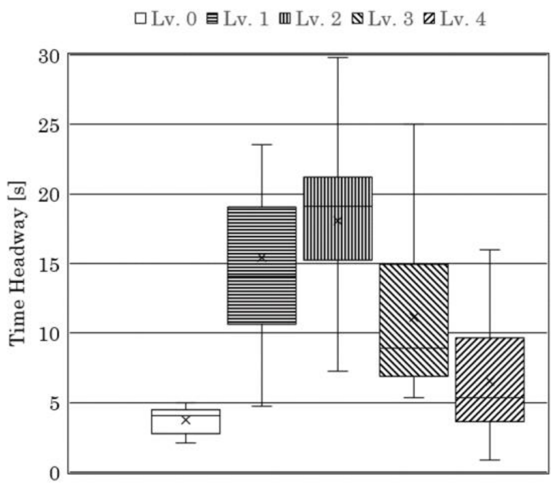

Fig.2 Time headway of each acceptability level

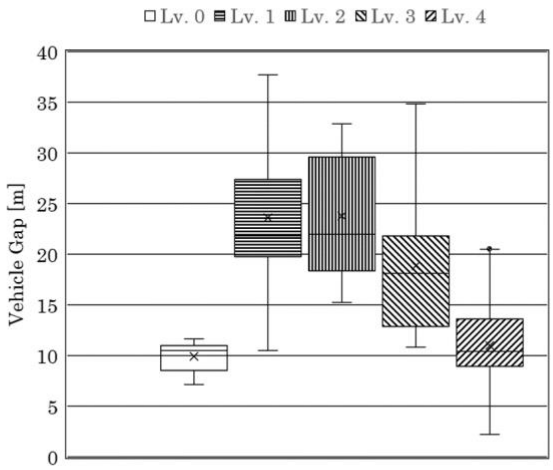

Fig.3 Vehicle gap of each acceptability level

merging and rear vehicles, and Fig.3 represents the vehicle gap between them. It is shown that the time headway and vehicle gap differ depending on the acceptability levels. It means that human drivers flexibly make a decision according to the driving characteristics of the main lane drivers. Based on the above results, the decision model of lane-changing was constructed as the Gaussian probability density function.

We conducted simulation to assess the safety of the lane-changing performed by the proposed method. The characteristics of the main lane drivers were randomly determined each trial, then, 100 trials were conducted. Through all trials, there was no collision between the merging and rear vehicles. From the results, it was demonstrated that the proposed method can perform safe lane changes autonomously at a congested merging area.

CONCLUSION

This paper proposed an autonomous lane-changing system at congested merging area. The decision model of lane-changing was construction by imitating human driver's operation. The effectiveness of the proposed method was demonstrated through simulation.