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A dynamic automated lane change maneuver based on vehicle-to-vehicle communication

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ABSTRACT

Automated driving is gaining increasing amounts of attention from both industry and academic communities because it is regarded as the most promising technology for improving road safety in the future. The ability to make an automated lane change is one of the most important parts of automated driving. However, there has been little research into automated lane change maneuvers, and current research has not identified a way to avoid potential collisions during lane changes, which result from the state variations of the other vehicles. One important reason is that the lane change vehicle cannot acquire accurate information regarding the other vehicles, especially the vehicles in the adjacent lane. However, vehicle-to-vehicle communication has the advantage of providing more information, and this information is more accurate than that obtained from other sensors, such as radars and lasers. Therefore, we propose a dynamic automated lane change maneuver based on vehicle-to-vehicle communication to accomplish an automated lane change and eliminate potential collisions during the lane change process. The key technologies for this maneuver are trajectory planning and trajectory tracking. Trajectory planning calculates a reference trajectory satisfying the demands of safety, comfort and traffic efficiency and updates it to avoid potential collisions until the lane change is complete. The trajectory planning method converts the planning problem into a constrained optimization problem using the lane change time and distance. This method is capable of planning a reference trajectory for a normal lane change, an emergency lane change and a change back to the original lane. A trajectory-tracking controller based on sliding mode control calculates the control inputs to make the host vehicle travel along the reference trajectory. Finally, simulations and experiments using a driving simulator are conducted. They demonstrate that the proposed dynamic automated lane change maneuver can avoid potential collisions during the lane change process effectively.

1. Introduction

Automated driving is considered as a promising solution to improve road safety in the future, and research on this subject is gathering increasing attention (Hatipoglu et al., 1997; Carbaugh et al., 1998; Girault, 2004; Tideman et al., 2010; Fraedrich and Lenz, 2014). Research about automated lane following is found in many studies (Adell et al., 2011). In contrast, little research about automated lane changes has been undertaken; however, the automated lane change is a necessary part for automated driving. Because lane change is not only the reason for 4–10% of all the accidents, but also cause for 10% of the latencies on roads (Ammoun et al., 2007).

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(Hidas, 2002) presented lane-changing models in a microscopic traffic network and developed an intelligent concept for lane changing and merging. However, the models are based on autonomous agent concept, which is far different from the real car. Zheng (2014) summarized two kinds of models about the lane change decision-making and lane change impact in detail. It is useful to have a better understanding of the lane change. However, the paper did not deal with the maneuver that guarantees an automated lane change. Chee and Tomizuka (1994a,b) and Chee et al. (1995a,b) studied automated lane change maneuvers including a comparison of four different desired trajectories and two trajectory-tracking algorithms. They selected a trapezoidal acceleration trajectory as the virtual desired trajectory and showed that the sliding mode controller was better at stabilizing the system. However, they considered lane-changing vehicle in isolation. Hatipoglu et al. (1995) designed an optimal lane change controller. The closed-loop system with respect to a certain optimality criterion led to a smoother and slightly delayed response compared to the open-loop system. A closed-loop lane change maneuver can be accomplished on curved roads in the same manner. Sledge and Marshek (1997) compared six candidate lane-change trajectories based on selected criteria. The comparison was treated as an optimization problem with prescribed continuity and boundary conditions, in which the length, curvature, and rate of change of curvature were taken as its costs. The maximum constant velocity was employed as an additional discriminator. The comparison showed that a quintic polynomial is the simpler of the two best lane-change trajectory functions. Papadimitriou and Tomizuka (2003) employed quintic polynomial to compute a lane change trajectory. Their trajectory treated obstacles as simplified s-topes and dynamic constraints were taken into consideration. The criterion for selecting the desired and achievable trajectory involved the choice of a single coefficient. This strategy can only handle obstacles at the starting instant; it cannot address obstacles that appear during the lane change process. Wan et al. (2011) introduced an algorithm for an automated lane change maneuver based on recognition of the surroundings. The algorithm employed on-board sensors for signals such as the speed of each vehicle and the relative distances between vehicles and estimated the final positions of the host and surrounding vehicles after the lane change maneuver. Wang et al. (2015) focused on the lane-change decision-making during the car following control, however, it did not pay much attention to the lane change process and just employed a simple lane-change reference trajectory, which did not consider the lateral speed and yaw rate of the lane-change vehicle. To the best of our knowledge, current research has not found a way to handle the potential of a collision occurring during the lane change process, and the existing trajectory planning methods have their limitations when dynamically planning a reference trajectory. One of the reasons is that on-board sensors cannot acquire information on the vehicles in the adjacent lane accurately.

However, with the development of vehicle-to-vehicle communication, which equips the vehicles with ability to communicate with each other, and its benefits, which include a larger perception range, more accurate information and more kinds of information (Ammoun and Nashashibi, 2010; Guan et al., 2011; Greg, 2014). With vehicle-to-vehicle communication, we can obtain more information about the surroundings and the available information is more accurate. A variety of applications in vehicle safety have already been developed (Kato et al., 2002; Gallagher et al., 2006; Misener, 2008; Williams et al., 2012; Hu et al., 2012).

With the help of vehicle-to-vehicle communication, the position, speed and acceleration of the vehicles in the adjacent lane can be acquired more accurately. Therefore, we design our automated lane change maneuver based on vehicle-to-vehicle communication.

The contributions of this paper are:

(1) The problem of how to avoid potential collisions occurring during the automated lane changing process is solved through a universal automated lane change maneuver. Other previous studies have seldom considered potential collisions during lane changes; in this paper, we employ minimum safety spacing as a guarantee of safety in the automated lane change process. With these criteria, the dynamic automated lane change maneuver adjusts its reference trajectory according to the environment with the help of vehicle-to-vehicle communication. It maintains a sufficient distance between the host vehicle and the other vehicles to avoid any type of collision. The dynamic automated lane change maneuver is not a special maneuver that is effective only for potential collision avoidance. It can also guarantee a smooth automated lane change when there is no potential collision threaten.

(2) The trajectory planning method is a universal method that can be applied to different scenarios. It takes safety, comfort and traffic efficiency into account. It employs a quintic polynomial as the trajectory function and the problem is converted into a constrained optimization problem based on the lane change time and distance. When the boundary conditions are updated as constraints, we update the reference trajectory. Therefore, this trajectory planning method can plan not only a reference trajectory in which the other vehicles maintain their states but also one in which the states of the other vehicles vary. In particular, it can plan a reference trajectory during the lane change that makes the host vehicle return to the original lane.

The rest of the paper is organized as follows. Section 2 describes the design of the dynamic automated lane change maneuver, which includes trajectory planning and trajectory tracking; Section 3 provides the results of simulations and experiments on automated lane changes in several typical scenarios, and Section 4 presents the paper's conclusions.

2. A dynamic automated lane change maneuver

An automated lane change maneuver should be carefully designed by considering a variety of factors, including safety and comfort. The proposed dynamic automated lane change maneuver has the structure shown in Fig. 1.