Connectivity Enhanced Safe Neural Network Planner for Lane Changing in Mixed Traffic

Extended Abstract

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ABSTRACT

Connectivity technology has shown great potentials in improving the safety and efficiency of transportation systems by providing information beyond the perception and prediction capabilities of individual vehicles. However, it is expected that human-driven and autonomous vehicles, and connected and non-connected vehicles need to share the transportation network during the transition period to fully connected and automated transportation systems. Such mixed traffic scenarios significantly increase the complexity in analyzing system behavior for highly interactive scenarios, e.g., lane changing. It is even harder to ensure system safety when neural network based planners are leveraged. In this work, we propose a connectivity-enhanced neural network based lane changing planner. By cooperating with surrounding connected vehicles, our proposed planner will adapt its planned trajectory according to the analysis of a safe evasion trajectory. We demonstrate the strength of our planner design in improving efficiency and ensuring safety in various mixed traffic scenarios with extensive simulations. We also analyze the system robustness when the communication or coordination is not perfect.

KEYWORDS

Connected and Autonomous Vehicles; Safe Neural Network Planner; Mixed Traffic; Human-driven Vehicles

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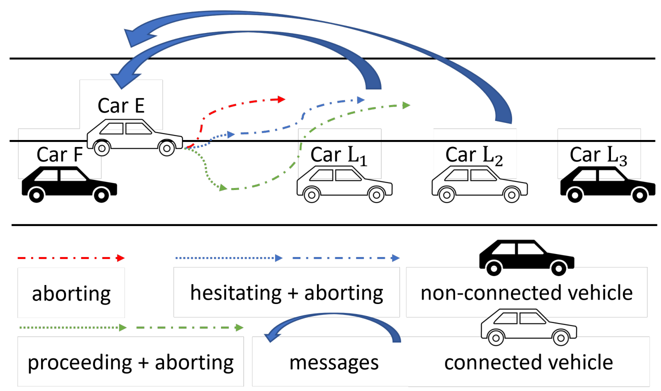

Figure 1: The ego vehicle E intends to change lane. With connectivity technology, vehicle E receives planned acceleration profiles and real-time motion states from connected leading vehicles L_i, $1 \le i \le N$, and then analyzes the maximum deceleration of vehicle L_1 during the lane changing process. By identifying the behavior of following vehicle F and analyzing system safety in the worst case, vehicle E may proceed to change lane, hesitate around the current lateral position, or abort the lane changing plan. This figure shows an example with $N = 2$ and the following vehicle F is non-connected.

1 INTRODUCTION

Connectivity technology [2, 3] for autonomous driving has been increasingly studied in academia and industry, which is expected to significantly improve transportation safety [1], energy efficiency [9] and mobility [8], although its adoption still faces various challenges including technical ones such as security [4, 5, 11] and communication disturbance [12, 13]. During the transition period to the next-generation transportation system, a mixed traffic stream of human-driven and autonomous vehicles [10], and connected and non-connected vehicles need to share the transportation network. It is an open challenge to model the behavior of a general system with all kinds of vehicles, not to mention providing safety guarantee while not overly sacrificing efficiency.

To overcome these challenges, we propose a connectivity-enhanced neural network based planner design, which can ensure safety for lane changing in mixed traffic. In this general framework, we assume that the ego vehicle is connected and autonomous, while surrounding vehicles can be either connected or non-connected, and either autonomous or human-driven. Figure 1 shows an example of the lane changing scenario.

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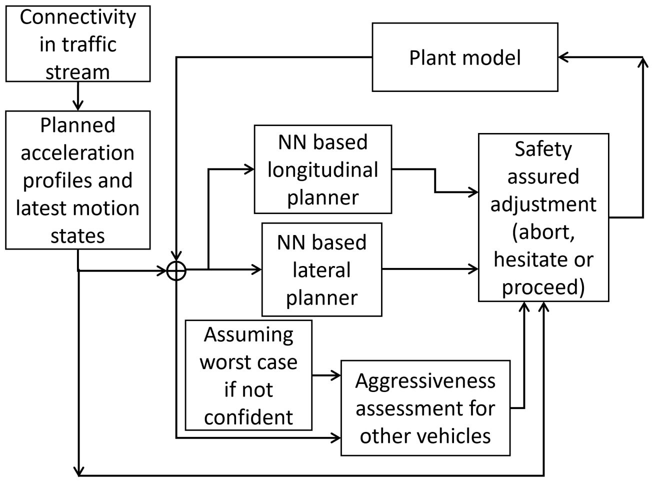

Figure 2: Design of our framework.

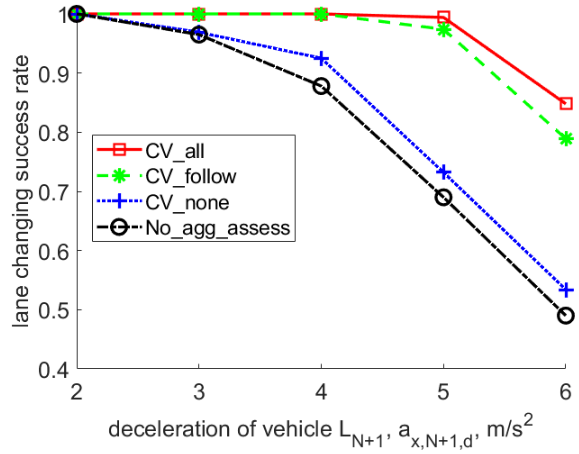

Figure 3: Lane changing success rate under different planners are compared when the number of connected leading vehicles is $N = 5$. The horizontal axes show the sudden deceleration of non-connected leading vehicle L_{N+1}.

2 DESIGN OF OUR FRAMEWORK

The intuition is that the planned trajectory does not need to complete the lane changing in one go. As long as there is a safe evasion trajectory, the ego vehicle can start the attempt and interact with surrounding vehicles. The framework is presented in Figure 2. Based on the planned acceleration profiles in the planning horizon and the real-time motion states of surrounding vehicles, we can leverage neural networks for longitudinal and lateral trajectory planning. At the same time, we can derive the maximum deceleration of the leading vehicle L_1 (scenario as shown in Figure 1), and then perform system analysis for the worst case and adjust trajectory to ensure safety. Here we adopt the same aggressiveness assessment method for the following vehicle F as in [7] when vehicle F is non-connected. For the case that the following vehicle F is connected, we assume that it is collaborative.

Safety analysis and trajectory adjustment are conducted periodically. At every step during the lane changing, the ego vehicle has three behavior-level options with strictly decreasing preference: proceed changing lane, hesitate around current lateral position, or abort changing lane and return back to the original lane. It analyzes the state after executing the accelerations under neural network based planners for one time step. If it has a safe evasion trajectory in the worst case, it can go ahead and change lanes. Otherwise, it has to attempt a less preferred behavior until a safe evasion trajectory is found following that.

For connectivity assumptions and detailed safety analysis, please refer to our full paper [6].

3 EXPERIMENTAL RESULTS

We compare system performance under a few different planners to demonstrate the effectiveness of our approach: ‘CV_all’ represents the complete planner framework as in Figure 2, in which we leverage information shared by all connected vehicles; ‘CV_follow’ means that we only use information shared by the following connected vehicle F; ‘CV_none’ means that connectivity technology is not leveraged, which is the planner in [7] and can be viewed as our main baseline; ‘No_agg_assess’ means that we conservatively assume following vehicle is always aggressive and disable the aggressiveness assessment function.

In this work, we use synthesised data to train longitudinal and lateral planners, similarly as the work in [7]. We conduct extensive simulations with different initial system states. Figure 3 presents the average lane changing success rate under different planners. Because safety is ensured by the trajectory adjustment function and there is indeed no collision in all simulations, we only present the results of lane changing success rate.

As we expected, lane changing success rate decreases when the deceleration $a_{x,N+1,d}$ gets larger. It shows that ‘CV_all’ performs slightly better than ‘CV_follow’, and these two planners result in considerably larger success rate, when compared to ‘CV_none’ and ‘No_agg_assess’. **This clearly shows the effectiveness of our approach in improving system performance.** It means that understanding the following vehicle’s intention can greatly help the lane changing maneuver of the ego vehicle, and connectivity of leading vehicles can further improve that.

For experiments with varied N and $a_{x,N+1,d}$, and unexpected promise violation, please refer to our full paper [6].

4 CONCLUSION

In this work, we present a connectivity-enhanced planning framework for neural network based lane changing in mixed traffic. The framework can significantly improve lane changing performance by coordinating with surrounding connected vehicles in dynamic environment. Extensive experiments demonstrate the strength of our planner design in improving efficiency while ensuring safety. Our experiments suggest that connectivity of the immediate following vehicle plays a more important role for ego vehicle’s lane changing than the connectivity of leading vehicles. We also demonstrate the system robustness under different extent of promise violation rate of surrounding connected vehicles.

ACKNOWLEDGMENTS

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