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主　論　文　の　要　旨

論文題目　Integrated Planner for Autonomous Driving in Urban Environments Including Driving Intention Estimation
（都市環境における自動運転のための他車運転意図推定機能を有する統合動作計画に関する研究）

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論 文 内 容 の 要 旨

Thousands are killed every day in traffic accidents, and drivers are mostly to blame. Autonomous driving technology is the ultimate technological solution to this problem. Moreover, autonomous driving technologies provide new social experience, reduce carbon emissions, reduce fuel consumption, save time and support aging communities. Planning, which determines the movement of autonomous vehicles, is the cornerstone of autonomous agent navigation. It is also one of the most difficult tasks to perform, because the safety of the vehicle, its passengers and other road users depend upon it.

Despite the thousands of autonomous vehicles currently operating on public roads for testing, there are still many unresolved problems with autonomous driving technology. For example, these systems are designed to drive defensively, but safety threats occur continuously while moving in traffic, especially in complex situations that involve interaction with human drivers. Better, more innovative, solutions for autonomous understanding of the intentions of other road users are still needed in order to achieve more natural driving performance. Another problem is that autonomous driving technology is still not standardized. Roads need to be mapped and driven on multiple times before automated driving tests can be conducted, and every development team has its own specific, closed implementations. This portability problem is the result of poor utilization of road network mapping standards.

Planning applications consist of multiple modules with different input/output spaces, and these modules need to be integrated correctly. Another challenge is the lack of open-source planning projects that allow cooperation

between development teams globally. Problems such as social interaction, understanding the intentions of other road users, and environment differences between various countries cannot be solved by just one team of developers, no matter how resourceful they are.

Open-source autonomous driving planners should also meet certain standards, such as the ability to support multiple platforms and adherence to mapping standards, as well as having acceptable performance, usability and extensibility. Although several open-source motion planners are currently available, unfortunately they all have drawbacks, such as poor utilization of standard road network maps, inability to support multiple platforms, difficulty of use and customization, and a lack of tutorials and support.

One reason that existing solutions for global planning (i.e., point-to-point navigation) are not efficient or portable enough is that they do not use standard road network maps. Likewise, performance of local planning algorithms tends to be improved by using imprecise object representations, and intention and trajectory estimation solutions for surrounding vehicles are currently able to achieve acceptable results in custom situations, but they usually cannot be generalized for other driving scenarios. And current generalized intention estimation techniques are still unable to achieve acceptable performance.

In order to address these problems, in this dissertation we describe the development of an open-source, integrated planner for autonomous navigation called "OpenPlanner". This planner is composed of a global path planner, a behavior planner, a probabilistic trajectory and intention predictor, and a local planner. The global planner generates smooth, global paths which are used as a reference, after considering traffic costs annotated in a road map. A road network map and a goal location are required to compute a global path and then execute it while avoiding obstacles. The local planner generates smooth, obstacle-free local trajectories, which are then used by a trajectory tracker to achieve low-level control. The behavior state generator then uses surrounding vehicle estimated intentions to handle tasks such as object following, obstacle avoidance, emergency stopping, stopping at stop signs and traffic light negotiation.

A novel technique for estimating the intention and trajectory probabilities of surrounding vehicles is also introduced, which enables long-term planning and reliable decision making. First, the behavior planner models an average driver following the driving rules, utilizing information provided by a road network map to provide the agent control signal. Next, a customized particle filter is integrated with the planner to model the uncertaint y of various intentions and trajectories. This probabilistic filter uses multiple sensing cues, such as pose, velocity, acceleration and turn signal information. The proposed estimation method supports various sensor modalities, depending on the availability of different types of sensing information. Finally, by using the sensor data, the probabilistic process is able to estimate the probabilities of various trajectories and intentions.

The integrated planner described in this dissertation was evaluated using simulation, and through field experimentation with a non-holonomic, Ackerman steering-based mobile robot. Results from our simulation and field experimentation indicate that the proposed planner can generate global and local paths dynamically, navigate smoothly through highly dynamic environments and operate reliably in real time, by utilizing the probabilities of the estimated intentions and trajectories of other road users.

This integrated planner has already been implemented as part of Autoware, which is an open-source autonomous driving framework, built using the Robot Operating System (ROS). Autoware has drawn a lot of attention internationally, and has been utilized in several projects by academic and commercial teams. Collaboration and feedback from the open-source autonomous driving community has allowed us to tackle some of the problems mentioned above.