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Industrial PhD

Safety and Robustness in Mobile Robot Motion Planning

Learning- & Optimization-based Control

There exists more than one definition for safety of motion planning in dynamic environments. These loosely range from requiring that the motion plans are (provably) collision-free considering any legal maneuver by other agents [1]; to the much less conservative requirement that there always exists at least one collision-free braking maneuver for all moving objects [2]. More generally, one can consider safety as a part of a game where other agents are considered to be rational actors (collaborative or competitive), the goal here is to identify the Nash equilibria and ensure safety for those cases [3]. In general, achieving safety in motion planning non-conservatively is challenging, operating at the highest efficiency often implies that robots move on the boundary of what is still safe. At the same time, it needs to be addressed that information about the environment is incomplete, and sensors, actuators and models of the vehicle itself are imperfect.

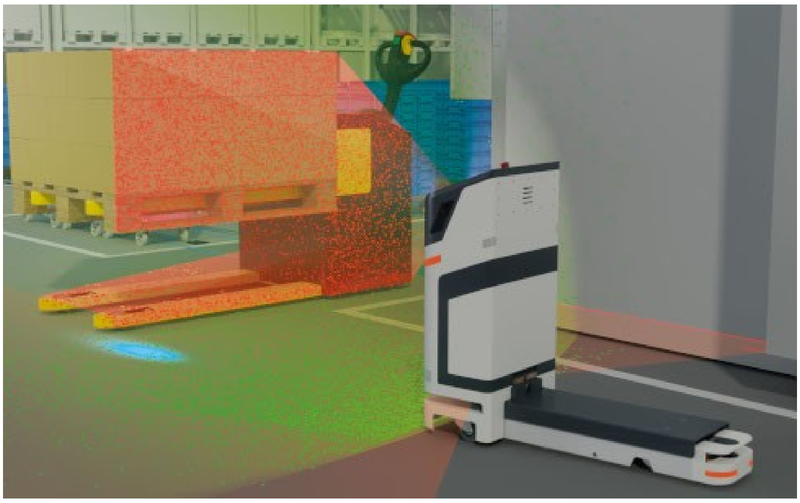

Figure 1: The ActiveShuttle by Bosch Rexroth, an autonomous transportation robot.

The common approach to achieving safety in industry and across various fields of research is to dedicate a separated safety control unit to intercept all control commands and alter the commands if ought necessary. In industry it is common to install one or multiple safety laser scanners on the mobile robot from that continuously monitor velocity-dependent areas around the robot to be free of any obstacles and brake otherwise. This approach is straightforward and practical for low-speed driving scenarios (< 3 m/s) where the monitored areas can be kept small through short braking distances. Safety concepts from research includes those based on reachability analysis, with applications in autonomous driving [4, 5, 1] and mobile robotics [6, 7]. This approach advances beyond the industrial safety laser scanner-based concept in two ways, firstly, by explicitly considering all possible future trajectories (composing the reachable set) of surrounding agents and secondly, by computing fail-safe emergency maneuvers that can have any realizable shape instead of "reserving" areas based on pre-defined braking trajectories. More recently, the concept of a so-called safety filter is proposed in the context of robotic applications [8]. This filter is based on Model Predictive Control and uses an updating safety policy considering uncertainties in the state and input of the system and automatically adapts the policy as more data is collected. It attempts to achieve safety while minimally changing the commanded controls. Note that all the above-mentioned methods do not perform the motion planning of the desired trajectories themselves and do not make strong assumptions about what (higher-level) algorithm provide the control commands.

Consider the increasing complexity of motion planning algorithms that comes from planning in dynamic environments [9], introducing interaction-awareness [10] and applying learning concepts such as reinforcement learning [11]. It is indeed practical to keep the safety control separated from the motion planning. It can be ensured that the safety control unit is certifiably safe, which will at least require real-time (deterministic) execution and the possibility to exclude unexpected behavior. Both of these requirements can currently not be realistically guaranteed for motion planners of the classes mentioned above and a separation of safety is a way to deal with that. However, in practice it is observed that the motion planner does need to be aware of the behavior of the safety controller in order to not "deliberately" trigger its interference. This can be achieved by either explicitly modeling the behavior of the safety controller, or to accommodate that the controller can learn the behavior of the safety controller.

This thesis is about exploring the possibilities to increase performance of the robot control system by achieving a tighter integration between the motion planning and safety control, e.g. by a continuous information exchange. Performance is here primarily measured in terms of the efficiency at which the robots executes its tasks while collaborating with its environment. A major goal is to achieve that the devised methods and algorithms are real-time applicable on cost-effective computational hardware by employing fast solvers for optimal control [12].

Scope

Possible directions of research for the PhD project are:

- Strategies to achieve provably robustly safe mobile robotic systems, going beyond the performance achievable by using current industrial safety concepts.
- Motion planning problem formulations that embed and exploit (uncertain) interactive models of the environment and autonomous dynamic agents.

- Development of efficient software and tools to achieve sufficiently fast computations of the proposed solutions to enable experimental validations.

Impact

In addition to the foreseen scientific outcomes, practical impact can be expected in applications where mobile robots operate in the vicinity of humans, such as on transportation robots in factories and in the intralogistics domain. The above research activities will enable mobile robots to move signficantly faster, while maintaining and potentially pushing forward safety standards for industrial mobile robots.

Candidate Profile

We expect from applicants that they have:

- An excellent MSc degree in Control, Mathematics, or a related field.
- Proven programming skills (preferably C/C++).
- A background in optimization-based control, and ideally robust control.

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