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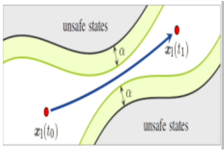
Start: Immediate start possible **Duration:** 6 Months

☐ Experimental ☒ Application-orientated ☒ Theory-orientated

Your Interests:

☒ Robotics ☒ Functional Safety
☒ Trajectory Planning ☒ Modeling
☒ Optimization ☒ System Dynamics



Master Thesis

Captivity-Escape Games as a Means for Safety in Online Motion Generation for Industrial Robots

Motivation: Robotics is a key driver of automation in modern manufacturing processes. Industrial robots enable high precision, repeatability, and efficiency, reducing costs and improving product quality. However, as robots are increasingly integrated into flexible production environments, the complexity of motion planning also grows.

In modern robotic applications, optimal trajectory planning is often employed to maximize efficiency and performance. Optimization methods, however, tend to produce solutions that lie on the boundary of feasible conditions. Even small modeling uncertainties or disturbances can therefore lead to violations of safety-critical constraints. To prevent this, specialized methods for ensuring safety in online motion planning are required.

Traditional approaches address this issue by introducing safety margins around obstacles or constraints. These margins are often chosen heuristically, resulting in overly conservative trajectories that limit efficiency. Furthermore, existing methods are frequently computationally expensive and lack numerical accuracy.

The theory of Captivity-Escape Games provides a foundation for developing minimally invasive approaches to guarantee safety in online motion generation. These approaches reduce the conservatism of existing methods while providing safety guarantees with low computational overhead and high numerical accuracy. So far, such methods have been successfully applied to mobile robots. The goal of this thesis is to adapt this methodology to industrial robots, which present different dynamics, workspaces, and safety requirements

Image source: ompl.kavrakilab.org/2017/12/05/fastrack.html

Task Description:

The thesis begins with a literature review covering the fundamentals of robotics, existing safety methods for trajectory planning, and the theoretical foundations of Captivity-Escape Games, as well as related concepts such as Barrier Functions and Reachability Analysis. The mathematical principles of the Captivity-Escape approach will then be revisited and deepened to establish a solid understanding of the underlying differential game theory.

A core part of the work is the computation of the Captivity Set, which inherently requires determining the optimal control strategy that defines this set. The developed methodology will then be adapted to the specific requirements of industrial robots and, if necessary, extended to handle higher-dimensional systems or more complex dynamics.

Validation will be carried out through simulation in an appropriate environment, with optional testing on a real robot (e.g., UR). Finally, the results will be documented, and potential extensions will be discussed.

Image source: www.universal-robots.com