

Contact Person:



Jan Riffel M.Sc.

IRS, Room 002

Tel.: 0721/608-42707

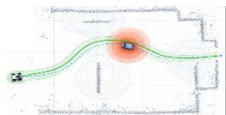
jan.riffel@kit.edu

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

☐ Experimental ☒ Application-orientated ☒ Theory-orientated

Your Interests:

☒ Mobile Robotics ☒ Functional Safety
☒ Autonomous Vehicles ☒ Modeling
☒ Optimization ☒ Safe Motion Planning



Master Thesis

Robust and Nonsmooth Control Barrier Functions Based on Captivity-Escape Games

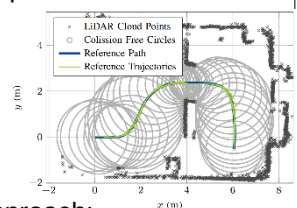
Motivation: How can a system react safely when unexpected effects occur, such as external disturbances or inaccuracies in its motion model? Safe motion generation for autonomous vehicles requires accounting for differences between simplified models used for motion planning and the actual vehicle dynamics. Previous work at the Institute for Control Systems uses Captivity-Escape Games (CEGs) to characterize robust tracking-error sets between a low-fidelity planning model and a higher-fidelity vehicle model. For the existing vehicle demonstrator, this results in a nonlinear three-state relative model.

Recent work provides two ways to obtain a Control Barrier Function (CBF) for this safety problem: a model-based construction from nested CEGs and a learned CBF that approximates the same safety information. CBFs encode safety as state-dependent constraints on the control input and can be integrated into an optimization-based safety filter, allowing the nominal controller to be modified only when necessary without requiring an explicit hard switch to a separate safety controller. Both CBF representations can therefore be enforced online through a common CBF-based safety filter.

The goal of this thesis is to develop and implement this safety filter and compare both CBF approaches in simulation, in the digital vehicle environment, and on the real demonstrator. The comparison focuses on safe-set approximation, conservatism, robustness, computational effort, and real-time performance.

Task Description:

- familiarization with Captivity-Escape Games, Control Barrier Functions, and the existing vehicle tracking framework;
- application of the existing nested-CEG CBF construction to the nonlinear three-state vehicle tracking model and integration of the provided learned CBF approach;
- design and implementation of a common CBF-QP safety filter that can use both CBF representations interchangeably;
- validation of the controller in simulation and within the digital vehicle environment;
- systematic comparison of both approaches regarding safe-set approximation, conservatism, robustness, offline effort, and online computation time;
- implementation and experimental validation on the real vehicle demonstrator;
- documentation and scientific discussion of the obtained results.



Background: This thesis is suitable for students interested in control engineering, robotics, autonomous vehicles, or learning-based control. Some background in control engineering and programming experience in Python, MATLAB, C++, or a similar language is helpful. Existing CBF and learning implementations are provided as a starting point; prior knowledge of differential games, CBFs or neural networks is not required.