Karlsruher Institut für Technologie

Institut für Regelungs- und Steuerungssysteme
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Contact:

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Start: Summer/Fall 2021 **Duration:** 4-6 months

Topics:

State Estimation, Optimization, Cooperative Control, Machine Learning

Abroad Research Stays / Master Theses

Cooperative State Estimation and Control

Description:

A research collaboration between the University of Waterloo in Canada and the Institute of Control Systems (IRS) of the KIT is offering research stays and master theses in the field of cooperative systems for outstanding master students.The projects have a duration of up 4 to 6 months and take place in Waterloo, Canada. The topics include modeling and identification, optimization and control of cooperative systems for applications in robotics and driving assistance systems.

Current research projects are the following:

- **Safe Merging for Automated-Natural Driving Systems**

The positions offer the possibility to experience research in an international environment, use state-of-the-art test facilities as the University of Waterloo's RoboHub (https://uwaterloo.ca/robohub/), and ultimately to contribute to further advances in automatic control theory. The research projects are supervised by Prof. Ehsan Hashemi of the University of Waterloo's Department of Mechanical and Mechatronics Engineering. The IRS officially nominates elected students for the application to exchange programs of the University of Waterloo and also supports them in organizational matters.

Further details on the research projects can be found in the next pages.

Requisites:

- Enrollment in the Master program of ETIT or MIT
- Solid knowledge in modeling and identification, state space methods and optimization, e.g. from the IRS lectures MI, RLM and ODS/ORS
- Proficient English speaking and writing skills

How to apply:

- Prepare a single PDF file which includes
    - a short motivation letter (addressed to Prof. Sören Hohmann)
    - your CV
    - A transcript of records of your bachelor and master studies
    - Other relevant documents of your choice
- All documents must be written in English (employer references may be submitted in German)
- Send the PDF to Jairo Inga (jairo.inga@kit.edu)

Project Proposals for Waterloo-KIT Collaborative Research

Ehsan Hashemi (University of Waterloo–MME) and Prof. Sören Hohman (KIT–IRS)
July 28, 2020

1. **Safe Merging for Automated-Natural Driving Systems**

   Overview of Project: Safe merging within the traffic flow in highways is an essential component for natural human drivers and advanced driver-assistance systems (ADAS). This problem is even more complex and crucial when the merging is happening between an autonomous vehicle (AV) and a natural human driver. Existing solutions in intelligent transportation system are generally focused on merging between two (or more) fully automated driving systems by using machine learning and leveraging advances in connectivity between the vehicle and infrastructure, or relying on accurate vehicle and tire models in AVs. However, such architectures for trajectory planning and guidance control between a human and a fully (or partially) automated driving systems in merging scenarios are prohibitively inefficient due to: *i)* not having access to the natural drivers' targets and more specifically cost functions; and *ii)* computational complexities and corner cases in data-driven methods for a control system having autonomous-human components. This project aims to develop a safe control strategy for automated driving systems, in highway merging scenarios, in presence of other vehicles with human drivers, by forming the problem in a game-theoretic representation and investigating how Machine Learning can contribute to adaptation of the controller.

   Project Specifics and Objectives: This research project aims to develop a safe non-cooperative (or cooperative) game-theoretic based control strategy and motion planning in highway merging for AVs while maintaining vehicle lateral stability by using available local sensory information (LiDar, radar, vision, IMU, steering, and wheel speed) and considering actuators' bandwidth and the combined-slip effect in the vehicle dynamics. The combined-slip tire forces is a contributor in such merging maneuvers due to quick acceleration/brake requests (by the motion planner) that result in considerable drop in lateral tire forces, thus affect vehicle stabilization and safety.

   You will first model the vehicle's combined longitudinal/lateral dynamics by considering the actuators' (i.e., active front steering and brakes) bandwidth and include the above mentioned available measurements that provide information on neighbour objects/vehicles position, ego vehicle localization, and vehicle states, such as sideslip and corner slip ratios. (see [1, 2, 3, 4, 5, 6]). Then, you will form a game-theoretic representation for two players (i.e., the ego autonomous vehicle and a regular vehicle with natural human driver) which do not have access to each others' cost functions and objectives for path tracking, stability, and handling criteria; you will also investigate how machine learning helps identification of major objective function components for each player, thus affect safety. Further challenges are:

   - Inter-vehicular distances and relative speeds are prone to error and disturbances based on GPS coverage/bandwidth as well as radar and vision system accuracy; you need to consider such disturbances and uncertainties in the model development and controller design

- Vehicle's corner/tire slip information, which affect lateral stability, is available only for the ego autonomous vehicle. Thus, based on consecutive observation of the regular vehicle with human driver, you need to investigate what states could be used in a non-cooperative game to quantify vehicle stabilization and tracking objectives in a game setting
- Varying road surface friction and robustness of a safe merging control strategy to major model parameters are challenges that needs to be studied and tackled.

More specifically, tasks to achieve main objectives include: *i)* develop a new merging model in a game setting by including tire slips, actuator dynamics/bandwidth, and longitudinal/lateral dynamics for the combined automated-natural driving systems, containing an ego AV and a regular vehicle; *ii)* characterize how robust is the control strategy due to uncertainties in the model (such as road friction), noises in the measurements (IMU, wheel speed, and steering), and errors in the localization and perception algorithms; *iii)* investigate how machine learning methods can contribute to identification of model parameters (by Recurrent Neural Networks, Locality-Sensitive Hashing, Long Short-Term Memory, etc.) and adaptation of the control law (by Reinforcement Learning); and *iv)* investigate a possible mitigation plan for measurement loss (such as GPS perception) through V2X connectivity.

Pre-requisites: Linear systems theory, game theory, machine learning, and MATLAB/SIMULINK®
Desirable: System identification and robust control theory

Learning Outcomes:

- Modeling vehicle longitudinal/lateral dynamics by considering the combined-slip effect and actuators' bandwidth
- Designing game-theoretic based controllers for highway merging between two vehicles/players that do not have access to the other player's cost function and objectives
- Understanding design for continuous-time and discrete-time dynamics
- Investigating robustness of such non-cooperative merging game to model uncertainties
- Applying machine learning methods (discussed above) for local model identification and game control law adaptation

References

[1] Ehsan Hashemi, Milad Jalali, Amir Khajepour, Alireza Kasaiezadeh, and Shih-Ken Chen. Vehicle stability control: Model predictive approach and combined-slip effect. *IEEE/ASME Transactions on Mechatronics*, 2020.

[2] Junqing Wei, John M Dolan, and Bakhtiar Litkouhi. Autonomous vehicle social behavior for highway entrance ramp management. In *2013 IEEE Intelligent Vehicles Symposium (IV)*, pages 201–207. IEEE, 2013.

[3] Yangliu Dou, Fengjun Yan, and Daiwei Feng. Lane changing prediction at highway lane drops using support vector machine and artificial neural network classifiers. In *2016 IEEE International Conference on Advanced Intelligent Mechatronics (AIM)*, pages 901–906. IEEE, 2016.

[4] Niclas Evestedt, Erik Ward, John Folkesson, and Daniel Axehill. Interaction aware trajectory planning for merge scenarios in congested traffic situations. In *2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC)*, pages 465–472. IEEE, 2016.

[5] Jackeline Rios-Torres and Andreas A Malikopoulos. A survey on the coordination of connected and automated vehicles at intersections and merging at highway on-ramps. *IEEE Transactions on Intelligent Transportation Systems*, 18(5):1066–1077, 2017.

[6] Roman Schmied and Patrizio Colaneri. Mixed $h_2 - h_\infty$ control for automated highway driving. *Mechatronics*, 57:63–72, 2019.