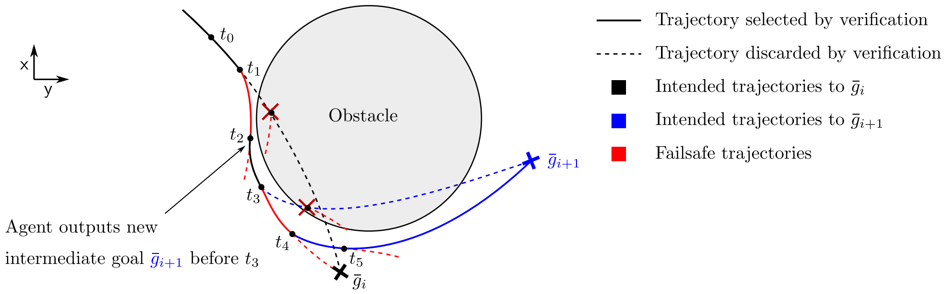
Predictive Safety Certification for Human-Robot Interaction

Background

The growing use of robots in various fields such as surgical procedures, manufacturing, agriculture, and construction has made the coexistence and collaboration between humans and robots increasingly crucial. Ensuring human safety during interactions with robots is essential to enable robots to work within human environments. Our approach, which is visualized below, employs a fail-safe planner designed to halt the robot before any potential collision occurs: For a given desired trajectory, at each time step, we compute the next optimal action followed by a fail-safe maneuver, which brings the robot to a complete stop within predefined braking limits. This trajectory is subsequently verified for safety using reachability analysis, wherein we calculate the reachable sets of both the human and the robot, checking for intersections along the fail-safe maneuver. If the trajectory is confirmed to be safe, the robot proceeds with the next planned step; otherwise, it adheres to the previously computed fail-safe maneuver. This methodology ensures provably safe robot behavior by leveraging the concept of speed and separation monitoring [1]. However, bringing the robot to a complete stop is not time-efficient and, thus, we aim to explore more economic alternatives.



Visualization of the existing safety concept [3].

Description

The goal of this thesis is to develop a time-efficient safety filter using model predictive control (MPC). MPC computes a sequence of control inputs by solving an optimization problem, which enables the seamless consideration of safety constraints. In case of the safety concept described above, we can formulate an optimization problem that makes the robot to follow the desired trajectory closely while keeping a safe distance to the human; thereby reducing the loss of time. Your task is to implement a suitable MPC algorithm and compare its performance with our previous approach, see e.g. [3] as well as the MPC-based approach in [2]. As a second part of this thesis, your implementation should be evaluated on a real robot.

This thesis provides you with the opportunity to get to know a state of the art control and motion planning algorithm as well as deploying your implementation on a real robot. Moreover, you gain/deepen your knowledge in numerical optimization.

Tasks

- Familiarization with our safety concept, see e.g. [3], and the MPC-based approach in [2].
- Familiarization with MPC and reachability analysis.
- Formulation of the optimization problem and suitable safety constraints.
- Comparison of your MPC-based approach with our exisitng safety concept and the approach from [2].
- Integration and evaluation on a real robot.
- Documentation of your results.

Technical University of Munich

TUM School of Computation, Information and Technology

Associate Professorship of Cyber-Physical Systems

Supervisor:
Prof. Dr.-Ing. Matthias Althoff

Advisor:
Julian Balletshofer, M.Sc.
Lukas Schäfer, M.Sc.

Research project:
Safe Human-Robot Interaction

Type:
Master's thesis

Research area:
Human-robot interaction, optimal control

Programming language:
C++, ROS

Required skills:
Solid C++ knowledge.
Background in numerical optimization beneficial.

Language:
English

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For more information please contact us:

E-Mail:
julian.balletshofer@tum.de,
lukas.schaefer@tum.de

Internet: www6.in.tum.de

References

[1] ISO/TS 15066:2016. Robots and robotic devices - collaborative robots. *International Organization for Standardization,Geneva, Switzerland*, 2016.

[2] Moritz Eckhoff, Robin Jeanne Kirschner, Elena Kern, Saeed Abdolshah, and Sami Haddadin. An mpc framework for planning safe trustworthy robot motions. In *2022 IEEE International Conference on Robotics and Automation (ICRA)*, pages 4737–4742, 2022.

[3] Jakob Thumm and Matthias Althoff. Provably safe deep reinforcement learning for robotic manipulation in human environments. *2022 International Conference on Robotics and Automation (ICRA)*, pages 6344–6350, 2022.

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