Academic advisor	
Industry supervision	Yunfan Gao, Dr. Andrey Rudenko, Dr. Niels van Duijkeren
Company	Robert Bosch GmbH, Corporate Research, Stuttgart
Earliest starting date	Feb. 1st, 2025

Master Thesis

Collision-Free Smooth Motion Planning Among Humans

Robots are increasingly becoming part of daily life, such as delivery robots on sidewalks and service robots in restaurants. Ensuring smooth motions while safely avoiding humans remains a challenge. Properly utilizing uncertainty-aware human trajectory predictions is one of the key aspects in achieving smooth robot motions among humans. Recent work of human trajectory prediction uses non-parametric distributions for human motion uncertainties, allowing for more diverse and accurate predictions [1, 2]. While leveraging advanced trajectory predictions could enhance robot motion planning performance, the literature on utilizing these results in mobile-robot motion planning is sparse.

Uncertainties modeled by Gaussian distributions (or Gaussian mixture models) can be treated in stochastic model predictive control (MPC) by tightening the constraints based on the uncertainty level sets quite straightforwardly [3]. For more general (including non-parametric) distributions, however, parameterizing such uncertainties for constraint robustification is far more challenging. Scenario-based stochastic MPC provides one way to handle such uncertainty distributions [4], but this results in a large number of constraints, making the optimal control problem (OCP) difficult to solve. In this thesis, you will investigate proper ways of sampling and selecting the human uncertain trajectories to be imposed as constraints in the OCP and assess the resulting computational efficiency and robot motion performance.

The developed controller will be made into a nav2 plugin[1] and be deployed on a physical mobile robot. The objective is to showcase a demonstration in which the robot drives among humans in the canteen during lunchtime, navigating through narrow, twist-and-turn corridors and avoiding moving humans based on their motion predictions.

The objectives of this thesis are to:

- Obtain the prediction of human trajectories and the uncertainty measurements using state-of-the-art neural networks.
- Formulate an OCP such that optimal robot trajectories probabilistically satisfy the collision avoidance constraints given the human trajectory predictions.
- Solve the resulting OCP sufficiently fast for real-time applications.
- Experimentally validate your method on physical mobile robots around people.

[1] https://docs.nav2.org/plugins/index.html

Prerequisites

- MSc in Robotics, Systems & Control, or similar.
- Affinity with programming in Python, C++, CUDA, and Rust.
- Experience with ROS2 is a plus.

References

[1] A. Gupta, J. Johnson, L. Fei-Fei, S. Savarese, and A. Alahi, "Social GAN: Socially acceptable trajectories with generative adversarial networks," in *IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, 2018.

[2] T. Salzmann, B. Ivanovic, P. Chakravarty, and M. Pavone, *Trajectron++: Dynamically-Feasible Trajectory Forecasting with Heterogeneous Data*. Springer International Publishing, 2020, pp. 683–700.

[3] X. Zhang, J. Ma, Z. Cheng, S. Huang, S. S. Ge, and T. H. Lee, "Trajectory generation by chance-constrained nonlinear MPC with probabilistic prediction," *IEEE Transactions on Cybernetics*, vol. 51, no. 7, pp. 3616–3629, July 2021.

[4] G. Schildbach, L. Fagiano, C. Frei, and M. Morari, "The scenario approach for stochastic model predictive control with bounds on closed-loop constraint violations," *Automatica*, vol. 50, no. 12, pp. 3009–3018, Dec. 2014.