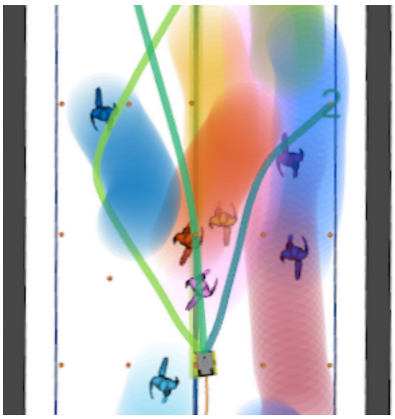
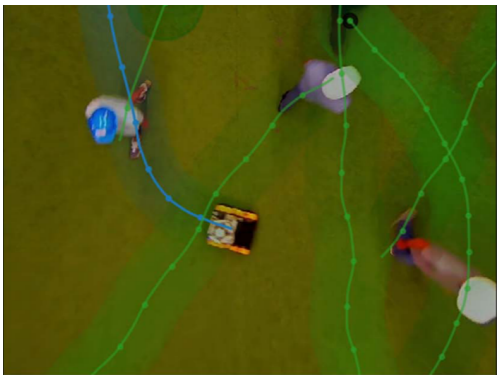
Interaction-aware MPPI for navigation in humanly crowded environments

MSc. Project at Autonomous Multi-Robots Lab, Cognitive Robotics, TU Delft





Brief Description: Navigation in humanly crowded environments has attracted substantial research attention over the last decade. The core challenge lies in enabling robots to move safely and efficiently while accounting for the complex and dynamic interactions among humans.

Many existing, such as Model Predictive Control (MPC) planners typically decouple prediction from planning: future trajectories of surrounding agents are predicted independently of the robot's planned actions. This assumption limits performance in crowded environments, where humans naturally react to the robot and adapt their motion accordingly.

Sampling-based methods such as Model Predictive Path Integral (MPPI) control allow interactions to be incorporated directly into the planning process. However, most interaction-aware formulations implicitly assume that dynamic agents optimize a known or simplified policy [3, 6], which may not accurately reflect human behavior. An appealing direction is to leverage data-driven human trajectory prediction networks that can model realistic human motion [7, 1], while conditioning these predictions on the robot's candidate plans. This would allow the planner to reason about how humans are likely to respond to different robot behaviors during planning itself.

Finally, to complement low-level interaction-aware control, topology-based planning [4, 5] can be used to guide high-level decision making. By reasoning over topological representations of the environment and crowd flow, the robot can select semantically meaningful strategies before refining them with MPPI. Nonlinear opinion dynamics [2] have the potential to enable a fast and robust high-level decision making process adaptable to human motion, providing indecision breaking guarantees. Combining topology-based planning with interaction-aware MPPI and conditioned human trajectory prediction has the potential to yield a scalable and socially compliant navigation framework for

crowded environments.

Requirements:

- Highly motivated
- Experience with deep learning
- Experience with MPPI and simulation
- Experience with hardware experiments is a bonus

What you can learn:

- Experience with combining deep learning and control for robotics
- Implementation of a full navigation system where you can see your results
- Chance to publish in high-ranking robotic conferences/journals

Start Date: January 2025-April 2025

For further questions or to apply, please contact Diego Martinez-Baselga (d.martinezbaselga@tudelft.nl). When applying, please provide a short motivation, an up-to-date CV, a transcript of your current degree program, and the intended start date.

Group information: www.autonomousrobots.nl

References:

[1] Inhwan Bae, Young-Jae Park, and Hae-Gon Jeon. Singulartrajectory: Universal trajectory predictor using diffusion model. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pages 17890–17901, 2024.

[2] Anastasia Bizyaeva, Alessio Franci, and Naomi Ehrich Leonard. Nonlinear opinion dynamics with tunable sensitivity. *IEEE Transactions on Automatic Control*, 68(3):1415–1430, 2022.

[3] Yuxiao Chen, Sushant Veer, Peter Karkus, and Marco Pavone. Interactive joint planning for autonomous vehicles. *IEEE Robotics and Automation Letters*, 9(2):987–994, 2023.

[4] Oscar de Groot, Laura Ferranti, Dariu M. Gavrila, and Javier Alonso-Mora. Topology-driven parallel trajectory optimization in dynamic environments. *IEEE Transactions on Robotics*, 41:110–126, 2025.

[5] Diego Martinez-Baselga, Oscar de Groot, Luzia Knoedler, Luis Riazuelo, Javier Alonso-Mora, and Luis Montano. Shine: Social homology identification for navigation in crowded environments. *The International Journal of Robotics Research*, 45(1):60–79, 2025.

[6] Dorsa Sadigh, Nick Landolfi, Shankar S Sastry, Sanjit A Seshia, and Anca D Dragan. Planning for cars that coordinate with people: leveraging effects on human actions for planning and active information gathering over human internal state. *Autonomous Robots*, 42(7):1405–1426, 2018.

[7] Tim Salzmann, Boris Ivanovic, Punarjay Chakravarty, and Marco Pavone. Trajectron++: Dynamically-feasible trajectory forecasting with heterogeneous data. In *European Conference on Computer Vision*, pages 683–700. Springer, 2020.