Harmonious Mobility for Robots that Work with and around People

Christoforos Mavrogiannis

Department of Robotics
University of Michigan, Ann Arbor, MI, USA
cmavro@umich.edu

The integration of advances from machine learning and computer vision with the classical autonomy stack has brought successful robot deployments in fulfilment, manufacturing, and transportation. However, unstructured and dynamic environments such as pedestrian spaces and streets, workplaces, and homes pose additional challenges such as modeling human behavior, understanding user perceptions, and ensuring human safety and comfort. My work addresses such challenges to enable robots to fluently work with and around people to increase productivity and assist users.

Competent navigation in crowds. Humans seamlessly avoid collisions with each other in pedestrian domains, thanks to cooperative collision avoidance encoded in their passing strategies. My work formalizes mathematically a notion of passing using tools from algebraic topology. Based on this formalism, I developed a reactive, passing-aware model predictive controller for crowd navigation. This controller reasons about and expedites the unfolding pairwise passing encounters with conavigating humans. I have deployed this controller on multiple robot platforms, including a human-size telepresence robot and a shorter, self-balancing robot. Across extensive lab experiments featuring challenging and diverse crowd conditions, my controller delivered significantly safer and more efficient performance than state-of-the-art baselines (Mavrogiannis et al. 2023b).

Beyond safety and efficiency. Human safety and robot efficiency don't say much about user experience next to navigating robots. My work delves deep in understanding users' impressions. In one of my studies (N=105), our robot navigated under dense and diverse crowd conditions in a tight lab space (Mavrogiannis et al. 2022). When running our passing-aware navigation algorithm, users exhibited lower acceleration and reported fewer disruptions by the robot, compared to baselines, suggesting that our algorithm allowed users to walk more comfortably around it. Crucially, this quantitative observation was appreciated by users, who contributed quotes like "I barely noticed the robot when I was performing the tasks" when navigating next to our controller, versus quotes like "I felt the robot was in my personal space" or "I had no idea what the robot was doing" when the robot was running baselines.

Robust field deployment via bystander help. The complexity and richness of dynamic and unstructured environments often challenges robots in ways that they were not designed to handle. As such, it is crucial to equip them with strategies for short-term recovery but also lifelong learning. One practical strategy is to leverage human help. While help from expert researchers is most effective, it is not scalable; in contrast, help from nonexpert bystanders might help keep robots running and learning over long periods. In a recent study (Nanavati et al. 2022), only 30' of human help from a researcher empowered a robot to navigate a 28,000 ft^2 building floor for 4 days. However, scaling to bystander help requires reasoning (among others) about contextual and individual factors influencing human help, like human busyness, and intrinsic helpfulness, as we saw in an online user study in a virtual office environment (Nanavati et al. 2021).

Robots that fluently work with and around people. My future agenda seeks to develop pieces of autonomy that will enable robots to reason about humans, and plan autonomous or semi-autonomous human-aware behavior to ensure human comfort, safety, and productivity across lifelong field deployments. Tying together human behavior prediction, context understanding, and robot motion generation while drawing connections between quantitative and qualitative measures remain central parts of my research (Poddar et al. 2023; Mavrogiannis et al. 2023a).

References

Mavrogiannis et al. 2022. Social Momentum: Design and Evaluation of a Framework for Socially Competent Robot Navigation. *ACM Transactions on Human-Robot Interaction*.

Mavrogiannis et al. 2023a. Core Challenges of Social Robot Navigation: A Survey. *ACM Transactions on Human-Robot Interaction*.

Mavrogiannis et al. 2023b. Winding through: Crowd navigation via topological invariance. *IEEE Robotics and Automation Letters*.

Nanavati et al. 2021. Modeling Human Helpfulness with Individual and Contextual Factors for Robot Planning. In *Robotics: Science and Systems*.

Nanavati et al. 2022. Not All Who Wander Are Lost: A Localization-Free System for In-The-Wild Mobile Robot Deployments. In *ACM/IEEE International Conference on Human-Robot Interaction*.

Poddar et al. 2023. From crowd motion prediction to robot navigation in crowds. In *IEEE/RSJ International Conference on Intelligent Robots and Systems*.