Doctoral Dissertation
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Learning and Planning for Social Robot Navigation

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Summary

Autonomous mobile robots have reached impressive achievements in the last few years and are expected to revolutionize our daily lives even further in the near future. Service robots have been deployed in human-centric environments to carry out the most various tasks across diverse fields, including medical assistance, elder care, support for individuals with physical impairments, indoor cleaning and sanitation, search and rescue operations, inspection and exploration, and precision agriculture. The introduction of autonomous mobile platforms alongside humans has significantly boosted research on systems capable of exhibiting socially acceptable robot behaviours. Robotic platforms must smoothly and safely operate and interact with people in shared environments, such as homes, workplaces, and public spaces. Designing systems that account for human social norms, etiquette, and expectations has become critical to encourage trust, promote cooperation, and minimize potential conflicts or misunderstandings.

However, while intuitive and seemingly trivial for humans, these social behaviours pose significant challenges when it comes to implementing them in robots. Humans acquire social skills through complex cognitive processes, years of observation, and cultural conditioning, allowing them to adapt to dynamic social contexts. In contrast, robots rely on pre-programmed algorithms that must be explicitly implemented to recognize, interpret, and replicate social cues like body language, facial expressions, tone of voice, and contextual subtleties.

Social robotics emerged as a direct consequence of service robotics. When robots started to enter human-centred environments, the need to integrate safe, socially acceptable behaviours and interaction models into robotic platforms became increasingly clear. This necessity gave rise to the field of social robotics, a multidisciplinary domain at the intersection of robotics, artificial intelligence, cognitive science, psychology, and human-robot interaction. Social robotics focuses on providing robots

with the ability to interact and behave in a human-like manner. Contrary to traditional service robots, which prioritize task completion efficiency and optimality, social robots focus on human-centred outcomes, such as emotional engagement, trust-building, and social acceptance. This shift makes service robots truly effective and welcomed by human users, enabling them to exhibit behaviours that are not only functionally appropriate but also socially intelligible, predictable, and comfortable.

As the complexity of introducing robotic platforms into human-centric environments increased, researchers realized that traditional navigation and planning methods were no longer sufficient on their own to enable socially intelligent behaviours. While they are able to provide robustness, predictability, and near-optimal performance, traditional algorithms often fall short in interpreting social contexts, adapting to unwritten social conventions, and generalising to unscripted, real-world situations. At the same time, learning-based navigation methods, particularly those based on deep learning and reinforcement learning, show significant advantages in approximating complex behaviours and adapting to diverse contextual scenarios. However, they also introduce challenges related to unpredictability, lack of guarantees, and robustness.

Recognizing the complementary strengths and weaknesses of these approaches, this thesis is dedicated to exploring and advancing novel methodologies aimed at enhancing social robot navigation, leveraging a combination of traditional approaches and learning-based techniques. By integrating classical planning and control frameworks with modern data-driven methods, the research seeks to address the multifaceted challenges of enabling robots to navigate intuitively within human-centric environments. Specifically, this work explores advanced planning and control strategies that bridge the gap between pure technical navigation efficiency and the demands of socially intelligent behaviour. These strategies go beyond basic obstacle avoidance, focusing on enabling robots to interpret and respond to social dynamics proactively. Such behaviours include maintaining appropriate interpersonal distances to respect personal space, following human movement patterns to support and assist the user, and dynamically adapting to context-specific norms, such as queuing in a line and respecting interaction spaces of a group of people engaged in a conversation.

Specifically, the main contributions of this thesis are summarized as follows:

- The development of a full novel modular and flexible robotic platform, designed through the integration of traditional and artificial intelligence methodologies, to assist elderly and physically impaired users;
- The implementation of an innovative human-centred navigation system, leveraging omnidirectional mobility to continuously monitor a user while navigating;
- A complete study on person following and guiding by autonomous mobile robots, spanning from early research to the latest advancements in the field;
- The implementation of an innovative framework for Deep Reinforcement Learning navigation, designed to simplify, enhance, and standardize research efforts in learning-based autonomous navigation;
- The study and implementation of novel methodologies in the field of social robot navigation, enabling robots to learn and exhibit a variety of socially compliant navigation behaviours without compromising the robustness and reliability of traditional navigation systems.

Each proposed methodology has been validated through a rigorous series of experiments, providing detailed descriptions of the experimental setups, the collected results, and the evaluation metrics employed. Particular attention was given to testing each approach in real-world scenarios, dedicating significant effort to assess their feasibility and effectiveness in practical social contexts. The validation process involved a variety of testing environments to thoroughly evaluate the robustness and adaptability of each solution, emphasizing their potential for broad application and meaningful impact.

This thesis and its work aspire to make a meaningful contribution to the scientific literature by enriching the understanding of robotic navigation and guiding future research toward approaches that are more attentive to human needs and social requirements.