Evolutionary-based Coordination of Multi-Robot Systems with Dynamic Constraints

Ethical Look at Coordination of Multi-Robot Systems in Industrial Environments

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

As automation becomes more prevalent in all applications of society, the specific case of autonomous robots in work environments has been advancing quickly in all industries. The capstone project, Human‑Robot Augmented Reality Smart Inspection, aims to plan realistically optimal paths, leveraging the multiple traveling salesman problem, for multiple robots in an environment where tasks need to be performed. Additionally, the robots are aware of one another's locations, avoid obstacles, and are able to interact with a human providing new information including a sudden, high-priority task (Tompkins et al., 2003). Altogether, this system should allow multiple robots in a system to operate with algorithmic efficiency and practical feasibility. On the other hand, the STS research on this topic focuses on the social interactions between robots and humans in these industrial environments and the impacts of socially unaware development on safety. At a fundamental level, robots being autonomous creates concerns of spatial awareness, safety, labor concerns (for humans and robots), and over/under-reliance on the robots due to bias and societal norms (Etemad-Sajadi et al., 2022). This transforms the research from being about a system that increases the efficiency of an industrial environment to the transformation of the current boundaries of human-robot interaction to perform work.

These two topics have a vital intersection when considering implementing the technical solution into a workplace environment with many humans involved. Some humans are more comfortable with robots than others which can lead to fear/avoidance or mistrust/over-reliance towards the autonomous robots (Martinetti et al., 2021). Generally, fear and trust are not considered problems during the development process, but the adoption of autonomous robots depends greatly on development that is cognizant of the intricacies of human-robot interactions.

This understanding is vital for refining human-robot interactions, optimizing scheduling, and assigning tasks of varying complexity.

The connection between the technical and STS research in this capstone is a mirror of a broader technological issue: the balance between pushing the limits of innovation in technology and innovating for the sake of society and human use. This issue persists in artificial intelligence, autonomous cars, and more. In an ideal implementation, two different aspects of research, technical and STS research, come together to achieve groundbreaking milestones while considering the human elements involved in the technology. Overall, both research approaches aim to allow humans and robots to cooperate efficiently and create an environment where both exist harmoniously. Therefore, the purpose of this research is to take a step in this direction by innovating a new use case of autonomous robots while analyzing the social and human elements involved in a human-robot system where the innovation would be implemented.

Human‑Robot Augmented Reality Smart Inspection

The foundation of the human-robot smart inspection system lies in giving multiple robots a realistically efficient/optimal path in order to perform a set of tasks. These tasks could have no specific order or task prioritization which requires robots to consider the path at which they approach tasks slightly differently. The path planning solution which generates a path for each robot to travel is generated by considering the multiple traveling salesman problem. This is an NP-hard problem or intuitively, a problem that is hard to find a solution for but also hard to verify as correct when a solution is found. This can be attributed to the fact the multiple traveling salesman problem is a more complex version of the traveling salesman problem (also NP-hard) where each problem takes an increasingly unreasonable amount of time/energy to solve with each slight increase in the number of parameters (i.e. 10 robots, 120 tasks). The three pieces that allowed our research to generate each robot's realistically best path are a genetic algorithm, an A* algorithm to avoid obstacles, and a map.

The genetic algorithm smartly searches the possible configurations by creating an initial diverse population of potential solutions where each solution represents different routes for the robots. Through a cycle of selection based on best fit, the algorithm evolves those solutions over generations with the goal of optimizing the routes in order to have the robots travel the least total distance and balance the load of tasks amongst the robots. In order to let the genetic algorithm know how far a task is from the robot or another task, the A* algorithm is used to find the shortest path from one point to another given that there are obstacles in between the two points (i.e. go from one corner of a square room to the opposite corner but there are obstacles on the way). The A* algorithm uses a predetermined map called an occupancy grid. that points out the locations of the obstacles and free travel space. The occupancy grid is a large matrix that takes on the shape of the map and has a value of 1 where the robot is free to travel and 0 where there is an obstacle. By combining these three parts, the robots are able to receive a path to travel in order to efficiently travel to each task on a map with obstacles.

Lastly, this path planning is integrated with a human wearing an augmented reality headset who can prioritize tasks and communicate with the robots even if they are in different locations than the robots or tasks. Together, a robust system of autonomous robots can be implemented in a hospital, warehouse, or other industrial environment to read gauges, take pictures, deliver tools, and more. This has the potential to improve the efficiency of workers, automate low-level procedures, and advance human-robot interaction.

Social Interactions and Safety in Human-Robot Interaction

The Human-Robot Augmented Reality Smart Inspection solution can be properly developed and implemented with a thorough understanding of how societal norms, trust, and discomfort towards autonomous robots in industrial environments influence human-robot interaction. Despite using terms like efficiency and robustness, a purely technical solution does not encompass the societal and human aspects of efficiency and robustness which include safety, fear, and reliance. Without knowing how mistrust and discomfort towards robots (or even over-reliance) can hinder the benefits seen during the development stages, the solutions will never be fully efficient and robust.

Previous research on effectively designing social robots has shed light on the importance of a robot physically acknowledging the presence of a human and being purposeful about proximity in a human-robot relationship in order to make autonomous robots more natural in their environment (Fortunati et al., 2018). Other research emphasizes that autonomous robots are a replacement and are used with respect to variables like “social cues”, “trust”, and “safety” (Etemad-Sajadi et al., 2022). Moreover, there are ethical considerations such as privacy, security, liability, and dehumanization that are concerns for the users of autonomous robots who are replacing laborers where the ethical concerns already have laws and precedents (Kim et al., 2022). Altogether, even fully functional autonomous robots could potentially not account for variables like fear, trust, over-reliance/under-reliance, safety, poor interaction with humans, and social cues.

An analytical approach to better understanding patterns in human-robot interaction in shared workspaces or work environments will involve gathering evidence from surveys with workers who currently work or have worked alongside autonomous robots, analyzing existing case studies from industries that have integrated robots into the workspace, and further analyzing literature exploring human-robot interaction from similar evidence. This data may offer insight into the human-robot relationship as it comes to trust, fear, and reliance. In order to gain information about other variables like privacy, security, liability, and dehumanization, an interview will be conducted with the leads of this research from the university and the leads from the sponsor/client who has other robot solutions actively in production already. Ideally, a deeper understanding of the ethical problems and social values of autonomous robots in a work environment can be provided from qualitative and quantitative analysis of the data. Survey data can be examined through statistical analysis while interviews and literature review can be used to find common themes among users of this research. As a whole, the STS research will provide further information on the social, technological, and societal impacts of the technical solutions provided by the capstone.

Conclusion

This research explored Human-Robot Augmented Reality Smart Inspection by enhancing the efficiency of path planning in industrial environments with multiple autonomous robots that algorithmically approach the multiple traveling salesman problem. Simultaneously, the STS research focuses on the human-robot interactions themselves by examining safety, trust, discomfort, and reliance alongside ethical concerns like privacy and dehumanization. Combining surveying with literature reviews and expert interviews allows this research to shed more light on the complexity of human-robot relationships and how technological innovation in this field can positively impact work environments. The results are expected to favor autonomous robots that naturally fit into their applied environments, interact with their human counterparts, and the adoptions of human-robot training prior to introducing autonomous robots into the workplace. By performing this research, human-robot interaction advances to a unique path-planning solution but also specific, unique considerations for societal impacts and ethical concerns. In a broader context, this research contributes to robotics and human-robot interactions but also serves as a step toward a future where all technological innovation has a deep social understanding.

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