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. Research in Human-in-the-Loop Multi-Robot Task Allocation for Smart Inspections helps plan close-to-optimal paths, leveraging the multiple Traveling Salesman Problem (mTSP)[1] for multiple robots in an environment where tasks need to be performed. The robots are aware of one another's locations, avoid obstacles, and can interact with humans providing new information such as priorities, time constraints, and precedence constraints (task K before task D) (Tompkins et al., 2003). Altogether, this system should allow multiple robots in a system to operate with algorithmic efficiency and practical feasibility. Despite systemic efficiency, multiple robots in industrial environments include many other dependencies and considerations. By focusing on the social interactions between robots and humans in industrial environments and the impacts of socially unaware development on safety, it is possible to understand social inefficiencies in this work. 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). The current boundaries of human-robot interaction (HRI) in performing work are under drastic revision with innovation and corporate pressure. In the end, the purpose of incorporating autonomous robots and unmanned ground vehicles (UGVs) is to enhance workplace safety, security, and productivity.

The actors affected by the developments of this research include industrial workers (hospitals, warehouses, etc.), corporate leaders, and engineers/developers in the overall

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[1] A variation of the classical Traveling Salesman Problem where is to minimize the total distance traveled by all salesman, ensuring that each city is visited exactly once and each salesman returns to the starting point.

human-robot system. Integration into the workplace implies real adults and a consistent information flow between robots and humans for long periods. Robot system failure currently sits at approximately 12% on average which can have disastrous consequences over multiple years (Koepsel, 2022). Additionally, real humans do not all behave the same and guarantee varying results when supplied with UGVs. Therefore, if the engineering goal is to improve productivity, humans must be actively considered to make that a reality rather than a theoretical simulation. 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 HRIs. This understanding is vital for refining HRIs, optimizing scheduling, and assigning tasks of varying complexity.

The purpose of this research is to take a step towards socially adept autonomous robot development by analyzing how social and human elements involved in a human-robot system should be leading the developmental stages of new autonomous robot research. To accomplish this, UGVs and autonomous robots should be developed and introduced to physically acknowledge the presence of humans; be deliberate about their distance, speed, and other behavior in the proximity of humans; have corporate programs to train workers on trust and safety around autonomous robots; regularly discuss over/under-reliance on robots within the software and in corporate meetings; account for labor replacement with alternative training programs for replaced roles; and, include clear rules for ethical liability in case of failures.

Background and Significance/Motivation

The rapid evolution and integration of autonomous robots into various industrial sectors highlights a transformative shift in workplace/corporate dynamics. Corporations look to increase labor reliance on UGVs with high efficiency and productivity as part of a trend to reshape the definition of labor and what industrial work represents. With this shift, many ethical, social, and engineering issues require a multifaceted approach to anticipate the potential negative impacts of this movement. Interactions between humans in robots in shared workspaces are not only a technical task but also require feasible social acceptance and ethical responsibility in place to facilitate those interactions. This is especially important with the annual growth rate of the global adoption of industrial robots exceeding 12% (IFR World Robotics, 2020). 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.

One of the primary concerns when considering the deployment of autonomous robots is the issue of job displacement. With robots capable of performing tasks previously undertaken by humans, there is a growing anxiety over job security and the future of human labor. This concern is heightened by studies that have shown that automation can lead to significant shifts in employment patterns and the nature of work itself (Kim, 2022). Therefore, an ethical approach to robotic integration must consider the potential for labor displacement and explore strategies for workforce adaptation and re-skilling.

Moreover, there are psychological and social aspects to HRI that cannot be ignored. 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 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 concerning 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.

Furthermore, the integration of autonomous robots raises significant ethical questions regarding privacy, security, and accountability. In scenarios where robots are responsible for critical tasks or operate in close proximity to humans, the implications of a malfunction or breach of privacy are great. Thus, ethical considerations must be embedded in the development and deployment of robotic systems, ensuring that they adhere to principles of transparency, accountability, and respect for human dignity during their entire lifetime through mechanical, software, and corporate development.

In light of this impact, the research into Human-in-the-Loop Multi-Robot Task Allocation for Smart Inspections cannot be considered as simply a technical project but an important social stepping stone in autonomous robots integrating into society. By examining the ethical, social, and technical dimensions of HRI, this research aims to contribute to the development of robotic systems that are not only efficient and effective but also socially responsible and ethically sound. Through a combination of empirical research, worker/corporate interviews, and ethical analysis, this project seeks to advance our understanding of the optimal integration of robots into human work environments, ensuring that technological progress serves to enhance, rather than undermine, a human's role in societal development.

Methodology

An analytical approach to better understanding patterns in HRI 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 HRI from similar evidence. This approach to the question helps discover potential underlying reasons for negative impacts like labor concerns and fear of robots. Age or experience with technology may be a large factor in over/under-reliance. Gathering or finding data may offer insight into the human-robot relationship as it comes to trust, fear, and reliance in these workplace settings. 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. This methodology aligns with the complexity of the research question why investigating the technical aspects of autonomous robot task allocation but also the social, ethical, and psychological impacts on human workers during integration in industrial environments.

The primary quantitative method used in this study involves analyzing survey data among industrial workers who have experience working alongside autonomous robots. The survey design focuses on variables such as trust, fear, reliance, and overall satisfaction with HRI. Surveys conducted in this study will formulate questions tailored to gauge workers' perceptions and attitudes towards robots within academic and work environments in a variety of age groups (students, PhDs, professors). The quantitative nature of surveys allows for the collection of measurable data that can be statistically analyzed to identify patterns, correlations, and significant differences among different worker demographics.

Complementing the surveys, this research involves analyzing existing case studies from industries that have integrated autonomous robots (Gunadi & Ryu, 2021). These case studies provide contextual depth and insights into the practical applications, challenges, and outcomes of HRI implementations. They offer real-world examples of how different companies including the sponsor of the technical project approach the integration of robots, the strategies they employ to train their workers, and the resultant effects on productivity and worker well-being.

The initial details of research have been established through a review of existing literature on HRI in workplace environments, with a particular focus on studies that explore the social, psychological, and ethical dimensions of interacting with autonomous systems. This review includes academic papers and theoretical frameworks applicable to the study including actor-network theory as a sociotechnical analytical framework. Actor-network theory accurately captures each stakeholder relevant to this discussion involving corporations, customers, labor workers, engineers, robots, and international locations. It focuses on each interaction in this industrial environment which is not done outside of sociotechnical research. Reviewing literature allows further discussion and provides potential solutions to related problems.

Placing the data and information gathered in this research in the context of actor-network theory for autonomous HRI in workplaces is vital to appealing to STS values, engineers, and corporate values. Understanding the stakeholders (workers, robots, buildings, managers/businesses, clients) and the role of each in the broader context helps address the societal concerns of pushing for autonomous robot task allocation en masse. This approach ensures that the findings are robust, relevant, and grounded in relevant experiences and concerns for the humans who are truly affected by the implementation of autonomous robots in the workplace.

Literature Review

The exploration of human-robot interaction (HRI) in industrial environments has been a subject of increasing academic and corporate interest seen in the capstone project, *Human-in-the-Loop Multi-Robot Task Allocation for Smart Inspection*. This project is a clear example of the interest in finding the best ways to integrate robots into workplaces that have traditionally been run by people. The wide range of research on this topic helps outline where we currently stand in understanding these interactions and points out the challenges of bringing automated robotic systems into environments with human workers. This research particularly looks into the complex relationship between humans and machines, aiming to improve how well they work together to boost efficiency and maintain a safe environment for people. The idea of "Human-in-the-Loop" stresses the importance of keeping human judgment and decision-making as a central part of managing robots' tasks. This approach explores how to effectively distribute tasks among robots, considering human directions to prioritize and make real-time changes.

The existing literature on this topic provides well-thought insights into setting up and maintaining these interactions such that it is beneficial to all parties. It covers less of the technical sides of deploying and managing robots, and more of how these technological additions affect the psychological state and social lives of human workers. Studies emphasize the need for robotic systems that are efficient, safe, and capable of fitting into the social fabric of the workplace. Thus, looking into human-robot interactions in industrial contexts reflects a wider conversation about the evolving nature of work, the role of technology, and how humans and machines can work together harmoniously.

Significant research and thinking have been considering ethical issues and safety standards within HRI. Ethical concerns, particularly around robot replacement anxiety, bias, and societal norms can significantly influence workers' acceptance and utilization of robots in service-oriented roles (Etemad-Sajadi et al., 2022). The research extends to industrial-oriented roles where HRI remains pivotal to the increase in productivity of the entire system. They show that tackling these ethical issues is key not just for getting robots to fit smoothly into roles that serve people but also for making sure they help rather than hinder productivity in factories and other industrial settings. Meanwhile, literature also suggests a call for a redefinition of safety standards to include not only physical but also psychological and societal impacts (fear, misuse, under-reliance, over-reliance, etc.), advocating for a holistic approach to robot deployment in workplaces (Martinetti et al., 2021). They argue that safety is not just about preventing accidents but also about ensuring people feel secure and respected while the social atmosphere at work does not suffer due to the inclusion of autonomous robots. This broader view of safety is essential to make HRI a positive part of the workplace, making jobs safer and more enjoyable rather than adding stress or fear. By pointing out these high-level concerns, both studies emphasize that introducing autonomous robots is beyond a technical success but about how people emotionally and socially interact with these robots. As the capabilities of technology expand, all stakeholders from consumers and workers to corporations should be benefiting from the results. This requires more planning during development and careful training when implementing.

The annotated bibliography further introduces key themes related to social interactions and the technical intricacies of robot collaboration within industrial settings. Other discussions involve the enhancement of manufacturing performance through human-robot collaboration, emphasizing the necessity for robots to match human standards of performance, safety, and flexibility (Hentout et al., 2019). Similarly, we need to understand that there is a shift towards collaborative control in robotic systems, where robots act as equal partners to humans, necessitating autonomous robots to have high adaptability and intelligence (Vorotnikov et al., 2018).

Moreover, the discussion by Breazeal (2004) and Li et al. (2011) on social robots underscores the critical role of social capabilities in robots, suggesting that effective HRI requires robots not only to recognize and respond to human presence but also to engage in meaningful social interactions. These capabilities are essential for fostering trust, safety, and a positive working environment between humans and robots.

The literature thus reveals a consensus on the need for a multi-faceted approach to the development and integration of autonomous robots in industrial settings. This approach should consider technical efficiency, ethical implications, safety standards, and the capacity for meaningful social interactions. My research contributes to this discourse by examining how these elements interact within the specific context of Human-Robot Augmented Reality Smart Inspection, addressing both the technical challenges and social dynamics of implementing autonomous ground robots in industrial locations.

Discussion/Results

The use of autonomous robots in work settings from hospitals and warehouses to restaurants has shown various outcomes. In addition to worker testimony and developer insight, there is data to highlight the delicate balance between new autonomous robot technologies and human concerns. This research, building on the Human-in-the-Loop Multi-Robot Task Allocation for Smart Inspection, goes beyond looking at just the algorithms necessary to accomplish tasks efficiently and explores how HRI impacts social dynamics, productivity, and ethical concerns. The results of the capstone research suggest that a human involved in using the algorithm can influence the autonomous robots' actions by adding priority constraints, expected task time constraints, and precedence constraints. This allows a human operator to prioritize where the robots go, how long the robots can expect to spend on a task, and if any tasks need to be performed before another task. By giving a worker the ability to control multiple robots in the environment, there is an added level of safety and trust beyond preprogrammed obstacle avoidance or robot feedback. This research emphasizes the need to go beyond considerations in developing autonomous robot algorithms and to implement programs throughout this pipeline for actors that use the technology. To this end, it is vital to view how industrial environments hope to use autonomous robots from the lens of actor-network theory.

While the evolutionary algorithm has shown good results in improving task distribution and safety measures like avoiding obstacles, it also brought up issues related to trust and mental health. Interestingly, feedback from workers on their tasks through surveys and data showed that low-skilled U.S. workers reported better physical health and fewer disabilities due to increased automation (Gunadi & Ryu, 2021). On the other hand, a study in Germany, a country that widely uses autonomous robots, found that increased automation was associated with more deaths due to drug or alcohol abuse (Gihleb et al., 2023). Moreover, survey data from the U.S. found that workers who work with or are liable to work with autonomous robots suffer from much higher job insecurity which is associated with poor physical and mental health.

Survey data also points to a clear link between how often workers interact with robots positively and their level of comfort or discomfort. Workers who had regular contact with robots generally felt more trust and comfort towards the use of the robots (Fortunati et al., 2018). This urges industries that wish to use robots to implement intentional training sessions between workers and robots before using an autonomous system. Being familiar with robots helps shape positive human-robot relationships which in turn foster higher productivity, less fear, reliable usage of robots, and safety. It is in corporations' and workers' best interests to increase exposure to robots.

Using actor-network theory to view these interactions offers a helpful way to see robots and humans as partners within the work environment. There are a variety of actors involved in this system including the autonomous robot developers, the workers, corporations/managers, clients/customers, and the robots themselves. Each has a unique stake in the system and holds different values in different outcomes such as workers valuing their jobs and safety, corporations valuing productivity and costs, and customers valuing consistency. In fact, there is significant research supporting robots that are more human-oriented. When robots are more natural by physically acknowledging (gesturing, motioning, engaging in conversion) the presence of a human and by following social and cultural norms, humans are much more satisfied with the output of this “social” robot (Cabibihan et al., 2013). Further, problems including safety, flexibility, perception, and intelligence in HRI involving physical interactions between humans and robots can be explained by the daily interactions that take place between the actors (Hentout et al., 2019).

Exploring the use of autonomous robots in workplaces like hospitals, warehouses, and restaurants reveals mixed outcomes, largely influenced by how these technologies interact with humans. This research goes deep into examining the impact of HRI on social dynamics and ethical issues in industrial environments. These findings highlight the importance of human guidance in robot operations, training programs between workers and robots, and social robots. Utilizing actor-network theory alongside the survey data and literature allowed viewing humans and robots as partners, suggesting that improvements to the status quo involving robots that acknowledge human presence and follow social norms can significantly improve results for all actors in the network.

Conclusion

This investigation focuses on the difficult balance of novel robot technology and human apprehensions/emotions towards that technology. This study explores the impact of human-robot interactions on the social environment, productivity, and ethical considerations within the workplace. A significant insight from our research is the value of human involvement in robot task management. When operators have the authority to dictate task priorities and sequences, it fosters an enhanced level of trust and safety, demonstrating the need for comprehensive user training alongside technological advancements. Further, employee training is crucial for subconsciously easing concerns and preventing the extremes of over-reliance or avoidance of robot systems. This approach ensures that each actor in the large network of industrial workplaces can confidently work with one another, promoting the smooth inclusion of the robot actor into the system.

Moreover, the importance of engineers and developers considering the emotional and social aspects of human-robot interaction becomes apparent. Developing responsive software that adapts to human presence not only optimizes operational efficiency but also deepens mutual trust and comfort. Encouraging frequent and positive worker-robot interactions at a corporate level has been shown to solidify trust and ease, urging the need for deliberate robot familiarization efforts prior to workplace deployment. These initiatives help reshape human-robot relations positively, enhancing productivity and ensuring a safer work environment.

Actor-network theory provides a comprehensive lens for understanding these dynamics, highlighting the roles of developers, workers, companies, and robots themselves. It reveals that robots designed to acknowledge and interact with humans in familiar ways yield greater satisfaction. The path forward should continue to refine these technologies and promote innovation while deeply considering the human aspect along the way. Success in this approach can be defined by a collaborative approach to the goal between humans and robots. Looking forward, future research and dialogue will steer the future of industrial work where human-robot collaboration can thrive.

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