Assessing Right-of-Way with Autonomous Mobile Robots

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When people encounter Autonomous Mobile Robots (AMRs) in their workplace, there is a need for simple coordinating interactions arising from shared movement through space. These interactions serve pragmatic functions (i.e., allowing people to decide whether they have right-of-way) and are layered with social meanings. In industrial contexts, norms around movement are also heavily influenced by workplace rules, roles, and responsibilities. Misinterpretations arising from interactions between people and AMRs create both real and perceived risks, increasing operator stress and risk of injury. This paper explores how people account for interactions with AMRs in industrial settings to better inform the design of AMRs used in this context. We conducted an exploratory study with thirteen participants who had experience with AMRs. Rather than a definitive set of common understandings, results reveal diverse interpretations and rationales about these issues. A useful path forward is to see the ambiguity and disagreement between participant interpretations as providing relevant design dimensions to consider for the development of further research into AMR interaction design.

Additional Keywords and Phrases: Autonomous Mobile Robot, social norms, industrial, HRI

1 INTRODUCTION

Previously, integrating robots into factories meant robots working "alongside" humans, often separated by physical barriers or cages. However, advances in this field have created robots with greater levels of autonomy, leading to more direct and proximal interaction between humans and robots [22,26,30]. The shift to greater autonomy and more direct interactions has led to a growth in research interest around how humans and robots can better work together to achieve shared goals through human-robot collaboration (HRC) [14,26]. This shift toward greater levels of autonomy and more direct and proximal human-robot interactions is particularly apparent in the development of Autonomous Mobile Robots (AMRs). AMRs are mobile wheeled logistics robots with greater levels of autonomy and freedom of movement than older forms of logistics robots such as Autonomous Guided Vehicles (AGVs). AMRs can be used in warehouse environments for autonomous transport of goods and equipment without the need for supporting infrastructure such as magnetic tracks. AMRs can adapt to environmental changes through internal mechanisms that guide their movement and actions and allow for real-time dynamic path planning and adaptation [13,23,27]. Improved sensor technologies and collision detection systems allow AMRs to operate within shared spaces with humans, which represents a level of human-robot collaboration (HRC) not previously possible with older logistics robot technologies [5,23]. This freedom of movement presented by AMRs leads to greater unpredictability and requires greater levels of information processing and feedback from robots to workers to determine the robot's intentions in movements and actions. In this paper, we present the results of an exploratory study in which thirteen participants with experience of interacting with AMRs were presented with a series of simple scenarios of interaction between a person and an AMR and asked to give their interpretations of how they expected the interaction should unfold in terms of right-of-way, safe passing distance, and required level of awareness for the robot and human.

2 BACKGROUND: AUTONOMOUS MOBILE ROBOTS AND SOCIAL CUES

Robot cues communicate important information during interactions, such as movement intention [9], and a lack of effective communication can increase cognitive load leading to stress and mental strain [26,30]. Because AMRs now share the social space with human users, they are expected to conform to human social norms [17,18,20,26]. Communication and navigational control systems informed by human social behaviours could allow robots that lack social intelligence or an internal emotional state to comply with social norms through socially aware navigation and actions, such as "giving right of way" or "passing on the right" [4,15,20,25,28]. The effective use of these socially derived behaviours would assist the robot in communicating movement intent, their internal state or goals and provide feedback to a human observer in a way more appropriate to the context. This approach would allow them to integrate into workplace environments more easily [17,18,21,24,25]. Furthermore, the misinterpretation of the AMRs intention can be perceived as a transgression of workplace social norms resulting in negative associations and detrimental workplace practices [26,29].

An area of research interest that has emerged in response to these challenge is how social robotics frameworks and principles can be applied to robots that operate within manufacturing and logistics contexts; and what impact this could have on HRC effectiveness and operator health and safety [14,30]. As yet, little research has applied these frameworks to logistics AMR platforms. However, previous research on other robot platforms can provide relevant insights for AMRs. For example, robotic arms facilitate broader behavioural cues such as postural behaviours and limb-based gestures. The Baxter robot, in particular, leverages anthropomorphic features and humanoid forms within its designs to allow the robot to communicate in ways that are more "human" [8,19,22,29].

Given that AMRs movement through shared space is a part of social interaction, there is a need to understand people's interpretation of these interactions to inform the design of AMRs. Furthermore, AMRs must better communicate their movement intentions in ways that comply with workplace social norms. A failure to effectively communicate movement intentions and internal states from AMRs in industrial settings increases cognitive load, which is connected to increased stress, increased risk of injury for workers, reduced efficiency, and other adverse outcomes. Given the challenges with industrial AMRs discussed in the literature above, the research presented here asks the following.

"What are people's perceptions of autonomous mobile robots' interactions with workers in industrial settings?"

3 METHODOLOGY

The research utilised a qualitative approach in which experienced individuals who interact with AMRs in their work were surveyed. The survey was distributed through social media channels and through an industry contact at the BMW Group subsidiary idealworks, who agreed to assist in distributing the online survey to staff through their company's internal communication platform. The primary filter for inclusion within the study was that participants needed to have experience working with or alongside AMRs.

The survey included a collection of 20 multi-choice and 14 short response questions. These questions covered three main areas. Firstly, demographic questions such as age, gender, country, and job title were used to general background information on each participant. Secondly, questions relating to years of experience and the tasks AMRs perform in their workplace were used to identify common use case scenarios. Participants were also asked how often they interact with AMRs, whether they had positive or negative experiences interacting with AMRs, and how often they had these experiences. Finally, three simple interaction scenarios were presented as still images taken from publicly available videos of AMRs operating in workplaces (refer to Figure 1). The scenarios were chosen based on observations of AMRs in shared space interaction with a worker. These included:

1. Right of Way Scenario: an interaction occurring at an intersection.
2. Hallway Passing Scenario: a hallway interaction where a robot and a person are passing one-another.
3. Passing Behind Scenario: depicts the robot passing behind a stationary person.

Figure 1: Three Interaction Scenarios: Right of Way (left) [public domain], by Cars Garage 2021, via YouTube. (https://www.youtube.com/watch?v=Wan_M1PwcOQ&ab_channel=CarsGarage); Hallway Passing (center) [public domain]. by Mobile Industrial Robots (2021). via YouTube. (https://www.youtube.com/watch?v=AQVDwW7uKZE&ab_channel=MobileIndustrialRobots); Passing Behind (right) [public domain]. by Mobile Industrial Robots (2021). via YouTube. (https://www.youtube.com/watch?v=AQVDwW7uKZE&ab_channel=MobileIndustrialRobots).

Still images were deliberately chosen rather than showing the full videos to highlight a specific interaction within the video where the interaction could be interpreted in multiple ways or situations in which the outcome was unclear. The aim was to elicit a range of interpretations and reasonings from participants for how people and robots should behave within a given interaction rather than more definite accounts of the outcome of the interactions [10]. Participants were asked to indicate a perspective in each scenario, such as (A) the person or (B) the robot has the "right of way". This was followed by an indication of their confidence in their response. Finally, participants were asked to provide an account of their rationale or reasoning for their choice as a written response.

FINDINGS

13 participants met the criteria for inclusion. These respondents were from six different countries, including Australia (3), China (1), Germany (5), Japan (1), Switzerland (2), and the United States (1). Participants ranged in age from 18-50, with one female, 11 males and one participant that preferred not to say. Participants reported two common use cases for AMR robots in their workplace: logistics and material handling; and surveying and mapping. From these use cases, five types of interactions were identified. These included: Operating: taking control of the robot when it faulted or became "stuck"; Task Assignment: assigning tasks, jobs, or "missions" to the robot; Software Development: developing behaviours and functions for the robot and for the interface platform; Quality Control and Assurance: testing the robot in different conditions; Shared Space Interactions: working alongside the robot.

3.1 Right of Way Scenario

For the first scenario, participants were first asked whether the robot or the human had right-of-way at an intersection and then to explain their choice with a short answer response. Out of these, the participants who responded that the person had right-of-way (n=4) reported that the goal should always be to keep the human safe and expected the robot to have the capacity to perceive the oncoming person. However, they highlighted that there was no sign from either party as to their intention, which "lead to the confusion".

By comparison, the participants who believed that the robot had right-of-way (n=9) included environmental factors as a consideration, reporting that the person in this situation had failed in their responsibility to operate safely and maintain awareness of their environment by stepping into a hazardous operating area. These participants reasoned that the AMR should be given the same priority as a forklift which would have "right-of-way" in this operating area but suggested that the robot should still notify the person when in close proximity. Furthermore, they felt that the robot should have emergency stop capabilities to protect workers. However, one of these participants also highlighted that having the robot attempt to stop in this proximity would be difficult due to hardware constraints, which could cause harm to the person regardless. Therefore, people should maintain awareness of their surroundings in hazardous environments and responsibility for their own safety.

3.2 Hallway Passing Scenario

For the second scenario, participants were first asked to respond whether they felt that the distance between the person and the robot in the scenario was safe. For participants who responded that they believed the distance was safe (n=5), no further questions were asked.

For the other participants, who responded that the distance was not safe (n=8), a follow-up question was asked whether it was the person or the robot's responsibility to maintain a safe distance. Out of these eight participants that responded the distance was not safe, three indicated that they felt that it was the person's responsibility to maintain a safe distance. These participants' responses highlighted that people currently have greater flexibility and adaptability in how they respond to situations, greater decision-making capabilities, and superior sensing and cognitive abilities to robots. People should therefore be responsible for maintaining safe distances, and we should be more accommodating to emerging robotics technology to aid their development. The other participants, who felt it was the robot's responsibility to maintain a safe distance (n=5) reported an expectation for the robot to adapt to the environment and dynamic obstacles. They argued that people should not have to accommodate or adapt to this new technology entering their work environment. Instead, robots should understand the work environment's boundaries and their proximity to people to ensure they are operating at safe distances. Furthermore, the robot should accommodate this "errant" behaviour through adequate sensory and safety technologies to manage these situations appropriately.

3.3 Passing Behind Scenario

For scenario three, participants were first asked whether they felt that the person in the scenario was aware of the robot passing behind them. Participants who felt the person was not aware of the robot passing behind them (n=7) reported an apparent lack of communication between the robot and the person, with no visual or auditory communication or feedback involved in the interaction. Therefore, the person would not be aware of the robot. Participants identified several contextual factors that would also diminish the person's awareness; as the person was wearing a legionnaires hat restricting peripheral vision, they had their back turned to the robot so there would be no visual feedback. Participants felt that the robot would need to provide some information or feedback to get the person's attention and communicate that it is passing behind them.

Participants who felt that the person was aware of the robot passing behind them (n=6) reported that the robot had adequate signal lights or blinkers at eyesight level, which would inform the person in the scenario of the robot's presence. One participant also reported that the person's body language indicated that they were aware of the robot and had moved to allow it to pass. They speculated that the robot may have communicated its presence with an alert or combination of sound and lighting. Participants also reported that people become familiar with the workflow and the space over time, giving them contextual awareness.

4 DISCUSSION

Movement through shared space is part of social interaction between humans and AMRs as these robots are expected to conform to human social norms when traversing these spaces [3,12,17,18,20,26]. Findings from this study present an interesting parallel to the work of Mutlu and Forlizzi [2008] and suggest that participants evaluate the robot against the social order or workplace hierarchy. Participants who reported that the robot had "right-of-way" suggested AMRs used in logistics have adopted the role of the forklift or forklift driver. As forklifts have "right-of-way" within this operating area, the robot adopts this precedence, pointing to the give-way sign in the scenario photo as evidence. Furthermore, they reported that people should ultimately maintain awareness and responsibility for their own safety within these environments.

In contrast, participants who argued that the person should have "right of way" suggested that the goal should be to maintain worker safety, as they can be injured while the robot cannot. Furthermore, robots should be capable of perceiving and responding appropriately to the person in this scenario. This account gives the robot responsibility for maintaining awareness and safety. The difference in participants' accounts suggests the robot can be seen to occupy two different positions within the social order depending on the participant's perspective. They either adopt the position of the forklift and the social norms associated with this role, or they take on a new role within the workplace regardless of the established "right-of-way" precedence [1,6,7,16].

The purpose of this discussion is not to establish the robots' position within the social order or what it "should be", but rather to highlight that there is a difference in participants' accounts of this social order. The lack of consensus in participants' accounts is significant as this ambiguity in expectations for how the robot should behave within these environments could have negative consequences. For example, if people expect the robot to stop and the robot fails to do so, this could be perceived as a transgression of social norms [2]. Furthermore, this transgression could result in negative associations with the robot, which can lead to detrimental workplace practices and behaviours [2,18].

This is further evidenced in participants accounts for human-robot responsibility in maintaining safe distances. Participants who responded that it was the robot's responsibility suggested people should not have to adapt to robot's entering the work environment as robots should be capable of managing these dynamics. This aligns with Mead and Matarić [2017], who argue that an autonomous robot must develop the capacity to both understand and control proxemics and employ communication mechanisms analogous to those used by humans in order to operate successfully in this context. In contrast participants who reported that it was the persons' responsibility to maintain safe distances suggested people should be more accommodating of new robotic technologies due to greater human capability. This contrast further indicates a lack of consensus around expectations for robot behaviour and the social norms that workers should follow within the work environment. These findings reflect Chen et al. [4] that highlight the challenges in having robots navigate efficiently and safely in close proximity with people as they tend to follow subtle social norms that obfuscates goals and intentions.

This leads to a discussion of communication and intentions. Within scenario one participants reported that a lack of communication of intention between the robot and the person led to confusion. This was raised by participants in scenario two who suggested the robot had attempted to respond to the person but was unable to read their intentions. This was further highlighted in scenario three where accounts for the persons awareness of the robots was based on its ability or capacity to communicate presence through design features. This supports the argument of Goetz et al. [2003], that a robot's appearance and behaviour provide cues to the robot's abilities and propensities [29]. However, there appears to be ambiguity in the physical cues the robot in scenario three is displaying due to the lack of consensus.

When addressing the research question the results of this study suggest that there is a lack of consensus among participants who have experience working with AMRs as to how shared space interactions with AMRs in the workplace are perceived. Based on the findings of this study design considerations are presented to inform the design of AMRs used in manufacturing and logistics contexts (refer to Appendix 1).

5 CONCLUSION & FUTURE WORK

The findings of this study indicate ambiguity in how participants account for AMRs within the social order of the workplace and by extension, their expectations around the social norms that AMRs must comply with and the associated behaviours these social norms would dictate. There are clearly factors present within these situations that introduce ambiguity into participants' perceptions of these interactions. These issues will need to be addressed as transgressions of social norms by robots can lead to detrimental workplace practices and behaviours in HRI. This research also highlights the need for more ethnographic based design studies that consider how physical and social factors present within a given context could be used to inform HRI and effectively design and implement robots into the workplace. Finally, this research has been an exploratory study to inform the next phase of the research project, where participants will interact with a virtual AMR prototype created using the UNREAL engine. This future research will explore how natural communication mechanisms analogous to those used by humans, such as social cues, could be utilised to inform AMR appearance and HRI design, to address the issue of ambiguity and make robot intentions more explicit.

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APPENDICES

Appendix 1

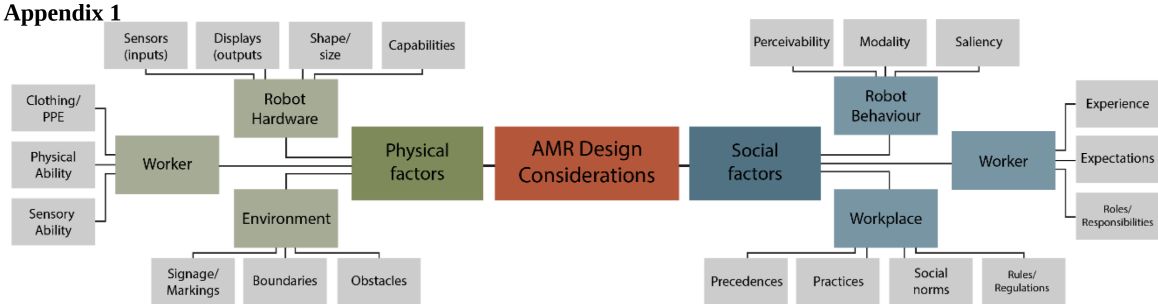

Figure 2. AMR Design Considerations

Note. These considerations are groups into two factors the physical and the social, then further separated in robot, worker, and context. It should be noted that these considerations are not exhaustive but rather provide grounding for future design and research work in this space.