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Published in:
IST 2023 - IEEE International Conference on Imaging Systems and Techniques, Proceedings

DOI (link to publication from Publisher):
10.1109/IST59124.2023.10355723

Publication date:
2023

Document Version
Accepted author manuscript, peer reviewed version

Communicating robot intentions: Usability study of a socially-aware mobile robot

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***Abstract*— Mobile robots need to understand human actions and produce socially accepted behaviors. In this paper, we address this issue and propose a method for mobile robots to communicate their intentions to humans. We also recognize the need for robots to move in a social manner by respecting the personal space of humans and not interrupting their interactions with other people or objects in the environment. We present a retrofitted MiR100 equipped with an RGB-D camera and a video projector. The RGB-D camera is used in human-aware navigation to recognize humans and predict their trajectories so as for the robot to react proactively to human actions, creating a safe and seamless human-robot collaboration. Here, the video projector acts as a communication channel between the robot and humans, as it transmits the robot's motion intentions. In order to evaluate the robot's ability to communicate its intentions, we performed extensive human-centered HRI experiments where 30 participants interacted with the robot integrated with socially aware navigation and a video projector. Our experiments demonstrated that the social acceptance of the mobile robot was favored by the use of human-aware navigation and its combination with the video projector raised the mobile robot's usability and comfort by 6% and 12%, respectively.**

I. INTRODUCTION

For the past decades, mobile robots have proven successful in navigating constrained industrial environments for logistic operations [1], [2]. The challenge, however, arises when introducing robots to our everyday social settings such as shopping centres, classrooms, hospitals or nursing homes. Mobile robots that can only follow a pre-defined path in such challenging environments present certain limitations. Therefore, many researchers have enhanced their robots with human-aware navigation features [3]–[5] and even adapted them to follow specific social awareness protocols during the COVID-19 pandemic [6]–[8]. Human-aware navigation can help mobile robots plan their trajectories according to predefined rules that allow them to detect the presence of humans in their vicinity and subsequently understand specific human actions better [9]. Transparent communication in human-robot interaction (HRI) has been proven to assist with predicting the robot's behavior and increase the trust that the humans have towards the robot system [10], [11].

However, to achieve successful HRI, humans should be able to understand the robots' intentions, and the robots should be able to communicate their intentions comprehensively [12]. There are plenty of examples in recent literature where researchers have combined various cameras, projectors and AR technologies with mobile robots to achieve

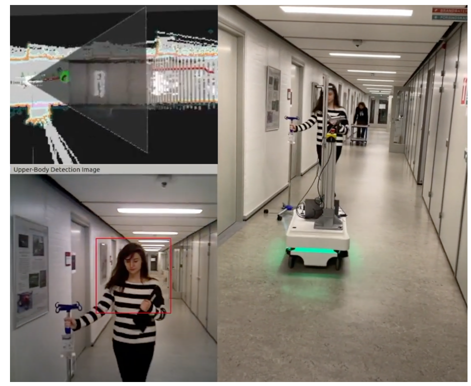

Fig. 1. (Top left) Visualization of the predicted trajectories in the human-aware navigation module, (bottom left) detection of a human based on the on-board camera, (right) the mobile robot navigates inside a narrow corridor exhibiting socially-aware behavior.

transparent communication and socially acceptable robot behavior [13]–[16]. Despite the plethora of such systems, there is still a gap of knowledge concerning the systems' usability. It remains unclear which modules provide the most usable mobile platform for human-aware navigation and transparent robot-human communication. Moreover, most surveys used to track user impressions for these systems, lack standardised metrics and keep their questions hidden rendering their replication almost impossible.

Therefore, in this paper, we attempt to bridge these two gaps by performing a comprehensive usability study of our proposed robot and by sharing the backend of our questionnaires to enable easier reproducibility from future studies. We equipped a MiR100 mobile robot with an RGB-D camera and a projector and performed human-aware navigation, as shown in Fig. 1, based on the prediction of human trajectories and Timed Elastic Band [17]. Afterwards, we conducted usability experiments with 30 participants to evaluate the system based on the standardised USUS [18] and UTAUT [19] metrics to reflect on the user experience, social acceptance and overall usability. Our experiments demonstrated that a projector is an excellent tool for transparent communication in HRI as it significantly improves the mobile robot's overall usability and user experience.

II. RELATED WORK

Studies have shown that humans can communicate effectively with non-verbal signals [20], [21]. We can rely on our social cognition to infer information based on our knowledge of the social world, to interpret others, and proactively predict their intentions. When it comes to collaboration between

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humans and robots, non-verbal communication can also be used for robust prediction of the robot's intentions [22], [23].

A detailed study of how robots can affect human's trust was presented by Weigelin et al. [24], where a robotic manipulator was used as a therapeutic robot to measure the issues of trust in the robot's interaction with patients by examining the degree to which 12 participants identified a situation as uncomfortable, the degree to which the robot was responsible for those situations, and their effect on the participants' trust towards the robot. Their results concluded that an increased level of transparency from the robot could help gain the participant's trust since, in many cases, the participants asked the person in charge of the experiment for guidance. At the same time, in some experiments, participants were informed of the actions the robot was about to perform. In such cases, the prior knowledge proved impractical. Hence, humans do not need to know the final goal of the robot's operation. Instead, it is sufficient to obtain feedback in a timely fashion on how the robot is going to achieve the goal and the level of trust can remain high [10].

One of the most effective ways to provide such feedback is augmented reality (AR) and light signals. Chadalavada et al. [25] used a fork-lift robot equipped with a video projector to project a simplified map with the robot's plan. The experiments showed an increase of 31.72% in user ratings compared to when the robot navigated without conveying its intentions. Overall, the robot was more communicative, predictable, and transparent than without a projection system.

Similarly, Matsumaru [26] used a projector to display the actions of the robots: *stop* and *back* and an arrow expressing the direction of motion, the length of the arrow represented the speed of the motion. A total of 200 participants were surveyed, and the results indicated that the usage of the AR-projector system communicated the intents of the robot in a more intelligible way.

In the same direction, Coovert et al. [27] projected an arrow on the floor to indicate the robot's directions. Instead of measuring trust or user ratings, they evaluated the robot's ability to transmit its intentions by asking humans to predict the robot's following action. The results were favourable, and humans could predict these actions in most cases.

As an alternative approach to AR, lights have been used in work proposed by Palinko et al. [28] where they used a joystick to control the robot navigation and hence produce the robot behaviors needed for the experiments. Then, they used the robot platform's lights to signal various robot behaviors. Different light signalling methods were used, such as blinking lights—an analogy to the standard car turn signalling—and rotating lights.

Based on the presented techniques, it is clear that projecting the robot movement intentions on the floor has the potential for more transparent robot-human communication. Approaches such as Palinko et al. [28] do not provide conclusive realistic results due to the usage of a joystick to control the robot movement. In a real scenario, the robot would need to navigate autonomously, resulting in arbitrary and sporadic trajectories, much different from those produced by a human-operated robot.

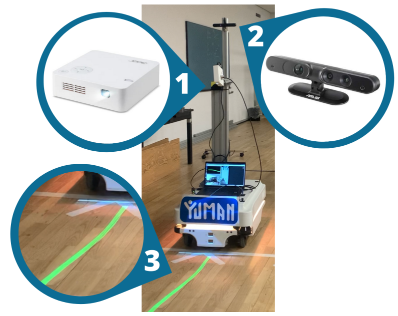


Fig. 2. Retrofitted MiR100 mobile base used for the HRI experiments. It is equipped with two SICK S300 Laser Scanners, an Asus Xtion Pro Live RGBD camera (1) and a video projector Acer C202i (2). The projected image illustrates the robot's navigation plan(3).

Moreover, to provide realistic HRI, it is necessary to evaluate the usability and acceptance of the chosen communication method. The above mentioned approaches evaluate their chosen methods using custom evaluation frameworks. It is therefore challenging to compare the different methods and judge which of the proposed methods is most useful to humans. However, multiple studies have shown that evaluation methods for HRI can be standardised and reused [29]. In our experiments, we used the so-called USUS Evaluation Framework for HRI proposed by Weiss et al. [18], which evaluates the factors of usability, social acceptance, user experience, and societal impact. This framework aims at understanding to what degree HRI methods contribute to humans accepting robots as part of society. To further measure social acceptance, we used the Unified theory of acceptance and use of technology (UTAUT) [30] as it was adapted from Han et al. [19] to evaluate the acceptability of users towards a tele-presence robot in an educational setting.

III. System Description

We address the study of HRI applied to a mobile base considering a robust human-aware navigation stack and a projection system to transmit the robot movement intentions and allow transparent robot-human communication.

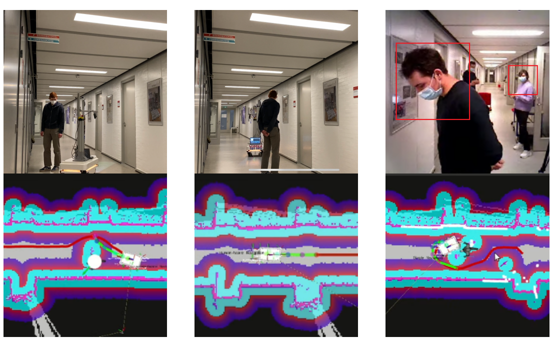
A. Robot Setup

We used a MiR100 mobile base equipped with an RGB-D camera and a video projector, as depicted in Fig. 2. The MiR100 was initially equipped with two Sick S300 Laser Scanners, an Intel RealSense D435 camera and Ultrasound sensors in the front of the robot. However, the position of the RGB-D camera was not ideal for human detection purposes as it could only capture images from 50 to 995 mm above the floor. In such a field of view, it is impossible to detect human bodies as only their legs can be detected. For this reason, we added an additional RGB-D Asus Xtion Pro Live camera, positioned 1.6 meters from the ground in the centre of the MiR base. To project the robot's navigation plan, an Acer C202i projector is attached in the custom structure 1.3 meters from the floor in the front part of the robot.

B. Human-aware Navigation

We consider the navigation in a known environment. Inspired by how humans navigate by understanding each other's behaviors and respecting personal space, we approached navigation as a cooperative activity between robots and humans. Unfortunately, traditional navigation using only LiDAR scans treats humans as any other obstacle, which is not sufficient. To alleviate this, we used the Asus Xtion Pro Live RGB-D camera to capture a more realistic and accurate representation of the environment.

Once the robot can distinguish humans from the other available objects in the environment, we utilize a people tracking module based on nearest-neighbor data association [31] to predict their trajectories based on their position and speed relative to the robot. Based on this information, we establish the necessary proxemics so the robot can proactively plan its trajectory in the same shared environment and avoid future collisions. In this way, the robot is not only able to navigate in ample spaces but also in areas with reduced space. As an example, Fig. 3 illustrates the navigation plan of the robot in a narrow corridor when humans are present in different scenarios.



(a) (b) (c)

Fig. 3. Navigation in real-world scenarios. From left to right: (a) the robot avoids/crosses a human walking, (b) the robot plans ahead a straight trajectory without obstacles in its vicinity, (c) the robot proactively avoids multiple humans in a narrow space from a relatively far distance.

C. Robot-Human Communication

To communicate the robot's motion intentions, we project the robot's planned trajectory as a line on the floor, showing its local plan. Since the users have no other way to perceive if the robot acknowledges their presence, they rely on the projected trajectory to rate the robot's communication abilities and gain trust in its human-aware navigation capabilities.

IV. Usability Study

We conducted a usability study in order to evaluate the use of the projector with our mobile robot and measure its effect on the robot usability, social acceptance, user experience and social impact. The scope of this study is to evaluate the use of the projector as a means of communication of the robot's intentions to the users, in comparison to the same mobile robot without use of projector.

A. Study Design

In total, 30 people participated in the usability study, divided in 10 groups of 3 people each. Two experiments were conducted in a 8×15 m room. Each experiment involved 5 groups (15 people) making sure that no group or individual participated in both experiments. Each of the experiments 1 and 2 consisted 2 sub-experiments (dubbed respectively, experiments 1.1, 1.2, 2.1 and 2.2).

a) Experiment 1: In experiment 1.1, the robot autonomously navigated around the classroom in a social manner (not necessarily on a straight line) without projecting its intentions (Projector OFF) while participants from each group were asked to walk along the classroom interacting with the robot as much as desired.

Experiment 1.2 was carried out in the same way as above, with the modification that a projector was used (Projector ON) to project a line with the robot's trajectory plan onto the classroom floor. The participants were explained that the projected line symbolised the robot's trajectory.

After the first participants were surveyed, we noticed that they got comfortable with the robot after a few initial runs. As a first interaction, these participants encountered the robot without the projector.

b) Experiment 2: To measure whether the usage of the projector had an effect on the initial trust humans exhibited towards the robot and in the overall social acceptance of the robot, in Experiment 2, we modified the order in which participants encounter the robot.

In experiment 2.1, the robot autonomously navigated projecting its intentions (Projector ON), and the participants were asked to move freely around the classroom, interacting with the robot as desired.

Experiment 2.2, the setting was the same as above, but the robot was not projecting its intentions (Projector OFF).

B. User Input

At the end of the experiments, each participant was asked to fill in a survey with 18 questions to explicitly evaluate their experiences with the robot. The survey was organized around the USUS and UTAUT evaluation frameworks. The following areas were therefore covered:

a) Usability: We evaluated the robot usability with and without the projector based on the System Usability Scale (SUS), an industry standard for measuring the usability of technological systems. This is represented as ten-items with a five-point Likert scale (from strongly disagree to strongly agree). The scores are converted to a 0-100 scale, where a system with a SUS score above 68 is considered sufficiently usable. The questions asked in our experiments are presented in Table I.

b) Social Acceptance: The social acceptance towards the robot was evaluated using the UTAUT framework, inspired by Han et al. [19]. We used four questions with a five-point scale and we measured four factors: Performance Expectancy (1), Effort Expectancy (2), Attitude towards Using Technology (3) and Self Efficacy (4). The used questions were:

1) *The behavior of this mobile robot is as I expected it.*
2) *How much effort does it require from you to understand where the robot is going to go?*
3) *I think the usage of a projector was good indicator of the robot's movement goals.*
4) *If I were to encounter the robot alone, I would be afraid.*

To quantify the social acceptance factor we have chosen a scoring similar to SUS. Each of the 4 questions contributes equally to the SUS score, negative questions (2, 4) are inverted, and the raw SUS score is normalized to match the 0-100 scale.

c) User Experience: To evaluate the user experience, we measured how engaging (1) and interesting (2) the robot seemed to the participants:

1) *Who would you choose to deliver the coffee for you? 1. The Robot, 2. A Human.*
2) *Would the robot seem interesting to use? 1. Extremely, 2. A bit, 3. Not much, 4. Not at all.*

The score was normalized to match the 0-100 scale.

d) Personalised Affirmations: Finally, 7 personalised affirmations with a five-point Likert scale (from strongly disagree to strongly agree) were asked with the aim to evaluate: (affirmations 1-3) the *comfort* of the participants with the robot at the start and end of the experiment, when the projector was on and off (or vice-versa); (affirmations 4-5) the *perceived competence* describing the belief that the participant is able to interact with the mobile robot; (affirmations 6-7) the *performance expectancy* to which participants believed that using the robot would help their daily activities.

1) *When the projector was turned OFF, I was comfortable approaching the robot.*
2) *After the projector was turned ON, I was comfortable approaching the robot.*
3) *If encountering the robot alone, I would walk more safely if the projector is ON.*
4) *It was easy for me to move along the robot.*
5) *It was easy for me to understand the usage of the projector.*
6) *I believe that the use of the robot for transporting stuff would improve my study life.*
7) *I used the projector to see where the robot was going.*

To quantify these results, the average score for each group of questions was computed and assigned to its respective factor.

V. EVALUATION

A total of 30 participants were surveyed. 56.7% of the participants were male, and the prominent age group (50%) was between 20 and 25 years old; 66% of the participants have a background in Robotics or Electrical Engineering, the remaining are engineers outside the robotics field. From the 30 participants, all of them have interacted with a robot before. The majority interacted with robot vacuums and classroom robots. However, 33% of the participants have never programmed and/or worked with mobile or other industrial robots. Since our target group was students from university, the majority in the robotics field, the results might be biased since the participants can judge the robot's performance based on their experiences programming and working with mobile robots.

a) Usability: The usability score differs based on the order in which participants encountered the mobile robot. The 5 groups who encountered first the robot without the projector rated both experiments 1.1 and 1.2 with a SUS score of 77.5. Whereas for the 5 groups who encountered the robot with the projector first, the SUS score for experiment 2.1 is 85, and for experiment 2.2, the SUS score is 80. Examining the results presented in Fig. 4, it can be seen that participants in experiment 1 did not experience a meaningful change in the robot's usability after the projector was turned ON. On the contrary, participants in Experiment 2 considered the robot to be more usable when the projector was turned ON. This can be seen by comparing the maximum SUS scores for experiments 2.1 and 2.2, 97.5 and 92.5, respectively.

In experiment 1.1, the robot was perceived with a high usability score before the projector was introduced, and the

Without the projector	**With the projector**
• *I think that I would like to interact with this mobile robot frequently*	• *I think that I would like to interact with this mobile robot frequently*
• *I found the mobile robot's movement unnecessarily complex*	• *I found the projected object unnecessarily complex*
• *I thought the mobile robot's movement was easy to comprehend*	• *I understood what the projected object meant*
• *I think that I would need the support of a technical person to be able to interact with this mobile robot*	• *I think that I would need the support of a technical person to be able to understand the projected object*
• *I trusted the mobile robot actions when the projector was OFF*	• *I trusted the mobile robot actions when the projector was ON*
• *I thought that the mobile robot could not recognize me when planning his actions*	• *I found the projected object difficult to understand*
• *I would imagine that most people would learn to interact with this mobile robot very quickly*	• *I would imagine that most people would learn to understand the robot intentions through the projected object very quickly*
• *I was stressed during my interaction with the mobile robot when the projector was OFF*	• *I was stressed during my interaction with the mobile robot when the projector was ON*
• *I felt secure during my interaction with the mobile robot when the projector was OFF*	• *I felt secure during my interaction with the mobile robot when the projector was ON*
• *I would need to learn a lot of things before I could get going with this mobile robot*	• *I needed to learn a lot of things before I could get going with this mobile robot*

TABLE I. SUS questionnaire to measure the robot's usability with and without the projector

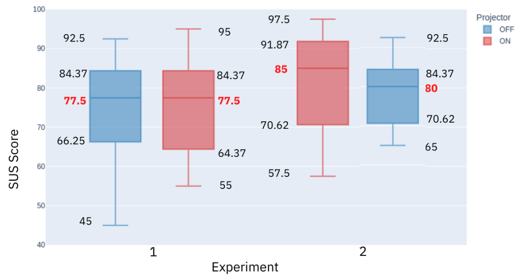


Fig. 4. Box plot of SUS scores for the two experiments. Experiment 1 has average SUS score 77.5 and experiment 2 has average SUS score of 82.5.

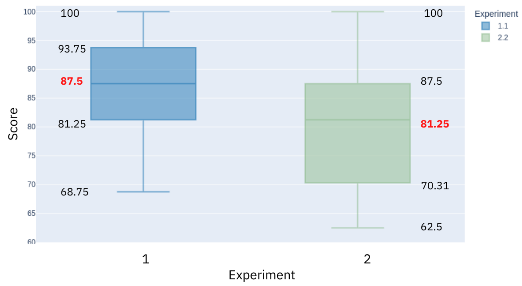


Fig. 5. Box Plot of Social Acceptance rating evaluation scores for 30 participants. The average scores are 82.5 in experiment 1 and 81.6 in experiment 2.

introduction of the projector did not have an apparent effect on the usability factor. However, in experiment 2.1, the participants used the projected objects to interpret the robot's motion. As this was their first interaction with the robot, when the projector was OFF in experiment 2.2, the absence of the motion indicator became more noticeable, resulting in a decrease in the robot's usability.

b) Social Acceptance: The answers to the questionnaire in both alternating experiments follow similar trends, also reflected on the social acceptance score. The resulting social acceptance scores based on the SUS scale are illustrated in Fig. 5. Experiment 1 has a median social score of 87.5, significantly close to experiment 2, with an 81.25 score. Hence, the order in which participants encountered the robot (with our without the projector) slightly affected the social acceptance towards the robot. The reasoning behind the difference in scores could be that the participants in experiment 1 had their last interaction with the robot when the projector was ON, which enhances their experience with the robot, as it will be concluded with the results from the user experience measurements. Overall, the average social acceptance for both experiments is 84.375, indicating a high social acceptance towards the mobile robot with the projector.

The standard UTAUT model comprises 7 indicators. To validate if the 4 selected factors can reliably be used to measure the social acceptance of the mobile robot, the Cronbach's Alpha score was computed. The obtained results showed that the modified UTAUT model for a mobile robot with a projector has a Cronbach Alpha of 0.71, considered acceptable [32].

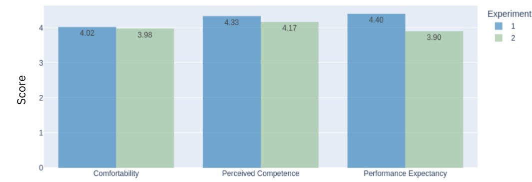


Fig. 6. Average Score Histogram of Personalised Affirmations factors in experiment 1 and 2. The overall score is 4.1 (out of 5).

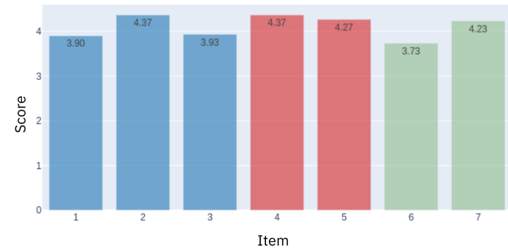


Fig. 7. Average Score of the seven Personalised Affirmations items: Comfortability (Items 1-3), Perceived Competence (Items 4-5), and Performance Expectancy (Items 6-7).

c) User Experience: The results of the engagement factor reveal that 73.3% participants would prefer the robot to a human in experiment 1 and 60% in experiment 2. In this case, the participants in experiment 1, who interacted with the robot projecting the path at the end of the experiment, were more eager to engage with the robot. However, it was observed that this question raised ambiguity, as some participants were more concerned about the details in which the coffee is received rather than the interaction itself. 93.3% of participants agree that the robot is enjoyable to use in experiment 1, and 86.7% in experiment 2. Some participants highlighted that the robot seemed to be alive during the experiments. Hence, the robot received a positive user experience review and very high interest.

d) Personalised Affirmations: The use of the mobile robot with the projector has received a consistently high score from each participant in every measured factor, as illustrated in Fig. 6. The slight difference in score between experiments indicates that the order in which the participants interacted with the robot did not affect the perceived comfort and competence factors.

To better understand the influence the projector had on the participants' Comfortability, Perceived Competence and Performance Expectancy, we individually examined the average scores for the seven items. The results are presented in Fig. 7. The comfortability with the robot is rated at 3.9 when the projector is OFF (Item 1) and 4.37 when the projector is ON (Item 2). Consequently, we can claim that the usage of the projector as means of communication for the robot intentions enhances the comfortability of humans towards the robot.

VI. Discussion and Future Work

This paper presents a system for socially-aware navigation and human-robot communication using a video projector to display the robot movement intentions with the goal of testing if such a system increases the robot's usability, social acceptance and user experience.

Experiments and surveys using the USUS and UTAUT frameworks demonstrated that introducing the projector as a means of communication increases robot usability, social acceptance and the feeling of comfort. The overall high scores indicate that using human-aware navigation was crucial for participants to feel safe and gain trust with the robot. After the first interactions with the robot, the participants realized that the robot could recognize them and avoid them by keeping safe distances. Hence, they automatically felt safer and more comfortable. Therefore, the projector was an enhancement to human-aware navigation.

Dividing the experiments into two groups and alternating the order in which participants encountered the robot and the communication system revealed that after getting familiar with the robot without the projector, the participants did not experience a significant change in their experience and had a high social acceptance towards the robot. However, in the opposite setting, participants noticed the projector's absence after it was turned OFF and felt as if they could no longer understand where the robot was going. This fact is represented by the lower social acceptance scores in experiment 2, in contrast to the scores in experiment 1.

References

[1] R. E. Andersen, E. B. Hansen, D. Cerny, S. Madsen, B. Pulendralingam, S. Bøgh, and D. Chrysostomou, "Integration of a skill-based collaborative mobile robot in a smart cyber-physical environment," *Procedia Manufacturing*, vol. 11, pp. 114–123, 2017.

[2] V. Krueger, A. Chazoule, M. Crosby, A. Lasnier, M. R. Pedersen, F. Rovida, L. Nalpantidis, R. Petrick, C. Toscano, and G. Veiga, "A vertical and cyber-physical integration of cognitive robots in manufacturing," *Proceedings of the IEEE*, vol. 104, no. 5, pp. 1114–1127, 2016.

[3] T. Kruse, A. K. Pandey, R. Alami, and A. Kirsch, "Human-aware robot navigation: A survey," *Robotics and Autonomous Systems*, vol. 61, no. 12, pp. 1726–1743, 2013.

[4] J. Rios-Martinez, A. Spalanzani, and C. Laugier, "From proxemics theory to socially-aware navigation: A survey," *International Journal of Social Robotics*, vol. 7, no. 2, pp. 137–153, 2015.

[5] R. Möller, A. Furnari, S. Battiato, A. Härmä, and G. M. Farinella, "A survey on human-aware robot navigation," *Robotics and Autonomous Systems*, vol. 145, p. 103837, 2021.

[6] M. Cardona, F. Cortez, A. Palacios, and K. Cerros, "Mobile robots application against covid-19 pandemic," in *2020 IEEE ANDESCON*, 2020, pp. 1–5.

[7] H. B. Barua, P. Pramanick, C. Sarkar, and T. H. Mg, "Let me join you! real-time f-formation recognition by a socially aware robot," in *2020 29th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*, 2020, pp. 371–377.

[8] R. Salek Shahrezaie, S. B. Banisetty, M. Mohammadi, and D. Feil-Seifer, "Towards deep reasoning on social rules for socially aware navigation," in *Companion of the 2021 ACM/IEEE International Conference on Human-Robot Interaction*, 2021, pp. 515–518.

[9] K. Charalampous, I. Kostavelis, and A. Gasteratos, "Recent trends in social aware robot navigation: A survey," *Robotics and Autonomous Systems*, vol. 93, pp. 85–104, 2017.

[10] P. A. Hancock, D. R. Billings, K. E. Schaefer, J. Y. Chen, E. J. De Visser, and R. Parasuraman, "A meta-analysis of factors affecting trust in human-robot interaction," *Human Factors*, vol. 53, no. 5, pp. 517–527, 2011.

[11] M. Lewis, K. Sycara, and P. Walker, "The role of trust in human-robot interaction," in *Foundations of trusted autonomy*, 2018, pp. 135–159.

[12] T. L. Sanders, T. Wixon, K. E. Schafer, J. Y. Chen, and P. A. Hancock, "The influence of modality and transparency on trust in human-robot interaction," in *2014 IEEE International Inter-Disciplinary Conference on Cognitive Methods in Situation Awareness and Decision Support (CogSIMA)*, 2014, pp. 156–159.

[13] A. Watanabe, T. Ikeda, Y. Morales, K. Shinozawa, T. Miyashita, and N. Hagita, "Communicating robotic navigational intentions," in *2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2015, pp. 5763–5769.

[14] R. S. Andersen, O. Madsen, T. B. Moeslund, and H. B. Amor, "Projecting robot intentions into human environments," in *2016 25th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, 2016, pp. 294–301.

[15] B. Lewandowski, T. Wengefeld, S. Müller, M. Jenny, S. Glende, C. Schröter, A. Bley, and H.-M. Gross, "Socially compliant human-robot interaction for autonomous scanning tasks in supermarket environments," in *2020 29th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*, 2020, pp. 363–370.

[16] N. J. Hetherington, E. A. Croft, and H. M. Van der Loos, "Hey robot, which way are you going? nonverbal motion legibility cues for human-robot spatial interaction," *IEEE Robotics and Automation Letters*, vol. 6, no. 3, pp. 5010–5015, 2021.

[17] C. Rösmann, W. Feiten, T. Wösch, F. Hoffmann, and T. Bertram, "Trajectory modification considering dynamic constraints of autonomous robots," in *ROBOTIK 2012; 7th German Conference on Robotics*, 2012, pp. 1–6.

[18] A. Weiss, R. Bernhaupt, M. Lankes, and M. Tscheligi, "The USUS evaluation framework for human-robot interaction," in *23rd Convention of the Society for the Study of Artificial Intelligence and Simulation of Behaviour, AISB 2009*, 2009, pp. 158–165.

[19] J. Han and D. Conti, "The use of UTAUT and post acceptance models to investigate the attitude towards a telepresence robot in an educational setting," *Robotics*, vol. 9, no. 2, p. 34, 2020.

[20] S.-J. Blakemore and J. Decety, "From the perception of action to the understanding of intention," *Nature Reviews Neuroscience*, vol. 2, no. 8, pp. 561–567, 2001.

[21] R. Buck and C. A. VanLear, "Verbal and nonverbal communication: Distinguishing symbolic, spontaneous, and pseudo-spontaneous nonverbal behavior," *Journal of communication*, vol. 52, no. 3, pp. 522–541, 2002.

[22] P. F. Dominey and F. Warneken, "The basis of shared intentions in human and robot cognition," vol. 29, no. 3, 2011, pp. 260–274.

[23] Z. Gong and Y. Zhang, "Robot signaling its intentions in human-robot teaming," in *HRI Workshop on Explainable Robotic Systems*, 2018.

[24] B. C. Weigelin, M. Mathiesen, C. Nielsen, K. Fischer, and J. Nielsen, "Trust in medical human-robot interactions based on kinesthetic guidance," in *2018 27th IEEE International Symposium on Robot and Human Interactive Communication (RO-MAN)*, 2018, pp. 901–908.

[25] R. T. Chadalavada, H. Andreasson, R. Krug, and A. J. Lilienthal, "That's on my mind! robot to human intention communication through on-board projection on shared floor space," in *2015 European Conference on Mobile Robots (ECMR)*, 2015, pp. 1–6.

[26] T. Matsumaru, "Mobile robot with preliminary-announcement and display function of forthcoming motion using projection equipment," in *ROMAN 2006-The 15th IEEE International Symposium on Robot and Human Interactive Communication*, 2006, pp. 443–450.

[27] M. D. Coovert, T. Lee, I. Shindev, and Y. Sun, "Spatial augmented reality as a method for a mobile robot to communicate intended movement," *Computers in Human Behavior*, vol. 34, pp. 241–248, 2014.

[28] O. Palinko, E. R. Ramírez, W. K. Juel, N. Krüger, and L. Bodenhagen, "Intention indication for human aware robot navigation." in *VISIGRAPP (2: HUCAPP)*, 2020, pp. 64–74.

[29] C. Jost, B. Le Pévédic, T. Belpaeme, C. Bethel, D. Chrysostomou, N. Crook, M. Grandgeorge, and N. Mirnig, *Human-Robot Interaction: Evaluation Methods and Their Standardization*, 2020.

[30] V. Venkatesh, M. G. Morris, G. B. Davis, and F. D. Davis, "User acceptance of information technology: toward a unified view," *Institutions & Transition Economics: Microeconomic Issues eJournal*, vol. 27, no. 3, pp. 425–478, 2003.

[31] O. H. Jafari, D. Mitzel, and B. Leibe, "Real-time RGB-D based people detection and tracking for mobile robots and head-worn cameras," in *2014 IEEE international conference on robotics and automation (ICRA)*, 2014, pp. 5636–5643.

[32] S. S. Saidi and N. M. Siew, "Investigating the validity and reliability of survey attitude towards statistics instrument among rural secondary school students." *International Journal of Educational Methodology*, vol. 5, no. 4, pp. 651–661, 2019.