

# Empirical evaluation of human trust in an expressive mobile robot

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**Abstract**—A mobile robot communicating its intentions using Spatial Augmented Reality (SAR) on the shared floor space makes humans feel safer and more comfortable around the robot. Our previous work [1] and several other works established this fact. We built upon that work by adding an adaptable information and control to the SAR module. An empirical study about how a mobile robot builds trust in humans by communicating its intentions was conducted. A novel way of evaluating that trust is presented and experimentally shown that adaption in SAR module lead to natural interaction and the new evaluation system helped us discover that the comfort levels between human-robot interactions approached those of human-human interactions.

**Keywords**—human robot interaction, mobile robot, trust, evaluation.

## I. INTRODUCTION

Classically, Automatic Guided Vehicles (AGV) navigate along pre-defined paths which are easy to predict for human workers co-populating the environment. Increasing autonomy allows AGVs to be more versatile and efficient, but the corresponding behaviors may appear unpredictable to humans leading to unacceptability of the technology and/or decreasing efficiency of the work environment. Human workers are used to collaborate with humans and, in certain scenarios, even do not need to rely on verbal communication. This kind of collaboration is possible because of the innate trust between humans. Trust is an important factor in human-human teams, and the same applies for human-robot teams. Humans convey necessary cues to develop such trust. In this work, we outline how a robot could achieve equivalent trust levels and how these can be measured.

Lee and Moray [2] define trust in such contexts as the attitude that an agent will help achieve an individuals goals in a situation characterized by uncertainty and vulnerability. According to Freedy et al. [3], trust is a complicated and multidimensional construct influenced by types of information received by humans and their approaches to developing and determining trust as well as external influences such as system capability and reliability. A human develops trust by observing the characteristics of the system, such as its performance and the manner in which the process of accomplishing goals is transparent [3]. Furthermore, researchers like Breazeal [4], Asada et al. [5] and Dautenhahn [6] suggest that a robot's ability to maintain appropriate interaction distance, to communicate effectively and appearing safe will make it appear more reliable, predictable and transparent to humans and thus facilitate the development of trust. Upon performing a meta-analysis, Hancock et al. [7] suggested factors that can affect

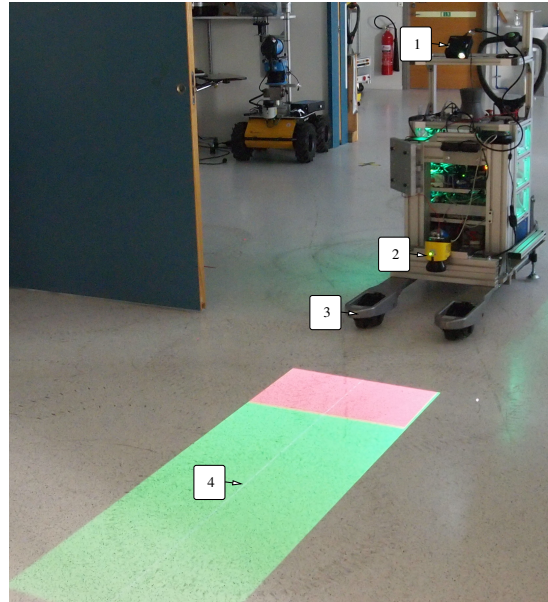


Fig. 1. The platform used for the evaluations: A standard projector (Optoma ML 750) (1) is mounted on a retrofitted Linde CitiTruck forklift AGV (3). Two SICK S300 scanners are mounted in front (2) and back to ensure safety for human co-workers. A projector is used to project the intention of the vehicle on the ground plane in front of the truck (4). The white line represents the future trajectory of the robot. The green area indicates the occupied vehicle footprint over the next 5 seconds, the area needed for an emergency stop is shown in red.

the trust in Human-Robot Interactions and we have adapted the relevant attributes for our evaluation purposes.

## II. PLATFORM AND SAR MODULE

In our previous work [1], we developed the Spatial Augmented Reality (SAR) module to experiment with a different projection pattern on the shared floor space using the platform in Fig. 1. Usage of the SAR module improved the robot's performance in key attributes and made the robot safer by encouraging humans to pre-plan their own motion[1]. In this work, we build upon [1] by adding adaptable information and control to the SAR module. SAR module shows the future trajectory of the robot in the form of a white line and using the data from the laser scanners on the platform we define two dynamic areas – green and red respectively (see Fig. 1). A human stepping on the green area, which is supposed to be safe for walking, will cause the vehicle to slow down (speed is  $0.05\text{ m/s}$  compared to the normal speed of  $0.6\text{ m/s}$ ). Red area represents an emergency-brake region, where if a human

steps, the forklift will immediately stop. The two areas are defined based on the intended velocity profile and the footprint of the vehicle as seen in Fig. 1. The slowdown region and the emergency-brake region are respectively defined to be the space the vehicle needs to occupy in the next 5s or 2s.

### III. EXPERIMENTS

In order to quantitatively evaluate how the designed system can affect the human trust towards the robot, two pilot experiments were designed. The first pilot experiment consists of an encounter in a corridor, while the second pilot experiment represents a junction crossing situation. For evaluation, we chose 14 subjects from various backgrounds and age groups. Each pilot experiment was divided into three tasks. Task 1: Human-Robot encounter, Task 2: Human-Robot with projection encounter, Task 3: Human-Human encounter. The order of the tasks is task 3, task 1 and task 2.

The task 3 of each experiment where the human encounters another human was designed in order to create a benchmark for the evaluations and to prepare the subjects for the follow-up experiments with the robot. This way of evaluation is expected to bring in more originality to the ratings as the subject interacts with the robot immediately after the interaction with a human in a similar situation. After all the tasks, the subjects were asked to rate their experience on a Likert scale against the following attributes for evaluation purposes: communication, reliability, predictability, transparency, and situation awareness. [7][3]

### IV. RESULTS AND CONCLUSION

The mean values of the Likert scale readings from both the Pilot experiments are shown in the Fig. 2. For analysis purposes, the data is grouped respectively to the tasks, Group 1: Human-Robot encounter, Group 2: Human-Robot with projection encounter and Group 3: Human-Human encounter (benchmark). When the projection is ON, there was an increase of ratings for all attributes in general. For the attributes communication, predictability and transparency in the pilot experiment 1, the ratings for group 2 even exceeded the group 3. The biggest discrepancy is in the reliability measure which indicates that an element of hesitation towards the robot remains. In general, the results are better for Experiment 1. We attribute this to the fact that, due to the straight approach, the robots proxemic data is visualized to the human over a longer time-span than in Experiment 2. However, the presented approach almost performs as well in terms of providing the necessary information to convey the current situation and thus allows a human to naturally interact with a mobile robot.

Results from both the pilot experiments Table. I show that there was a statistically significant difference between the three groups as determined by one-way ANOVA. Tukey's HSD test further determined that the means of group 2 and 3 are strongly overlapping and significantly different from group 1, which further strengthens the purpose of the intention communication system on the robot.

By using the developed SAR based intention communication system, we have seen an increase in the ratings for the attributes which contribute to the development of trust in a robot. By comparing the given ratings to the human-human

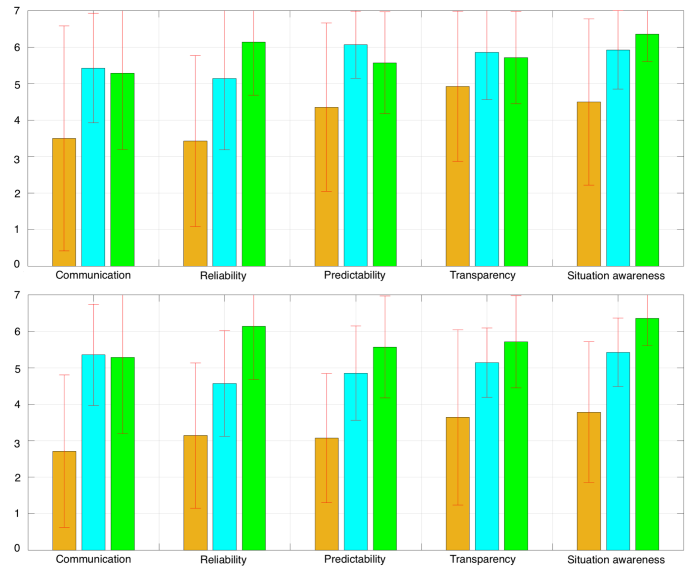


Fig. 2. Mean of the Likert scale results from the pilot experiment 1 with 14 subjects. Orange, blue and green bars represent task 1, task 2 and task 3 respectively. Pilot experiment 1 (Above). Pilot experiment 2 (below)

TABLE I. RESULTS OF ONE WAY ANOVA TEST, TUKEYS HSD TEST OVER THE THREE GROUPS FOR BOTH PILOT EXPERIMENTS

	<i>Pilotexperiment - 1</i>	<i>Pilotexperiment - 2</i>
One way ANOVA test	$F(2, 12) = 16.94470353,$ $p = .0003$	$F(2, 12) = 50.51658291$ $p = 0.0000014$
Tukeys HSD test	<i>Group - 1</i> <i>significantlydifferent</i>	<i>Group - 1</i> <i>significantlydifferent</i>

interaction ratings, we realised how well the system performed towards gaining human's trust.

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