Postprint

# Implicit intention transference using eye-tracking glasses for improved safety in human-robot interaction

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**Abstract.** Eye gaze can convey information about intentions beyond what can be inferred from the trajectory and head pose of a person. We propose eye-tracking glasses as safety equipment in industrial environments shared by humans and robots. In this work, an implicit intention transference system was developed and implemented. Robot was given access to human eye gaze data, and it responds to the eye gaze data through spatial augmented reality projections on the shared floor space in real-time and the robot could also adapt its path. This allows pro-active safety approaches in HRI for example by attempting to get the human's attention when they are in the vicinity of a moving robot. A study was conducted with workers at an industrial warehouse. The time taken to understand the behavior of the system was recorded. Electrodermal activity and pupil diameter were recorded to measure the increase in stress and cognitive load while interacting with an autonomous system, using these measurements as a proxy to quantify trust in autonomous systems.

**Keywords:** human-robot interaction, intention communication, eye tracking, spatial augmented reality, electrodermal activity, stress, cognitive load.

## 1    Introduction

Safety, legibility, and efficiency are essential for autonomous mobile robots that interact with humans. A key factor in this respect is bi-directional communication of navigation intent, which we focus on in this work with a particular focus on industrial logistics applications. In the direction *robot-to-human*, we studied how a robot can communicate its navigation intent using Spatial Augmented Reality (SAR) [1], [2] such that humans can intuitively understand the robot's intention and feel safe in robot's vicinity. In the direction, *human-to-robot*, we argue that robots in human co-habited environments need human-aware task and motion planning to support safety and efficiency, ideally responding to people's motion intentions as soon as they can be inferred from observable cues. Eye gaze can convey information about intentions beyond what can be inferred from the trajectory and head pose of a person. Hence, we propose eye-tracking glasses as safety equipment in industrial environments shared by humans and robots.

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**Figure 1.** (1) Eye-tracker worn by a participant (2) Empatica E4 band used for measuring electrodermal activity. (3) SAR projection "Arrow" projected on the shared floor space to convey robot's navigation intent. (4) Robot (a retrofitted Automatic guided vehicle - AGV) with SAR intention communication system. (5) The defined area of interest AOI-Robot. (6) Eye gaze fixation.
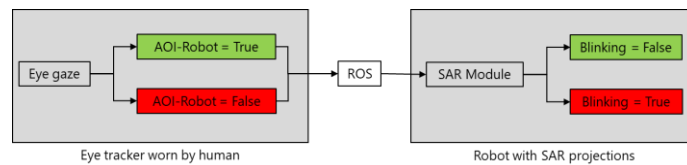


**Figure 2.** The methodology of implicit intention transference

In our earlier work [1], we investigated the possibility of human-to-robot implicit intention transference solely from eye gaze data. Our results have shown that, in the given scenario, a rather naive navigation intent predictor based on the simple rule, "*if people look more often to one side of the robot, they intend to go to that side*" would have predicted the correct navigation intention in 72.3% of the encounters with the simplest possible interpretation of "looking to the left/right" (as "left from the centre of the robot") and "looking more often" (as looking more often during the whole time when the gaze point relative to the robot could be established), i.e. likely leaving ample room for improvement. Building upon this encouraging result that human navigation intention can be predicted from the eye gaze data, we developed an advanced implicit intention transference system, and implemented and tested it with workers at an industrial warehouse. The research question considered for this work is 'Can we use eye gaze based implicit intention transference to enable a safe industrial environment where humans and robots are mobile?' To the best of our knowledge, this is the first work to implement an implicit intention transference system where both the human and the robot are mobile and also a system that is tested and evaluated with industrial workers at an industrial warehouse.

## 2    Related work

Eye gaze is tightly linked to attention and cognitive processes [3]. The eye-mind hypothesis [4] particularly refers to fixations (periods in which eye gaze point remains within a small area over a prolonged period of 200 ms upto seconds [5]) and states that there is no relevant delay between what is fixated and what is being processed cognitively. Baldauf et al. [6], Patla and Vickers [7], and Hayhoe et al. [8] studied the relationship between spatial attention of humans and how they planned their future movements. The main conclusion in [6]–[8] is that the attentional resources of a human are concurrently deployed to multiple locations which are relevant for the following actions. Baldauf et al. [6] further showed that more attentional resources are allocated to regions immediately following the movement goal, and to those parts that require more precise motor control". Patla and Vickers [7] conducted experiments with participants approaching and stepping over obstacles of varying height while wearing eye-tracking glasses. They analysed the spatiotemporal gaze patterns and observed that the participants did not fixate on the obstacles as they were stepping over but did plan in advance as they were approaching an obstacle.

Recognition of the human's navigation intent is first step in human-to-robot implicit navigation intent transference. Researchers such as Huang et al., Admoni et al., Li and Zhang, and Castellanos [9]–[12] to name a few have used eye-tracking for recognizing human intent in a collaborative manipulation setting in which a robot arm could respond to recognized intentions. Another recent work by Li and Zhang [5] also investigates the inference of intentions from gaze data to command a mobile service robot. In comparison to the related work, this work considers a scenario where both humans and robots are mobile.

## 3    Methodology

In this proposed system, robot has access to human eye gaze data in real-time, and it responds in real-time to the received eye gaze data through SAR projections (see Figure 2). In order to achieve this functionality,  we defined an area of interest *AOI-Robot* as shown in Figure *1* which includes an area that spans over the robot, projection and some area around the robot such that the robot would be in the field of view of the human. The eye gaze information was obtained  through the eye-tracker worn by the human. Using the Pupil Capture software developed by the eye tracker manufacturer Pupil Labs, we determined if the eye gaze is within the defined AOI or not. A network connection was established via ROS (see Figure 2) in between the eye tracker and the robot and this is used to communicate the location of the eye gaze to the robot's SAR module andhe robot responds to this information: if the eye gaze is within *AOI-Robot*, then the projected arrow remains static and if the eye gaze is not within the *AOI-Robot,* then the projected arrow blinks to get the human's attention (video ofthe demonstration: https://youtu.be/lMEp6TcjDiw, https://youtu.be/ov8q_KXB2a4). This is intended as a proactive safety approach in HRI in industrial scenarios to ensure safety where the robot

makes an attempt to get the human's attention when the human is in the vicinity of a mobile robot(AGV). The approach of blinking to get the attention was supported by the results in our earlier experiments [1], [13], which show that a blinking arrow immediately got the human's attention.

An Empatica E4[†] band was used to measure the electrodermal activity (EDA) of the participants. As the participant arrived at the experiment site, the first step was to put on the EDA device and start recording, and the participant was asked to relax. They were then given an introduction to the experiment, and the eye tracker was mounted and calibrated. The duration of the EDA recording before the experiment started is defined as *EDA while not focusing on the projections* (baseline condition).During the experiment, participants were asked to observe the robot and its projections to identify the behavior of projections with respect to their eye gaze and were asked to say it out loud when they had guessed the behavior. The time that they were trying to guess the behavior was timed using a stopwatch, which was stopped when the participant had a correct guess of the behavior. The stopwatch was concealed from the participants to not let them feel the pressure of being timed. The duration of the EDA recording during the experiment is defined as *EDA while focusing on the projections.* The eye gaze data including the pupil diameter data was recorded during the experiments.

## 4      Results and Discussion

The study was conducted at an industrial warehouse and all the participants were workers at the warehouse who work in the vicinity of manually operated forklifts and AGVs. Seven participants have participated in this study. All the participants have understood the behavior of the projections with respect to the eye gaze. The time they needed to understand the behavior of projections with respect to eye gaze was $17\pm2.3$ seconds (n=7), which indicates that the designed behavior of projections that respond to the eye gaze was intuitive and easy to comprehend. They were also verbally asked if a system like that would be useful when working with AGVs that are operating freely unlike the current AGVs which stick to a defined path. They have verbally opined that such a system could indeed be useful..

The electrodermal activity (EDA) was analysed and the results are presented in Table 1. (two out of the seven EDA recordings had to be discarded due to technical issues during the recording). A t-test was conducted on the EDA data before the participants started focusing on the projections and while they were focusing on the projections. A significant increase ($p<0.05$) in the EDA data was seen when the participants were trying to understand the behavior of the projections. A rise in the EDA data is an indicator of an increaseof cognitive load and stress [14] and considering the newly introduced intention communication system, the rise in the EDA is understandable.

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[†] https://www.empatica.com/research/e4/

In this work, we suggest the usage of EDA as a potential training tool for industrial workers to measure their progress in training in a quantitative manner i.e. by measuring how the stress levels and cognitive load vary during training. Apart from using the eye tracker as an intention communication tool, we have used it to record the pupil diameter during the experiment. We noticed that the pupils were dilated when the participants were doing the task despite being exposed to bright projections,which would normally result in a decrease of pupil diameter.This is another indicator of increased cognitive load [15]. However, further analysis needs to be conducted on the collected data to determine whether the increase in pupil dilation is due to increased cognitive load alone. Furthermore, the conditions at the experiment site with respect to the consistent lighting conditions, and the duration we had access to the participants were not suitable to obtain a baseline condition for the pupil diameter. Hence, the pupil diameter data is not presented in this work and would be focused on in the future work. Future work would also include using questionnaires to get deeper insights about intention communication methods and behaviors for robots such as AGVs in industrial logistics.

**Table 1.** Comparison of electrodermal activity (EDA) (in µS) while the participants were not focusing on projections and while they were focusing on projections.

|  | EDA while not focusing on projections (mean±std in µS) | EDA while focusing on projections (mean±std in µS) | p-value |
|---|---|---|---|
| **Participant 2** | $2.52 \pm 0.27$ | $3.49 \pm 0.4$ | $p < 0.05$ |
| **Participant 3** | $3.25 \pm 0.56$ | $6.63 \pm 2.61$ | $p < 0.05$ |
| **Participant 4** | $4.37 \pm 0.46$ | $4.61 \pm 0.49$ | $p < 0.05$ |
| **Participant 5** | $2.16 \pm 0.16$ | $3.09 \pm 0.55$ | $P < 0.05$ |
| **Participant 6** | $0.28 \pm 0.08$ | $0.38 \pm 0.11$ | $p < 0.05$ |

This work is a fundamental step in implicit intention communication methods similar to non-verbal communication methods in human interactions. resulting in human intention aware motion planning methods for mobile robots.

This work is a fundamental step in implicit intention communication methods similar to non-verbal communication methods in human interactions, which could be leading to human intention aware motion planning methods for mobile robots. Future work will be focused on further development of implicit intention behaviors for the robot, conducting more experiments in different mobile scenarios with a higher number of participants and calculating the correlations between EDA and pupil diameter. A long term goal of this direction of work is to evaluate whether it is possible to quantitatively measure workers' trust in autonomous systems by using stress and cognitive load as proxy.

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