Integrating Humans in Decentralized Control Systems with Autonomous Transport Vehicles under the Premise and Use of Proxemic Distances*

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Abstract. In future warehouses and production facilities co-working areas of humans and autonomous vehicles will play a more important role. There, humans are confronted with no longer centralized controlled transport systems but decentralized ones, where humans can not easily comprehend the autonomous behavior of robots. Additionally, safety issues may interfere with process optimization. Therefore, new ways of interaction between humans and robots have to be investigated. This paper describes an experimental setup where humans and autonomous transport vehicles share the same working environment. Using methods from communication sciences and psychology an interactive way is introduced to mitigate the problem of process interference. The integration of humans in multi-agent systems of autonomous transport robots and the increased awareness using augmented reality for the human are central purpose of the experiment.

Keywords: Human-Robot Interaction · Augmented Reality · Human Awareness · User Interface.

1 Introduction

For humans and robots sharing the same workspace and collaborating, the functional safety has to be analyzed [1]. Usually, expensive safety laser rangefinders for mobile robots are applied to guarantee safe operations. In some cases mobile robots and humans on the shop floor are separated - hence by default the possibility of collision is not given. In this case safety methods e.g. solid fences or laser barriers surrounding the working area of the robots are deployed. An activation of e.g. a single scanner or a simple breach of the fence will shut down the mobile robots. Here, the downtime of the system increases the process costs. To mitigate the costs humans and robot have to work together [9]. In decentralized control systems the same technologies can be applied but there is still more to research and evaluate to integrate humans in such decentralized systems. For the development process, psychologists, computer scientists, designers and mechanical engineers are involved. For usage, the system is designed in

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way that by the implementation of a virtual representation of the human worker, it can adjust to communication and properties for diverse needs of multiple individuals. The first step is to raise awareness of humans and robots between each other. The following experiment will show one way to overcome the investments for safety.

2 Background

2.1 Augmented Reality

Augmented Reality (AR) is not a new development the basic idea reaches back to the year 1901. Then Baum described in his short story "The Master Key" a kind of glasses with which the protagonist could get information about people directly on their foreheads [2]. Despite this early vision, it took almost 70 more years until Sutherland developed the first AR system [14]. For the first time the term "Augmented Reality" has been defined by Caudell and Mizell during their work at the company Boeing in 1992. Two years later, Rekimoto developed the first AR prototype for 6 degree of freedom tracking.

In general, with AR the real world of the human and his natural way of interaction will be enriched in real-time with computer generated information [6]. This leads to a fusion of real and virtual world. Although the enhancement can be used for all five human wits, usually AR developments focus on the visual sense with its high information transmission density. Besides AR, there exist other concepts for merging the real and the virtual world together e.g. virtual reality (VR). [11]

To sum it up, through AR the interconnection between human and technology offers significant potentials in various fields.

2.2 Proxemics

For a better integration of the human while collaborating with automated transport vehicles (ATVs) or other robots, not only safety aspects have to be met, also social aspects used in human-human-interaction have to be faced to increase the acceptance towards the ATVs [13]. One important part of the interaction between humans is the theory of proxemics introduced by Hall [7]. Depending on the kind of people one is interacting with, they are allowed to approach closer. Each person has four distinct spaces they maintain around themselves. The intimate space (0.15 m - 0.45 m) is used for partners whereas the personal space (0.45 m - 1.2 m) is reserved for good friends. In the social zone (1.2 m - 3.6 m) acquaintances take place. The last distance is the public one (>3.6 m). A problem occurs if a person enters a zone which he is not allowed to. The other one might feel uncomfortable and tries to distance himself. [7] Also an ATV has to stick to these rules depending if it is just passing by the human or has to interact with him.

Different experiments have examined the effects of robot sizes (see e.g. [3]) and velocities (see e.g. [12]) besides human factors. Those studies showed that people feel more anxious and are keeping a greater distance when facing taller or faster robots. In general, studies of proxemics in human-robot collaboration are conducted to maximize the user experience and to enhance the productivity of the collaboration.

Perception is one of the most important tasks in human-robot-interaction. The prerequisite is that humans as well as robots are aware of each other. Only than trust and reliance on one another can be build. To ensure this, one has to find ways to raise the awareness of the human towards the robot while considering information overflow and mental workload.

3 Human Awareness in Decentralized Systems

To increase the acceptance of the human worker towards the ATV he has to feel safe around it. In complex warehouses with a lot of racks, ATVs which drive underneath those to pick them up, cannot always be seen by the human. Therefore, we use AR to inform the human about ATVs close by.

3.1 Experimental Setup

The experimental setup is constructed in a way that we can test occlusion of an ATV in a known area by the use of an obstacle and the surrounding fence itself. The human wearing AR glasses is observing the inside area from different views and will eventually see the real ATV in some situations and in others not. To realize the overall system used in the experiment we implemented a multi-agent system following [8]. For being able to communicate between the human and the ATV we followed [10]. In that way it is possible to adapt to the human's individual zone, resulting from proxemics research, and change the user experience as described later on.

The area consists of a fence of 3 x 4 metres built of small load carriers in a research facility of 1000 square metres. Inside one finds an obstacle of the dimensions 0.8 x 0.4 x 0.8 m (L x W x H) and an ATV of the dimension 0.6 x 0.4 x 0.3 m (L x W x H) at two different locations (see Fig. 1; locations a1 and a2). Outside the fence a human, wearing a Microsoft HoloLens, is positioned at various locations looking inside the area from different angles (see Fig. 1; locations b1 to b5).

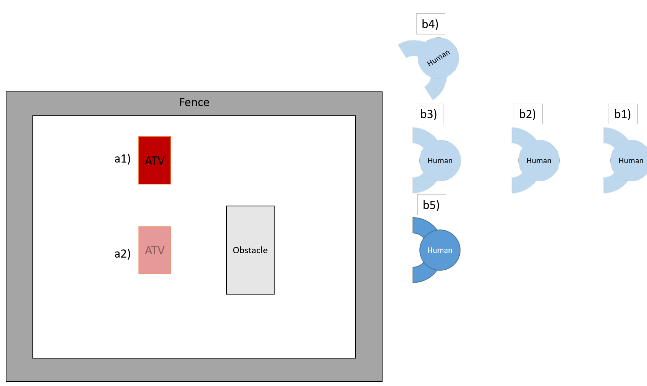

Fig. 1. Experimental Setup

The ATV is designed in a way that the safety concept allows to omit expensive safety sensors - meaning the weight and maximum velocity do not cause damage to humans in case of collision. Due to that fact, the control system of the ATV has to be implemented in such a manner that collision avoidance has to be integrated for drive control. The ATV is controlled by an implementation of ROS. All low-level control of sensors and actuators is handled by dedicated nodes. For navigation it uses the cartographer node enabling it to navigate in a taught map. This allows autonomous behaviour so that it can drive autonomously to positions to load or unload goods. There are interfaces implemented to command the ATV to drive to goals. On the one hand web services accessing the ROS topics are used to gain a relatively platform independent access to the ATV's functionality. Further, rosbridge [5] is used to communicate via a rosbridge client using websockets. For the purpose of this experiment the pose of the ATV (x, y, ϕ), the data of the laser rangefinders (one in the front and one in the back for navigation, each field of view of about 160 degree) and the status information like battery voltage or errors status are published on specific topics and available through the mentioned interfaces.

To communicate with the human agent the proposed design of the multi-agent system of [10] is implemented. The agent for the ATV is running on the ATV's control board and implements the rosbridge client via a hardware abstraction layer. The communication between ATV agent and human agent on the HoloLens is service based, where the provided services can be announced and discovered by a zeroconf implementation [4] to allow ad hoc integration of new users in the network.

The human uses the Microsoft HoloLens to be part of the decentralized control system and communicate with the ATV. Similar to the agent implementation on the ATV, the human agent is implemented on the HoloLens enabling the subscription to topics of the position and the laser rangefinder data. Additionally, the human agent keeps properties of the user like the proxemics distances which will differ from user to user. The agent is programmed in a way that it uses the native sensors and tracking feature of the HoloLens to locate the user in the environment. To locally incorporate both participants in the setup, a QR code is used to match the ATV's coordinate system

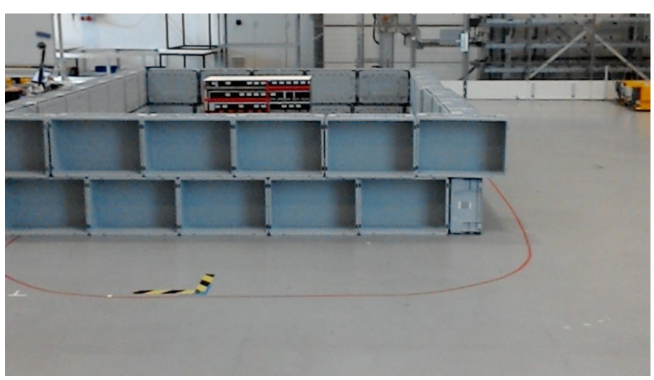

Fig. 2. A distant view inside the public distance

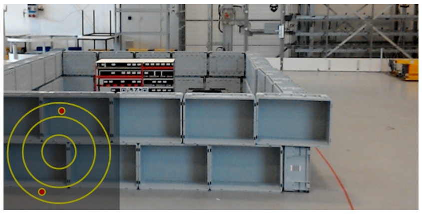

Fig. 3. A radar view informs the human about ATVs nearby - inside the social distance.

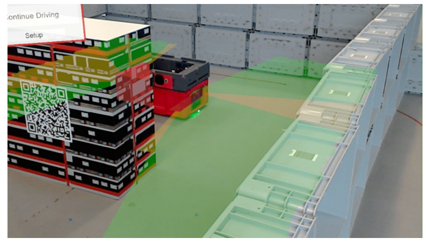

Fig. 4. The line of sight (LoS) between human and ATV is partially blocked through an obstacle.

with the one of the HoloLens. The actual pose of the human is also published, but not used in this experiment. Looking through the HoloLens, the human sees either no ATV specific information, or a radar indicating there is an ATV close by and raising awareness or the virtual outline (e.g. the 3D model) of the ATV, if it is in close range but occluded by an obstacle. The decision on what to show depends on the individual proxemics distances. Furthermore, the sensor data is visualized around the real ATV for debug purposes (e.g. the autonomous behavior may not be comprehensive to the user and might conclude from false data, in that case we can get more detailed visual data for analysis of this behavior).

3.2 Realization

Depending on the different distances analyzed in proxemics we use different views for the information. In case an ATV is inside the public distance of the individual (individual at position b1) in Fig. 1) no further information is given in the view field (see Fig. 2; live capture of the human's view through the HoloLens). If an ATV is entering the social zone of the individual (individual at position b2) in Fig. 1) the position of the ATV will be displayed on a radar view (see Fig. 3, remark: live capture of HoloLens). The radar can ensure a safe feeling while not disturbing the human at work. ATVs which are closer e.g. in the intimate zone (individual at position b3) in Fig. 1) and are not in the line of sight (see Fig. 5) or are partially blocked by a rack or another obstacle (see Fig. 4) are displayed through an x-ray view on the AR glasses. Through these methods the awareness of the human can be increased and a safe feeling can be ensured.

Since there are various types of workers e.g picker, service technician or warehouse manager different information about the ATV is needed. The picker is interested in the load of the ATV as well as its goal position. On the other hand the service technician needs to be notified about upcoming errors (e.g. predictive maintenance) as well as the functionality of the sensors (see sensor signals in Fig. 6). For an overview of common information of the different roles refer to Table 1.

This information will be requested by the human agent by subscribing to the needed services of the ATVs. Further, the human agent saves the worker's properties. Depending on the experiences with ATVs the proxemic zones are varying. This information is used to adjust the different types of views. Robotic experienced workers who are not

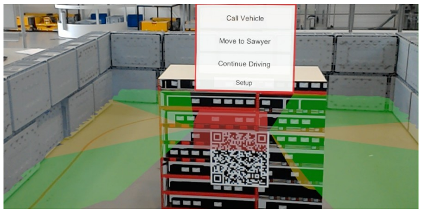

Fig. 5. The LoS between human and ATV is blocked through an obstacle.

Fig. 6. The LoS between human and ATV is given.

Table 1. Information requested by different roles

picker	service technician	warehouse manager
maximum load	errors	uptime
velocity	sensor data	efficiency
goal position	error rate	error rate
idle time	uptime	costs per job

afraid of ATV do not need to be notified so early since the ATV can move closer. Different distances used ensure that the information flood is kept small and one can focus on his own task.

4 Conclusion

The implementation and investigation in this experimental setup demonstrate an intuitive method to raise awareness for the human worker in robotic environments. It is a flexible way to include the human in a multi-agent system and thus making him able to virtually see robots or potential dangers close by. In this case AR is a feasible technology to present context-based information at the right location for the human to comprehend the ATVs' behavior. Methods from the field of proxemics are used to respond to the users' needs and each specific human gains the intended features and behaviors in the interaction human-robot systems.

5 Outlook

The next steps in our evaluation is the analysis of reaction of the humans. The x-ray view and the displayed information of the automated transport vehicles depending on the proxemics are used to raise the awareness of the human and therefore increase the acceptance of the human towards the ATVs. The different distances can vary depending on the individual humans in example because of his experience with the systems or with robots and complex technologies in general. Hence, the proxemics will be examined in more detail. The user might still move away from the ATV because he has seen the information of the ATV too late and is surprised by it. Furthermore, the awareness of each individual human might vary throughout the day or working week depending on personal situations e.g. tired, stressed, hungry, etc. To raise the awareness depending on the humans conditions we will examine the usage of eye-tracking as a feedback for the distraction of the user. Eye-tracking has already been used in other user applications to measure stress and awareness so that we believe it will influence the system positively when used during online computation. Also, we would like to evaluate user experience with respect to the way robots should be highlighted for raising the attention in an adequate manner. Finally, we intent to extend the setup on a larger scale in the whole research facility, where multiple ATVs roam around humans, to investigate interdependencies between the actors.

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