AR robot motion intent communication in collaborative assembly: Presentation of a study concept

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***Abstract*— Augmented Reality (AR) has been increasingly used in Human Robot Interaction (HRI) research also for the robot motion intent communication. One goal here is to find out how AR technology can be used to close the communication gap in human robot collaboration (HRC). More specifically, in which ways the AR-technology can be utilized to make robot's actions transparent and comprehensible to humans. Accordingly, this paper presents a study design that compares three different AR applications, two of them being existing approaches in slightly modified form and another newly developed approach. In this context, a collaborative assembly scenario in a robot-human object handover task is extended with the Microsoft HoloLens to investigate the extent to which the approaches differ in terms of perceived pleasantness and task completion time. In future work, the study is to be conducted in order to provide implications for the design of AR cues in robot to human object handovers.**

Keywords*— *Augmented Reality, Human Robot Collaboration, nonverbal communication, object handover

I. Introduction

In human-robot collaboration (HRC), the goal is to maintain humans as an active part of production and to support them with a robot [1]. For example, in collaborative assembly, humans and robots are meant to work co-located on the same objects. In the implementation, a human-centered design of HRC systems is essential according to Häusler & Sträter [2].

One approach to implement such a human-centered design is to provide the human with a robot teammate by which he is supported as by another human. To coordinate work activities, for example in assembly, humans use signals such as verbal and non-verbal communication, in the form of body posture, micro gestures, gaze and mimics. In collaborative assembly with a robot, on the other hand, some of the communication channels are not available due to the morphology of the robot. This is also the case with the robot Yumi from ABB used in the proposed setup of this work, which is equipped with 2 arms, but for example has no head. This raises the question of how coworking humans can still be provided with the information they need to understand the robot's current actions or anticipate its future actions. According to Wischniewski et al. [3], it is essential that the robot's actions are transparent and comprehensible to humans in order to achieve efficient cooperation between humans and robots. One approach that has been increasingly investigated recently is the use of augmented reality to improve situational awareness in HRC. This is done by visualizing relevant information about the current status as well as the "motion intent" of the robot. In these attempts to overcome the communication gap, care is also taken not to place additional cognitive demands on humans. Humans are used to exchanging information with other humans and it does not require any special cognitive load for them to understand another human. The subtle, partially subconsciously perceived signals that are necessary for collaboration are often transferred in AR applications into colorful visualizations that are unnatural for humans. In order to make the provision of information as simple and pleasant as possible for humans, this paper presents a study concept in which different methods of AR robot motion intent communication are in terms of their perceived comfort and processing time in a robot-to-human handover task are compared.

II. Related work in AR robot motion intent communication

AR technology has been increasingly used in HRI research in recent years, including teleoperation, as well as status visualization and robot intent visualization. Particularly relevant to this work are approaches that investigate collaborative assembly actions or actions that are similar but have not been studied in this specific context, such as object handovers.

In the work of Newbury et al. [4], object handover points are visualized in the AR headset HoloLens. The planned handover point is visualized in the form of a 3D wireframe of the object to be handed over during the human-to-robot handover. They come to the conclusion that AR robot intention visualization significantly improves collaboration in terms of fluency of interaction, trust towards the robot, perceived safety, mental load, and working alliance.

Rosen et al. [5] also conducted a study in which they compared an AR robot motion intent visualization with a visualization on a 2D display and a variant without assistance. They visualized the future robot arm trajectory by rendering meshes of the robot arm at different future waypoints. The study participants were asked to determine whether different arm trajectories collide with blocks built on a table or not. The AR variant led to an improvement in accuracy and a reduction in processing time compared to the other two variants. Gruenefeld et al. [6] also compared AR concepts for robot motion intent visualization in their study. They compared the variations they named (Path, Preview, and Volume) with each other. They found that, in general, AR visualizations can assist in communication between humans and robots. In your particular experimental setup, volume visualization of the robot's movement space resulted in fewer head movements needed, which can lead to easier perception of robot movements.

In their work, Hamilton et al. [7] examined the differences in deictic gesture from an AR robot arm versus a virtual Arrow. For task-oriented domains they suggest that the variant with the virtual arrow are better suited.

Previous work in this regard shows that visualizations are useful for the understanding of robot motion intent but there has been little work investigating AR cues to assist in robot-human object handover.

III. Setup of the AR enhanced collaborative assembly

The aim of this work is to investigate the nonverbally communicated motion intentions of a robot in a collaborative work environment. In the work listed in Section II., it has already been found that AR cues in robot intent communication are perceived as pleasant and helpful, so the study will compare different forms of AR cues. AR cues are designed to make the information necessary for collaboration accessible to humans by first gaining their attention and then conveying handover location and timing. For this purpose, three approaches are planned. The proposed study design is similar to that of Gruenefeld et al. [6] in that AR visualization concepts for robot motion intentions are to be compared. Both the experimental setup and the focus of the study differ. The focus in the work of Gruenefeld et al. is to find out which type of visualization is most comfortable and effective in avoiding collisions between the human and the robot. In our work, a similar approach is taken, however, it involves understanding handover points. Another difference of our work is that the robots used in the studies previously referred to usually had only one arm. Working with a two arm robot (as in our case the YuMi® from ABB) increases the complexity in a way that the human must pay attention to both arms when working together. The three variants to be compared in the study are briefly presented below.

1. The first visualization can be called "volume visualization" and was proposed by Gruenefeld et al. [6]. Here, a colored cylinder is projected onto the robot's motion joints, which indicate when and in which direction the robot will move according to their color. As described above, Gruenefeld et al. discovered that this form of visualization, besides facilitating the perception of the robot's movement intentions, was also found to have the most reliable effect on participants. For the planned research, the context of the use of volume visualization will be changed. While Gruenefeld et al. used it to predict collisions, it will be modified to communicate the motion of the robot arm to the human.

2. Unlike Gruenefeld et al., the second AR representation should only include the locations for object handovers and interactions between humans and robots. In collaborative assembly scenarios, object handovers are significant so that humans and robots can assemble parts together. Since this location is the only interface humans have with robots in safety-separated work environments, this is the focus of this visualization. Newbury et al. [4] determined in their work that through AR visualization of object handovers, study participants developed more confidence in their object handoffs. Furthermore, the trust in the robot and the perceived safety increased. For this work, this concept is reversed in function. Newbury et al. developed the approach for handing over an object from a human to a robot. Here, it is used to receive objects from a robot.

3. Finally, a self-developed approach is pursued. Here, symbols, short texts and acoustic signals are used to communicate the robot's motion intentions. The direction of movement is displayed for the left and right arm of the robot, and an acoustic signal informs the human when the movement is being performed. The acoustic signals do not contain spoken words or sentences, but only tones or melodies. The visualization is based on the most relevant design guidelines according to Rau et al. [8] and Blokša [9]. For example, visual and auditory cues convey different information that address different human communication channels. This relieves the visual channel, which can lead to lower cognitive load overall when working with the robot.

The three variants presented show a low degree of anthropomorphization. The reason for this is that they are to be used in a task-oriented assembly process. In an industrial context, an anthropomorphic representation design can lead to robots being perceived as less useful. In this case, the advantage of the increased acceptance by humans due to its anthropomorphic design is low [10, p. 171]. This conclusion was also reached in the study by Hamilton et al. [7].

The course of the study includes a short introduction for the participants. Subsequently, they are to complete a simple assembly task three times together with the YuMi® cobot, as shown in Figure 1.

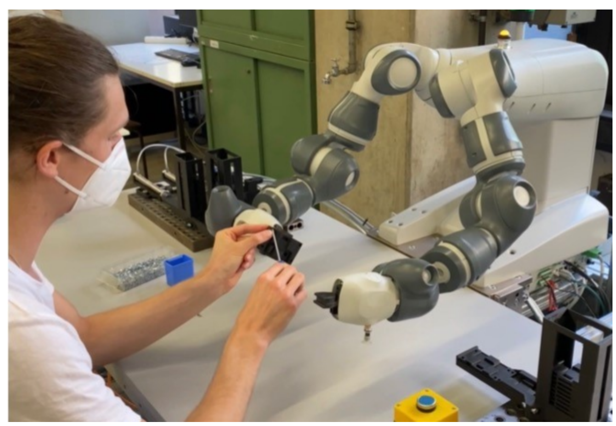

Fig. 1. Setup of the collaborative assembly

The presented setup is extended by the Microsoft HoloLens AR glasses, on which the information of the robot is displayed. The working area of the cobot is separated from that of the human. Only a small space directly in front of the human is provided for the robot to hand over objects to the human. The robot then hands over objects taken from different piles of parts. In each of the three cycles, a different type of AR visualization method is used to project the robot's information through the HoloLens. The location of each object transfer varies and is unpredictable to humans, except through information about the robot's motion intentions presented with the AR app. The AR apps for the HoloLens are developed with the Unity game engine.

IV. STUDY DESIGN CONCEPT

In order to compare the developments, a laboratory within-subject study is carried out. The independent variable is the AR based presentation of information of the robot. The following research questions are to be answered:

1. Which of the in section III. proposed visualizations is perceived as the most pleasant opportunity to understand the robot?

2. To which extend have the different visualizations an impact on human behavior, e.g., in terms of successful object handovers or component assembly?

3. Which of the visualizations is most comfortable for humans to use in this investigated example of collaborative work environment?

Data is obtained through primary static data collection. A mixed-methods design is used: qualitative data is collected by observing participants during the study. Questionnaires answered by participants before and after the study contain both open and closed questions representing an instrument for quantitative data collection. These questionnaires are (partially) standardized, for example, they consist of the Raw NASA TLX [11], the Godspeed I and V [12], and HRIES Sociability Scale [13]. A self-developed extension of the Godspeed scale is planned to explore the robot's believability and the enjoyment working with the robot. In addition, the time participants need to accept objects from the robot is measured during the study.

All people who currently or in the future work with robots can be counted as the basic population. For the planned study, a sample will be taken from the population consisting of researchers, teachers and students of the Cologne University of Applied Sciences. The participants have a relation to technology in general, but not necessarily to robots or augmented reality technology. The structure of the planned study is illustrated in the figure below.

V. DISCUSSION

With the proposed study concept, the authors want to find out which of the three selected types of AR visualization is perceived as most pleasant by the participants. Furthermore, they aim is to investigate which of the variants leads to the lowest reaction times of the subjects by measuring the time during the execution. However, it will only become clear in the course of development how well the existing types of AR visualization can be applied to this scenario and the modified task. Based on the results of previous work, we assume that the audio signal helps to get the attention at the right moment and that the extended information, for example by a timer, is perceived as helpful. Therefore, the proposed third approach is expected to be perceived by subjects as the most pleasant option and also to result in the least completion time in the handover task. However, the audio signal, which should be used to draw attention to the visualization at the right moment, could also be perceived as disturbing. Likewise, it is unclear at what point the amount of visualizations is perceived as disturbing and leads to visual overload in this scenario instead of being perceived as pleasant and helpful.

VI. CONCLUSION & FUTURE WORK

In this paper a study concept to investigate the nonverbally communicated motion intentions of a robot in a collaborative work environment is presented. Accordingly, a setup is proposed in which a collaborative assembly cell including the two-armed robot Yumi is extended by using the Microsoft HoloLens. The AR headset is used to visualize the information about the robot's motion intentions. Within this setup, an object transfer from the robot to the human is to be performed multiple times, with the transferring object, the arm used, and the transfer location and time varying. The aim is to investigate which of the three proposed AR applications for robot motion intent communication is perceived as most pleasant by the subjects and to what extent the use of the different applications affects the completion time of the handover task. In the follow-up work, the study is to be conducted in order to extend research on AR robot motion intent communication. The results obtained from this will afterwards be used to provide implications for the design of AR cues in robot to human object handovers.

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