Augmented Reality to Support Temporal Coordination of Spatial Dispersed Production Teams

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Abstract

This work presents a prototypic system that uses augmented reality technology to support temporal coordination of spatial dispersed production team members. This system is used to investigate the potential benefit of augmented reality for temporal coordination. We will present a study design as well as various research questions to be considered in future work.

1 Introduction

Temporal coordination constitutes an important aspect of teamwork (Bardram, 2000; Mohammed et al., 2015). In particular, the orchestration of the sequence and timing of interdependent actions is of high relevance for such team coordination (LePine et al., 2008; Marks et al., 2001). Especially in start-up phases of technical systems, *production teams* need to incorporate the timing of each other's actions into their own action planning (Sebanz et al., 2006). In contrast, low levels of shared temporal cognition and "not being on the same page" (Mohammed & Nadkarni, 2014) may lead to disagreement about when to start and finish sub-tasks and to team members subscribing to different schedules and pacing (Gevers & Peeters, 2009). Additionally, production teams may also work as spatially dispersed teams, e.g. when control room operators and field operators are performing routine maintenance tasks or non-routine start-up tasks (Kluge et al., 2014).

Temporal aspects of teamwork can be supported by scripted coordination (Bardram, 2000) and side-by-side work (Sebanz et al., 2006). Scripted coordination means coordination according

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to a script of actions, e.g. Standard Operating Procedure (SOP). SOPs are designed to support workers to store and process information correctly and in the right order (Kluge et al., 2013). Side-by-side work means that team members are allowed to share a work area and a visual context or work space (Sebanz et al., 2006; Vesper et al., 2016). A spatially dispersed teamwork is characterized by the exclusion of side-by-side work, the question arises of what are the critical elements of a shared visual space for temporal coordination in dispersed teams. One critical element is the awareness of the task state, which is the awareness of the current state of the collaborative task in relation to an end goal (Kraut et al., 2002), which can be supported by shared visual information (Kraut et al., 2002). In this respect, feedback about the timing of a team member's action is effective for anticipatory action control (Sebanz et al., 2006). Additionally, an awareness of the task state is assumed to improve activity awareness and coordination (Kraut et al., 2002).

Taking all aspects together, the presented state of the art suggests that the temporal coordination of spatially dispersed teams can be enhanced by coordination artifacts that support scripted actions in order to raise the awareness of the task state. Thus, we aim at investigating the impact of a coordination artifact that builds on *augmented reality* (AR). In this regard, the major contribution of this paper is the presentation of a conceptual framework and first insights into a prototypic implementation, which facilitates augmented reality technology to support the temporal coordination of spatially dispersed teams.

The paper is structured as follows. Section 2 highlights related work in the domain of AR considering the support of team work and team coordination in specific. This discussion is followed by the presentation of the previously mentioned framework including the discussion of a study design to measure the supportive impact of AR for team coordination in a technical control task (Section 3). Section 4 concludes the paper and highlights potential directions for future work.

2 Augmented Reality for Team Coordination

The use of augmented reality (AR) technology has been shown to be beneficial in single-user scenarios for solving complex tasks, for instance in the context of complex maintenance tasks (Webel et al., 2013) the programming of industrial robots (Stadler et al., 2016), or individual training (Kopetz et al., 2018). Moreover, AR technology has been found to be helpful for the collaboration of co-located as well as dispersed team members. For this purpose, AR overlays virtual objects onto the user's view of the physical world (Sluganovic et al., 2017). In this regard, the main focus of existing work on AR in teamwork lies on the implementation of virtual co-location of team members through AR-based communication and coordination support. For instance, the work presented by Billinghurst and Kato (1999) embedded avatars of remote users to increase the social presence of dispersed team members. Beyond the support of social presence, Poelman et al. (2012) presented evidence regarding virtual co-location in the context of supporting local investigators in the inspection of a crime scene. As co-location has been identified as beneficial for temporal coordination, the use of AR seems promising to

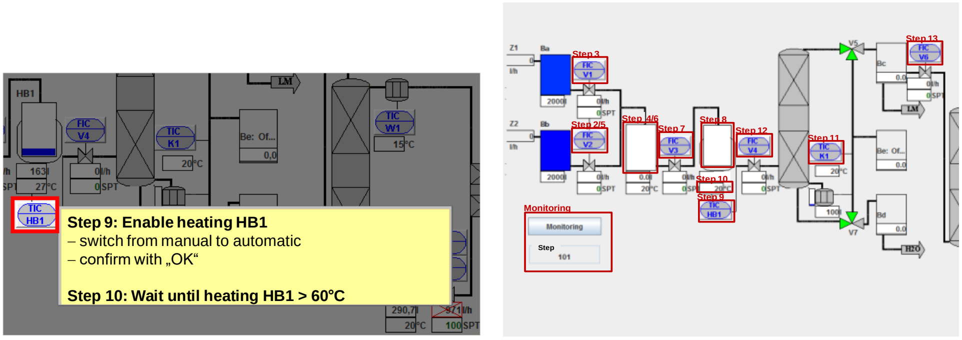

Figure 1: On the left, an example of the used gaze guiding tools is shown. On the right, the first part of WaTrSim interface is shown.

enhance the sense of co-location of dispersed team members and thereby support tasks, which call for temporal coordination.

However, research which considers AR in the context of temporal scripted coordination of dispersed team members is more scarce. Classic scenarios for collaboration in AR are either scenarios with co-located members investigating a single virtual scene or object, or setups in which a remote expert (or a group of experts) are supporting a user (or a team of users) on site in a great variety of tasks (Hobert & Schumann, 2016; Lukosch et al. 2015; Oppermann & Prinz, 2016). Based on the aforementioned findings, we assume that increasing the sense of co-location by using AR technology, which includes task state awareness of the team task using a scripted coordination, will amplify the effect of co-location. In addition, we deem AR in particular to be potentially supportive in providing “ambient awareness” of task states. We assume that team coordination and productivity can be enhanced if people are able to maintain awareness of the activities of the team that may affect their team performance - especially with

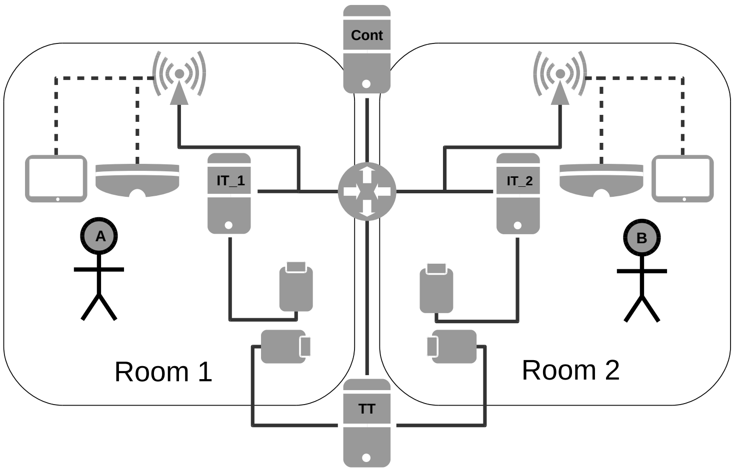

Figure 2: System architecture comprising various hardware devices, such as projectors, tablets, HoloLenses, as well as various machines running the simulations. The network communication is implemented using an Ethernet switch as well as two access points for wireless LAN in the two rooms.

teams that have to work in different locations (Streitz et al., 2003). To support this kind of team task state awareness, ambient presentations, which have low attentional requirements, can be used to present dynamic information in an at-a-glance manner (Downs et al., 2012). Such awareness system can be broadly defined as systems intended to help people construct and maintain an awareness of each other's activities, context or status, even when these individuals are not co-located (Markopoulos et al., 2009, p. V). We assume that ambient AR superimpositions can serve the purpose of communicating information in an implicit way. Finally, a very technical motivation to facilitate AR technology is that various types of additional information can be superimposed over physical control panels, which very often cannot be adapted or changed.

3 System and Study Design

Based on the previous discussion, the central research question for our research can be formulated as follows: *Can AR technologies support temporal aspects of scripted coordination by increasing the task state awareness of spatially dispersed teams in a production context, in combination with visual attention guidance including the individual task*? Therefore, we designed a study implemented via a system architecture, which has been instantiated as a prototype to measure such an effect during a realistic task in a controlled setting. The architecture is shown in Figure 1. The production setting and teamwork context build on previous work with the Waste Water Treatment Simulation (WaTrSim/AWASim, Burkolter et al., 2009) and the gaze guiding tool (Frank & Kluge, 2017; Weyers et al., 2015). In WaTrSim (see Figure 1, right), the operator's task is to separate waste water into fresh water and gas by starting up, controlling and monitoring the plant. The operation goal is to maximize the amount of purified water and gas and to minimize the amount of waste water. This goal is achieved by considering the timing of actions while following the start-up SOP. To support the correct timing and execution of the procedure, participants have been individually supported by the gaze guiding tool in three different task types of which we use only one in this work: the fixed-sequence operation (see Frank & Kluge, 2017 for more details all three task types). The fixed-sequence operation includes the start-up procedure of the plant, which is composed of 13 steps. For instance, the participant has to set flow rates for various valves in the plant, to activate columns and heating units, as well as wait until certain parameters (such as fill level of tanks) have been reached. Performing the WaTrSim start-up procedure correctly and in a timely manner leads to a production outcome of a minimum of 200 liters of purified water.

The gaze guiding tool has been described, pretested and evaluated as effective in a process control task in previous work (Kluge et al., 2014; Weyers et al., 2015). The gaze guiding tool is technically implemented with a semi-transparent overlay with a cutout for the cued element, thus the element that the user needs to interact with for the current step in the SOP. This element (see Figure 1, left) is additionally framed by a red-orange flashing rectangle and a box with textual information describing the next steps. A video demonstrating the gaze guiding application can be found here: http://www.aow.ruhr-uni-bochum.de/fue/gazeguiding.html.de. For this work, we adapted this concept to be used in AR glasses and to augment a physical (here projected) control room, which will be discussed in more detail below (Section 3.2).

3.1 Study Design

In the planned study, two dispersed team members (A and B) will perform an individual task in parallel to a team task. Therefore, A and B are located in separate rooms (see Figure 1). The two rooms are equipped equally and team members cannot communicate orally. Both team members execute the same start up SOP of WaTrSim (Frank & Kluge, 2017) parallel as an individual task (IT) completing all 13-steps each and in parallel as a team task (TT) operating parts of the 13-steps each, completing as team all 13-steps together. Therefore, the TT is executed interdependently by both dispersed team members. While working on the team task (TT), they have to orchestrate the sequence of steps, which only one of the team members is allowed to execute according to a predefined instruction depending on the task state. In parallel, each team member has to observe and execute their own IT, in which they have to execute each step of the start up SOP.

3.2 System Architecture

The used system architecture consists of three instances of the WaTrSim Simlutor: Two for running the individual task (in Figure 2 labeled with IT_1 & IT_2) and one that is controlled by both team members together as coordinated team task (in Figure 2 labeled TT). Therefore, in each room, two WaTrSim process screens are projected onto the room walls with projectors at a 90 degree angle (see Figure 2). The team members have to orientate to the other wall in order to see the current status of the technical process of the other task as both screens cannot be seen at the same time (Figures 2). This makes ambient awareness of the screen that cannot be monitored directly necessary. While working on their IT, each team member is assisted by AR glasses, which display a) gaze guiding for the task that is currently being executed (either IT or TT) and b) the state of the task that the team member cannot currently see. The latter provides task state awareness of the currently unseen task while executing the other. All control input done by the two users is done via a tablet (Figure 2). All devices are connected via a local network with additional wireless network access points for the tablets and the HoloLenses (see Figure 1).

The HoloLens superimposes the gaze guiding version for each screen as previously developed (Frank & Kluge, 2017) and described above (see Figure 2). Additionally to the gaze guiding, the state of the TT is displayed in coloured symbols at the right side of the IT screen showing the task state of the TT. Thus, the state of the IT is superimposed on the left side of the TT screen. Therefore, this arrangement corresponds to the setting of the task screens in the room. At the moment when team member A is focused on his IT and additionally is required to execute the steps of the TT for which he/she is responsible and which were announced by the superimposition of the AR, he/she turns from IT to the TT screen. The state of the AR - superimposed alongside his/her IT (see Figure 2) - switches and displays the gaze guiding for executing the TT, while now superimposing the IT in an ambient manner aside of the TT. The ambient information displays central information of the status of the IT of team member A so that the operator can switch back to his/her IT in time. After team member A has finished executing his/her step of the TT, team member B receives the information via AR that he/she now has to turn to the TT to execute the steps for which he/she is responsible, while receiving ambient information about his/her IT. In this way, gaze guiding and ambient information orchestrate the work of both team members for the TT while supporting the IT too.

4 Conclusion and Future Work

In the previous sections, we outlined criticality of temporal coordination in general if considering team task in technical control, but also its special needs if the team is comprised of spatially dispersed members. Based on the identification of research needs in this context, we presented a first prototypic system design that on the one hand offers AR-based gaze guiding for such spatially dispersed teams as well as a study design to investigate the potential effects such an AR-based assistance system might have. The system architecture as well as the porotype were developed under certain considerations. For instance, we decided to use the HoloLens (despite the problem of the limited field of view) because of the simple programming interface as well as the potential we seen in using the HoloLens in physical control rooms. The latter was also the reason why we did not use the projections directly for the augmentation but the HoloLens. This will make the transition into physical control rooms easier. Additionally, the simple-to-use tracking of the HoloLens is working well. Another aspect was the use of the tablet, which enabled us to let the participant move around freely in the room such that he/she can switch between IT and TT without a spatial limitation.

As major future work, we will execute the previously outlined study to answer the following major research questions, which result from the previous discussion: 1) Which influence has the use of AR on the temporal coordination of a team task? 2) Which effect may have different types of superimpositions on the execution of the team task? 3) What types of additional information provided during the execution of the individual task (through AR) is helpful for the individual coordination IT and TT? Additionally, we plan to investigate the use and development of superimpositions in more detail. In this regard, we will have a detailed look into dif-

Figure 3: A photo of the implemented prototype. Illustration of general set-up of Team member A's superimpositions in Room 1 (superimposition can only be seen by the team member through the HoloLens, not by an observer).

ferent types of superimpositions for gaze guiding, e.g. by comparing dynamic and static representation of additional information and how these can be modelled and implemented for various types of scenarios and control processes.

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