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USER GUIDED AUGMENTED REALITY MANUFACTURING ASSEMBLY INSTRUCTION DEVELOPMENT: CHANGING WORK MODES DURING COVID -19 AND ITS IMPLICATIONS

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Robots and automated technology are still being perceived as threatening by operators in manufacturing. The current study investigates how participants' feedback and evaluation of the user interfaces guide the final design. The initial development of the Augmented Reality (AR) guided assembly was completed over several stages; however, the current study focuses on testing the product after the initial comments on the AR demonstrator from the users were integrated. The work discussed here was completed over three steps: (i) An online survey where participants (N = 21) viewed pre-recorded videos of an experimenter completing the task and answered questions related to clarity and usability of the AR glasses; (ii) A trial experience where participants (N = 5) were invited to the lab to complete the task using the proposed solution, and (iii) experimental study where participants (N = 10) interacted with a robot via the developed AR guided instructions in two conditions where robot communicated its next steps (the transparency condition) and where it did not communicate its next steps (the neutral condition). The comparison between step (i) and (ii) provides information not only between two development points of the AR glasses guided instructions, but also estimates how at hand experience (trial experience and interview) influences the perception of the technology compared to distance experience (online survey). Finally, the experimental study indicates that robot behaviour transparency can affect experienced lower physical demand when the user knows the robot's next steps. The current paper will address issues of the development and introduction of technology while incorporating the users.

Keywords: human-robot collaboration, mental workload, user-centred design, trust, situation awareness, augmented reality guided assembly

1. Introduction

The introduction of robotic technology in manufacturing can be a challenging task from a technological and a human factors point of view. Technology rejection by the user is enhanced by lack of trust, which, among other reasons, can be caused by a lack of transparency in robot behaviour [1]–[3]. Yet, the understanding of the way people work with this new technology is still unclear with limited research done on the topic. Therefore, the communication interfaces may increase acceptance and trust on new technologies [4]–[7].

Lack of trust in new technology, rejection of new processes, and decreased motivation are consequences of psychological strain operators' experience if human factors are not properly accounted for when introducing a new technology. Being able to experience the technology, and a transparent introduction to the robot capabilities creates realistic expectations of this technology [2], [8]–[10]. This also can affect the success of introduction of technology and acceptance of new processes [11]. Furthermore, transparency in the technological capabilities and the establishment of clear rules and responsibilities would help to ease the uncertainty within new processes [12], [13].

On the other hand, robot's communication of its behaviour might cause ambiguity and decrease the sense of safety for the operator. Information communication in a clear and concise way leads to psychologically and physically healthier and safer environment [14]–[18]. It should be intuitive and well defined how an operator communicates with the robot, and how the robot would communicate about its next moves and directions. Moreover, robots' behaviour has a great influence on building trust [10], and when the operators do not trust the robot they tend to monitor its performance more than needed. In such cases, mental workload and cognitive demand increase due to monitoring robot performance. Such increase results in less cognitive capacity left for monitoring the environment and complying with safety procedures [6], [7]. Finally, lack of trust and increased monitoring of the robot might relate to decreased situation awareness. Situation awareness is necessary in order for the individual to operate in the environment safely, while a decrease in situation awareness can lead to an increase in work accidents and injuries [19], [20].

The main barriers for the technology acceptance and engagement by the user is the delayed introduction and lack of involvement in the development stage. The current study, conducted as part of the SHERLOCK project, investigates how participants' feedback and evaluation of the user interfaces guides the final design and affect users trust in industrial human-robot collaboration, situation awareness and mental workload. To involve potential users of Augmented Reality (AR) guided instructions for manufacturing and human robot collaboration tasks, the study was done in two stages. Firstly, the developed AR instructions were evaluated by the participants. The changes in working patterns due to Covid-19 over the last two years suggest that technology introduction and initial training methods will change, therefore, this step was conducted comparing online introduction to this technology with hands-on experience in the lab. Secondly, a human robot collaboration experimental study was conducted investigating the impact of robot transparency (in this case communication of its next steps) on user trust, situation awareness and mental workload.

2. Study 1 Methods

2.1. *Design*

The main aim of online study and trial experience was to compare the participant evaluation and feedback on the instructions on how to complete the manufacturing assembly tasks. The online study provided first person view of the AR glasses while completing the task, and in the other one participants completed the tasks themselves in the lab.

2.2. *Participants*

Twenty-one participants took part in online study. Six participants were manufacturing employees and 15 were university students and staff. Due to anonymous nature of the study, it was not possible to verify which use cases manufacturing employees came from. The average age of participants were 30.65 years old (SD = 5.97, min = 24, max = 46). 40% of participants had no experience with AR technology, while 60 % had "Some but never on a regular basis".

The hands-on trial experience the group consisted of five participants. Out of five participants, three were males, one female, and one identified themselves as other. Four of the participants were working at the University of Patras, and one participant was working both at the university and the manufacturing industry. Participants were asked about their experience with robots and AR devices; three participants indicated daily experience with robots, and two

- once a week; furthermore, four participants had experience with AR devices before, while one did not have any experience before.

Ethics approval was received form Cranfield University and University of Patras Ethics Committees.

2.3. *Materials*

Qualitative and quantitative questions were used to evaluate user experience of completing the assembly task with AR instructions. Qualitative questions asked for participants evaluation and feedback on instructions presented via AR glasses, voice commands, user interface and 3D animations (i.e. "what did you like about AR instruction presentation", "what would you change in the AR instruction presentation"). This data was used for further improvement of the AR guided instructions and human-robot interaction on the large panel assembly task and is not going to be presented in this study. The quantitative aspect was focusing to assess participants' evaluation of instructions Statements such as "*I found the instructions presented via VR headset to be effective/simple/precise/understandable/concise/predictable*" were asked to be rated from -50 (disagree with a statement (i.e. intrusions were not effective)), 0 neutral opinion (neither effective, nor ineffective) to 50 (agreeing with the statement (very effective)). With the respect of voice commands, participants were asked whether voice commands were self-explanatory and easy to memorize. Finally, the user interface aspect was concerned if it looks and feels friendly and whether it provides quick access to features and commands. All these aspects were evaluated on the scale from -50 (disagreeing with the statement), 0 (neither agreeing nor disagreeing), and 50 (agreeing with the statement).

2.4. *Apparatus*

AR glasses Microsoft Hololens 2 was used to guide operators on large industrial panel assembly. The instructions provided information about the necessary tools, sequence of steps and overlayed position on the panel where participants needed to assemble the components. Gesture (hand-detection) and voicebased commands were enabled to allow participants to go through the instruction steps

2.5. *Video clip*

Online context participants were provided with a video depicting the assembly task guided by AR instructions in collaboration high payload collaborative robot (AURA collaborative robot, Comau, see section 4.4). The video lasted for 3 min 38 seconds and can be viewed here: https://www.youtube.com/watch?v=mnI9OUjplR4.

2.6. *Procedure*

Once agreeing to take part, participants were provided with the information about the study and informed consent on Qualtrics the online platform. Online study participants were presented with the video of first-person perspective depicting the assembly of large component with the robot while using AR instructions for assembly guidance. On-hand trial participants after signing the informed consent were asked to complete the task in the laboratory. Participants were assisted with putting on the AR glasses, given a short demonstration of how to navigate the AR environment and asked to complete the task. Once they completed the assembly task, they were asked to answer the same questions as the online study participants on the Qualtrics platform. As a final step, participants from both studies were debriefed.

2.7. *Study 1 Results*

Participants from both the online survey and interview session were asked to provide the quantitative scores on their experience of instructions, voice commands and user interface. In this section the comparison between these two sessions will be conducted providing information not only between two development points of the AR glasses guided instructions, but also estimate how hands-on experience (trial experience and interview) influenced the perception of the technology compared to distance experience (online survey).

The adjectives describing participants attitudes to the instructions indicate that they all perceived them positively (Fig 1). Participants indicated that instruction effectiveness, understandability, and simplicity where the most positive aspects after real life experience, while online survey participants indicated that the most positive aspects of the instructions were the fact that they were concise, effective and simple. Further analysis with Mann-Whitney U test indicated that real experience participants scores were significantly higher on statements relating to "simple", "effective", "understandable" and "predictable" aspects of the instructions ($U = 9.50$, $p = .011$, $U = 8.00$, $p = .010$, $U = 10.50$, $p = .015$ and $U = 7.00$, $p = .019$, respectively). However, these differences were not significant after adjusting with Bonferroni correction for multiple comparison (2-tailed alpha = .008).

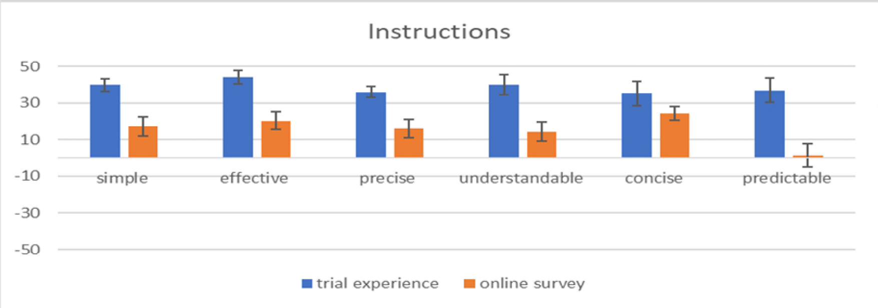

Figure 1: Participant attitudes towards the instructions presented via the AR glasses as a function of experience modality (real trial vs. online)

The adjectives describing participants attitudes to the voice commands and user interface indicate that they all perceived them positively (Fig 2). Although there was no significant difference between voice commands and participant group ($p \geq .387$), participants' responses differed regarding attitudes towards interface: "looks and feels friendly" and "provides quick access to features and commands" were both evaluated more positively in the trial experience condition ($U = 11.50$, $p = .035$ and $U = 10.00$, $p = .026$). Yet, only "provides quick access to features and commands" was at a trend significance after Bonferroni correction (2-tailed alpha = .025).

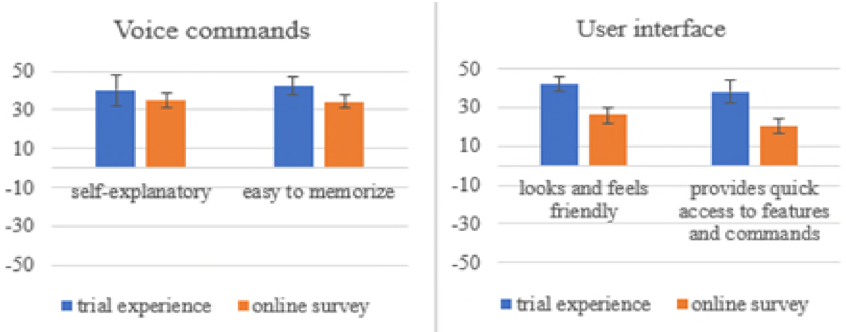

Figure 2: Participant attitudes towards the voice commands and the user interface presented via the AR glasses as a function of experience modality (real trial vs. online)

3. Study 2 Methods

3.1. *Design*

The experimental study investigated how the developed and adjusted AR guided assembly instructions can be used in the industrial human-robot collaboration. The main aim of the study was to capture cognitive and human factors involved while working with a high payload Aura robot as a function of the experimental condition (transparency where robot next moves are projected visually vs. no transparency).

3.2. *Participants*

Ten participants (1 female) with the mean age of 25.4 years (SD = 0.81) took part in the study. All participants were working at the University of Patras, and five of them had daily experience with robots (one-“once a week”, three “sometimes, but never on a regular basis”). Finally, when asked about experience with the AR technology, three participants indicated that they “never” interacted with it, five “sometimes, but not on a regular basis”, and two participants indicated that they experience this technology “on a daily basis”. The study received ethics approval from Cranfield University (UK) and the University of Patras (Greece).

3.3. *Materials*

The study assessed participants mental workload, situation awareness and trust in industrial human-robot collaboration via the established and validated questionnaires. Mental workload was measured using the NASA Task Load Index (NASA-TLX; [21]. It measures participants’ experience of a task across six different dimensions such as physical demand, frustration level and performance. Participants’ trust was measured using the Trust in Industrial Human-Robot Collaboration scale [22] and situational awareness was measured with Situational Awareness scale [23].

3.4. *Robot*

For the industrial human robot collaboration task, a high payload collaborative robot AURA (Comau, S.p.A, Italy) was used to assist participants with rotation of the large industrial panel to assist on the assembly. This robot has six safety levels to support safe human collaboration while performing manual tasks without the need for barriers or fences.

3.5. *Procedure*

The study was conducted in the LMS laboratory with laboratory members. The experiment was completed in a single session lasting around 30 min. Upon coming to the testing area, participants were provided with informed consent, informed about their participant rights, information about the task and experiment, how their data will be stored and used, and provided an opportunity to ask any questions relating to the study. Participants were additionally briefed about safety measures during the experiment relating to Covid -19. After they have signed the informed consent, the experiment began.

Participants were assisted in putting on AR glasses, explained the task, and performed half of the assembly followed by filling in the questionnaires. After the first set of questionnaires were filled in, participants finished the assembly task. All participants completed the task with the robot in two different conditions in the counterbalanced order. After the last condition was completed and the questionnaires filled in, participants completed demographic information (age, gender, experience with robots, experience with AR devices). As a final step, participants were debriefed.

4. Results

4.1. *Mental workload*

Mental workload was measured using the NASA-TLX. Non-parametric tests were used for the inferential statistics to account for the low participant number. As a first step, overall scores for each dimension was compared. This analysis yielded significant results between all dimensions with frustration dimension (Table 1).

Table 1: Inferential statistics for mental workload dimension comparison for both conditions combined

	Physical demand	Temporal demand	Effort	Frustration	Performance
Mental demand	Z = -0.89, p = .374	Z = -0.26, p = .799	Z = -.56, p = .676	Z = -2.55, p = .011	Z = -0.28, p = .770
Physical demand		Z = -0.51, p = .610	Z = -.56, p = .575	Z = -2.55, p = .011	Z = -0.97, p = .333
Temporal demand			Z = -1.27, p = .203	Z = -2.81, p = .005	Z = -0.255, p = .799
Effort				Z = -2.70, p = .007	Z = -0.89, p = .373
Frustration					Z = -2.60, p = .009

Further exploration between the conditions showed that there was a significant difference between physical dimension (Z = 2.37, p = .018) where in the transparency condition participants felt less physical demand than in no-transparency condition (Fig 3).

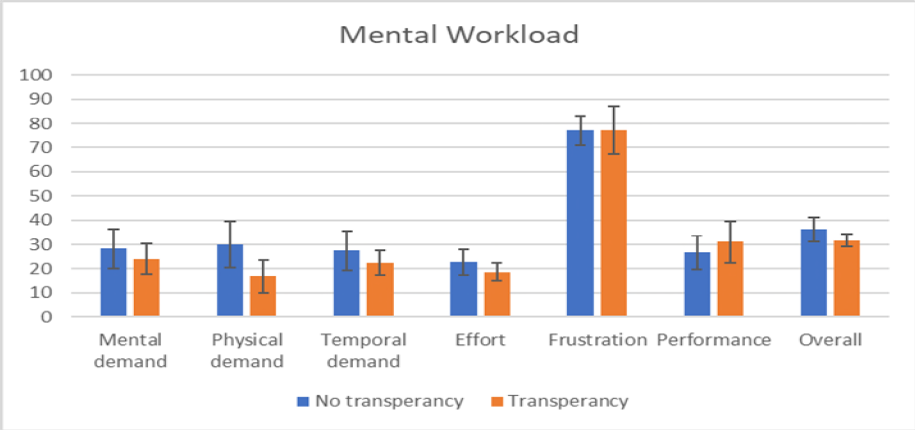

Figure3: Mean (+/- SEM) across mental workload dimensions as a function of experimental condition

4.2. *Trust and Situation Awareness*

Responses for the Trust in Industrial Human-Robot Collaboration scale and Situational Awareness scale indicate that there was little difference between responses after transparency and no-transparency conditions ($p \geq .05$). The future analysis will investigate between subject differences on participants who had at first transparency vs no-transparency trials.

5. Discussion

The current paper reports the work conducted to provide user evaluations and feedback on the development of the development of AR guided Human-Robot Collaboration instructions and the impact of robot transparency on participants situation awareness, trust and mental workload. This is particularly relevant in fields were user acceptance and trust in technology is of high importance.

The results indicate that participants had positive attitudes towards the AR technology both after viewing the videos and interacting in real life. However, it is important to note, that the comparison of the evaluation scores shows that hands-on experience participants had more positive attitudes towards the AR assisted assembly guidance. This is important because of two aspects. Firstly, due to Covid-19 pandemic there is an increased need for the remote work, and therefore there is a possibility that in future remote training might become more common. The results suggest that capturing feedback via remote means provide consistent results with real life training. Secondly, having higher scores on the real-life experience provides further emphasis on the importance of operator engagement in the early stages of technology development and introduction. Allowing individuals to experience the technology on the existing tasks yield more positive attitudes towards new technology.

Furthermore, the results of the experiment indicate that a high payload collaborative robot in transparency mode can alleviate self-reports of physical demand and increase self-perceived performance scores. Interestingly, the frustration dimension was significantly higher than other dimensions (e.g. mental, physical and temporal demands). One possible explanation being that task clarity or waiting times for the robot might have influenced such results. However, this result was unexpected and calls for further analysis: It is planned that further analysis will investigate the eye gaze patterns and correlate with the self-reported data to explore this unexpected result.

Automation role and need in the manufacturing industry is increasing significantly [24]. Yet, the lack of work done to assess an operator psychological safety can be detrimental in the integration of robotic applications [25]. Using a bottom-up approach, engaging users early on and increasing operators' ownership of new processes can positively affect employees' wellbeing and cooperation in further technological development [26], [27]. The findings and observations reported in this work serve not only to direct technology development, but also contributes to the development of methodology on how to assess operator psychological safety and human factors with the final SHERLOCK solution demonstrators. The results will feed into the final SHERLOCK studies while integrating the developed technology on the use case companies' shopfloor.

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