Industrial Augmented Reality: Lessons learned from a long-term On-site Assessment of Augmented Reality Maintenance Worker Support Systems

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ABSTRACT

Augmented Reality (AR) has ever since made big promises in terms of improving maintenance in industry. However, long-term on-site assessments of AR maintenance worker support systems do not exist. In cooperation with three industrial companies we developed two such systems and conducted a 14-month evaluation period. The lessons we learned from the pitfalls we ran into during this assessment period provide valuable insights for researchers and practitioners alike who want to deploy AR maintenance worker support systems to the shop floor.

Keywords: Augmented Reality, Evaluation, Deployment, Maintenance, Long-term Study.

Index Terms: Human-centered computing → Mixed / augmented reality; Computer systems organization → Embedded and cyber-physical systems

1 INTRODUCTION

Augmented Reality (AR) systems supporting assembly or maintenance tasks is one of its key application areas [1, 10–15]. AR (1) can break down task complexity into easy to follow instruction directly entangled to the real work-site and (2) allows a better remote support by superimposing digital information in the view of a person doing a task on-site. The promised main benefits from these two AR application areas are (1) reduced errors through clearer instructions, (2) breaking down task complexity to enable low-skilled workforce performing complex tasks, (3) persisting experience knowledge from workers in form of digitized AR instructions, (4) less time searching information in traditional manuals, (5) reducing travels through improved remote support of on-site workforce and (6) documentation of performed work to improve overall quality of work.

For conveying the information to the workers 3D-models, text, pictures, videos and audio are typically used as visual assets in AR maintenance support systems [3], sometimes accompanied by also integrating live machine control data [6, 7]. A plethora of research and commercial AR maintenance support applications have been implemented to date for just as many tasks. In research, the assessment tasks often uses bricks, computer mainboards or electrical cabinets [12, 15] which are either not realistic industrial use cases or are only covering a fraction of one. Given the focus and available resource in research these limitations are understandable. When looking at commercial AR systems supporting assembly or maintenance tasks, thorough evaluations are not performed respectively published. Often only successful implementations are reported in a general manner in press releases or business journals. Therefore, it remains yet an unsolved challenge to really prove and quantify the promised main benefits of AR systems supporting assembly or maintenance tasks on-site during normal operation.

In the Horizion2020 project PreCoM (Predictive Cognitive Maintenance Decision Support System) we started in 2017 with the development of two tablet-based AR applications, which have been evaluated in three industrial use cases during a 14-month period: a paper tissue machine, largescale milling machine for wind power plant hubs and grinding machines for high precision gears. Although, we had limited success to prove and quantify the benefits of the developed AR applications, we think that researchers and practitioners alike will find many valuable insights from our assessment approach and the lessons learned from the pit falls we encountered.

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2 AR MAINTENANCE WORKER SUPPORT SYSTEMS

In PreCoM two AR applications were implemented, (1) to provide step-by-step-instructions (AR Guidance System) and (2) to enable remote service support (AR Remote Service System) [5, 8].

The requirements analysis at the beginning of the development process showed that the AR Guidance System (see Figure 1) should enable new or unexperienced maintenance staff to perform medium to high complexity tasks by following step-by step instructions that usually only a very few highly experienced workers would do [9]. The step-by-step instructions were created by digitizing and customizing existing paper-based instructions and enhancing them with superimposed 3D-models, texts, pictures and videos. In addition, live machine and sensor data (e.g. axis positions) is accessible in the AR Guidance system, reducing walking time to the machine control. Further, documentation functionalities were integrated allowing the workers to create videos and pictures with notes and drawings that can be integrated in the instructions for future use or for other maintenance activities. The workers or maintenance engineers are able to create the step-by-step instructions themselves using an authoring system, so that no AR expert is needed for content creation.

The AR Remote Service System (see Figure 2) was implemented to allow the local maintenance staff to start a voice/video stream with internal or external experts using a tablet or desktop PC. Both are able to augment the video stream with drawings, text notes and 3D-models, take screenshots and videos as well as sharing documents.

3 LONG-TERM ON-SITE ASSESSMENT PLAN

The AR maintenance worker support systems were tested during a 14-month period at three different production companies. The aim was to select two meaningful maintenance tasks for each company for which step-by-step instructions for the AR Guidance Systems were made. Selection criteria had been: (1) the occurrence of the maintenance task during the evaluation period, (2) a medium to high task complexity and (3) the maintenance tasks were conducted by the companies' workers and not external experts from their machine providers. Further, a sub-set of maintenance workers from the companies as well as the companies' machine providers were equipped with installations of the AR Remote Service System.

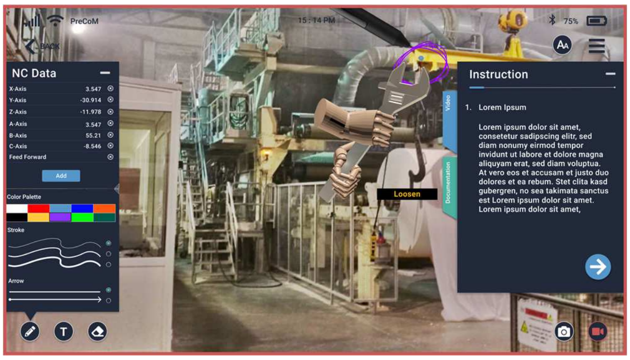

Figure 1: AR Guidance System demonstrated in an industrial maintenance scenario

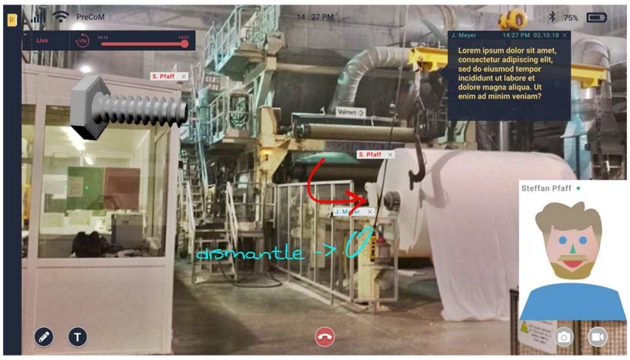

Figure 2: AR Remote Service System demonstrated in an industrial maintenance scenario

The aim of the evaluation was to assess the expected befits of the AR maintenance support systems in terms of (1) task performance time, (2) error rates and (3) supervising time. Further, the user experience of the application should be assessed with Brook's System Usability Scale [2] and the User Experience Questionnaire by Hassenzahl et al. [4] filled out monthly via an online survey. Part of this monthly questionnaire were also the users' demographics and the number of usages of each AR maintenance support system during that month. Filling out these questionnaires after each usage of the AR applications would have consumed too much time of the workers during their shift. To still get at least a rough feedback from the workers immediately after they used the AR applications, a second online questionnaire with only three questions (Was it useful?; Did you like it?; Did it bother you?) rated on a 5-point-Likert-scale was compiled. In addition, regular interviews with the workers were planned to get a qualitative feedback regarding user experience but foremost regarding performance. In all companies' error rates, task execution and supervising times were only available from experience. Therefore, the performance of the AR application had to be assessed from the workers themselves. Measuring the usage time of the AR application was also implemented. However, restarting the AR applications during one task or interrupting a task execution whilst the AR applications are still running could not be detected, so that no reliable measurements of task executions time could be guaranteed.

As AR supported task a cleaning process of paper pulp at the paper mill was chosen for the paper tissue production company. A second task could not be selected, as the requirements were not met. For the wind mill hub manufacturer, the maintenance of two different tool clamp holders of milling spindles were selected as two separate tasks. Instructions for changing a grinding spindle and calibrating the grinding spindle were made for the precisions gear manufacturer as separated tasks.

4 RESULTS & LESSONS LEARNED

With the briefly described evaluation plan in section 3 we were hoping not only to thoroughly assess the AR maintenance worker support applications but also to validate an evaluation protocol for their long-term on-site assessment. Whilst, we could achieve insight in the pro and cons of the AR applications and achieve certain improvements in the maintenance performance, our actual long-term assessment plan did in general not work out. However, we think that the lessons learned from our approach are very valuable for other researchers or practitioners who want to assess or deploy AR application in industrial environments.

1. The most important lesson was that AR is not just another tool for improving maintenance, it is foremost a change in the organization of maintenance processes itself. Through the AR applications informal work processes were suddenly needed to be formalized. This changed the way how the maintenance departments organized their work and also led to deeper analysis of their maintenance processes in general. Therefore, we strongly advise to approach the long-term evaluation or deployment of AR application as a change in organization of work, which needs to be accompanied by an analyzation process of existing maintenance processes.
2. Because, of this work organization effect the usage of the AR applications was bothersome for the workers as they basically needed to adapt to these new procedures whilst still performing the majority of their work routine the established way. All workers who did partake in the evaluation stated, that it is cumbersome to only have so little content and wished to have more AR step-by-step instructions. Therefore, we strongly advice to introduce AR application covering all maintenance tasks or a meaningful subset, so that the workers can completely switch to the AR supported work organization. Further, a process to maintain and update the step-by-step instructions needs to be established and the required resources allocated.
3. It is critical to carefully analyze for which tasks AR step-by-step instructions should be implemented. There are a lot of very simple tasks in maintenance, like checking oil levels, where using an AR application would be overkill. It only makes sense to cover medium to highly complex maintenance tasks. However, even for these kinds of tasks there are often workers who simply do not need any instructions as they know what and how to do. Therefore, we advise to adapt the detailedness of instructions to different skill levels. However, it might still be reasonable to also create AR instruction for easier tasks in case of high staff fluctuation to allow self-guided training-on-the-job for new employees.

4. Introducing tablets to the shop floor let to improvements of work conditions entirely unrelated to the AR applications. Workers were able to look up information on the internet or write Emails on the shop floor. Therefore, we recommend to consider the collateral benefits the AR devices can have.
5. The AR Remote Service System was only tried out once by the workers but almost never used after that. The most important reason for that were, that workers were often already using video calls via skype or whatsapp to receive remote support from their colleagues. Further, our AR system could just not live up to the very high user experience quality of skype or whatsapp. Although, the AR Remote Service System had tailored functions for remote maintenance support the workers were just satisfied with the capabilities of the tools they were used to. Therefore, we would advise to carefully analyze if AR capabilities are really beneficial when normal video calls are an already established tool in maintenance departments.
6. Both questionnaires we were using to track the developments of the perceived user experience of the AR maintenance worker support applications produced non-usable data. Despite reminders, the workers often did not fill out the questionnaires because they forgot it, there was too much work or they simply did not use the AR application during the evaluation interval. Therefore, we would recommend to rather not use questionnaires for frequently repeated measures without any means to ensure that they are filled out. It rather seems more advisable to have frequent interviews with the workers.

Concluding we can say for the 14-month evaluation period of the same technology at three different sites evaluated by seven users, that the benefits of AR in maintenance play out differently for each company. Therefore, an individual analysis and deployment plan is crucial for the successful introduction of AR into maintenance departments.

5 Future work

AR technologies comes in many forms, is rapidly improving and barely standardized. This flexibility allows to build highly customized solution which is curricula as companies are unique and there is no standard solution for improving their work with AR. Rather, AR applications have to adapt to the specific needs of a company. Therefore, the most curricle thing for future work would be the development of a standardized approach for the structured introduction of AR support applications and their continuous operation. Such an approach should start with describing methods for analyzing the current organization of work. Next the company's specific problems in their current organization and execution of work has to be analyzed. From this the technical, user, regulatory, environmental and organizational requirements for the supporting AR applications must be derived. However, it is curricle that also the problems which are not directly improved through AR have to be approached. Only such a holistic approach prevents AR applications failing due to non-AR related issues in the companies.

Further, a plan for the mid- and long-term usage of the AR applications have to be made. As any IT system, also AR applications 'live'. They need continuous improvement and must adapt to changes in the companies and incorporate technological advancements of AR. Especially, for AR application that are containing knowledge such as AR instruction, training and teaching applications it is of highest importance's to have domain experts continuously updating and improving the knowledge-base and to incorporate feedback from the AR end-users.

6 Conclusion

An AR remote service application and an AR step-by-step instruction application were developed for three different industrial companies based on their requirements. During a 14-month onsite evaluation period we aimed to thoroughly monitor and assess their benefits. The lessons we learned from this are beneficial for researchers and practitioners alike to avoid falling for certain pits. The key lesson is that AR is not just another tool but rather a change in the organization of maintenance work itself.

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