Human Factors and Ergonomics Evaluation of a Tablet Based Augmented Reality System in Maintenance Work

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ABSTRACT

Augmented reality (AR) technologies start to be mature enough to be used in industrial work settings. However, human factors and ergonomics (HFE) and safety issues have not been considered thoroughly yet. The purpose of this study was to identify what kind of postures users adopt when using a tablet based AR system during a maintenance task. In addition, safety, user experience and user acceptance were studied. Results indicate that the participants adopted varying kind of working postures with the AR system, but none of the postures were severe for the well-being. User experience was positive and user acceptance on a good level. The participants saw some safety concerns related to using the AR system but were mainly concerned if the tablet could be used in the harsh maintenance environments. The findings of this study can be used to improve HFE and safety of AR systems in industrial settings.

CCS CONCEPTS

• Human-centered computing~User studies • Human-centered computing~Mixed / augmented reality

KEYWORDS

Augmented reality, Human factors/ergonomics, Tablets, User experience, Safety

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1 Introduction

By definition, AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world [4]. AR solutions can support industrial maintenance and assembly tasks by showing situationally relevant instructions. Several studies show that AR technologies are promising because they are often fast to use, errors occur less frequently, and operators accept the technology well [6,13,19,20,32,38,41,42]. Nee et al. [37] categorize AR-assisted maintenance systems into three groups: presenting information on head mounted display [20], [34], presenting information with tablet or smartphone [39], [40], and projecting information at the workplace [14,17,30]. Due to the nature of AR technology, all these approaches will introduce different operating postures.

A maintenance technician needs a lot of information to support studying the status of the maintenance target, identification of faults as well as carrying out maintenance operations [3]. As the work is typically carried out in the field in customer premises, access to company information systems may be difficult. Paper instructions are difficult to handle in the maintenance site and they may be outdated. Thus real-time AR guidance readily available at the maintenance target has potential to improve both worker experience and performance.

Despite of the large amount of studies of AR in industry there are not many long term studies available [17]. Until now, AR technologies have not been mature enough for long-term use. Viewing maintenance targets and the augmented guidance through a tablet computer may influence human factors and ergonomics

(HFE) in the maintenance situation. This study addresses HFE with the research question "What kind of postures users adopt when using tablet-based AR system for instructions?". In addition, user experience, user acceptance and safety issues are addressed.

2 Related Work

When using AR systems, it is important to consider the risk of musculoskeletal disorders (MSDs). "Awkward postures, repetitive work or handling heavy loads are amongst the risk factors that may damage the bones, joints, muscles, tendons, ligaments, nerves and blood vessels, leading to fatigue, pain and MSDs" [15]. The neck, lower back and upper limbs (shoulder, elbow, wrist, and hand), are particularly vulnerable to MSDs [18]. International Ergonomics Association (IEA) [23] defines HFE as "the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance". The discipline of human-computer interaction (HCI) is closely related to HFE. However, HCI focuses particularly on the interaction of humans and computers, and evaluates user experience issues. These two approaches can be merged when considering body in interaction [16].

The HFE of handheld devices have been studied for example with smartphones and tablets. Bachynskyi et al. [5] investigated the performance and ergonomics factors of common touch surfaces (tablet, laptop, tabletop, public display, smartphone/two hands and smartphone/one hand). They found out that based on muscle activation laptops are suitable for long-term use, and tablets and tabletops are suitable for long-term use after adjustment or posture support. Public displays and smartphones were not suitable for long-term use based on their study. Young et al. [44] studied ergonomics when using tablets in four different usage conditions: (1) tablet on the lap without its case held by the subject's hand, (2) tablet on the lap in its case set to its lower angle, (3) tablet on the table in its case set to its lower angle, and (4) tablet on the table in its case set to the higher angle for watching movies. They evaluated head and neck flexion angles during the study. According to [16], there is a need to better understand how technology, like mobile phones, alters bodily ways of being in the world.

Although ergonomics of handheld devices are investigated in some studies, the ergonomics of AR systems have not been studied widely. Colley et al. [8] studied ergonomics of a smartphone AR browser in a poster browsing task. They recognized different interaction styles regarding holding the device, wrist position, stance and movement. They found out that users which stand further from the poster were able to complete the browsing task more quickly than those standing closer to the poster. Aaltonen et al. [1] identified use of hands and positioning of a tablet-based AR system in maintenance task. In their study, users mostly applied their left hand for holding the tablet, and performed tasks using their right hand. Three different angular offsets between camera and smartphone screen of an AR browser system was evaluated in [9]. They discovered that the standard see-through AR browser configuration was fastest in a searching task but 45° degree offset between the camera and screen had the lowest workload. Kerr et al. [26] evaluated strength and weaknesses of an arm-mounted AR system in an outdoor environment. They also addressed ergonomic issues briefly such as posture, position and comfort during the study. In addition, they had done similar study with HMD earlier [27]. They summarised key pros and cons between these two systems. Kurz et al. [33] studied the usability of handheld AR applications for the elderly. They found out that holding handheld AR applications could be exhausting for the elderly.

AR systems will influence HFE at the work place. They may also raise new kinds of safety issues as people are viewing the environment via the AR devices. Kristoffersen and Ljunberg [31] see challenges in handheld devices in many mobile use contexts such as inspection work and engineering in the field. Thus before these kinds of systems are widely adopted in everyday use, it is important to understand HFE as well as safety issues. The importance of including a focus on the physical body is recognised also in HCI field [22].

3 Material and Methods

3.1 The Augmented Reality System

The AR system (Figure 1) was developed to support performing a maintenance operation for an elevator hydraulic control unit. The purpose was to give guidance by visualising maintenance steps by using 3D models of the control unit and written step descriptions. The information was superimposed to the real view of maintenance technician. The demonstration system consists of (1) the elevator hydraulic control unit equipped with visual tags to support positioning the AR guidance and (2) AR guidance software running on a tablet device. The tablet device (HP Elite X2 1012) utilizes Windows operating systems. The AR guidance software was made with the Unity development platform and the software can be utilized in other operating systems. The demo system utilizes VTT's ALVAR augmented reality SDK [45] to enable AR features. ALVAR tracker enables visual tag based tracking, planar image tracking and 3D point cloud tracking. In this study, the visual tracking method is used. Visual tags are on a rotating plate in which the control unit is attached.

The AR guidance on tablet combines camera view and 3D model parts of the hydraulic control unit (Figure 1). The 3D objects are embedded on the right locations related to the control unit. 3D objects are supplemented with animations that illustrate and highlight which parts e.g., screws should be dethatched or assembled and in which order. The users are able to pause animations and freeze camera view by using control buttons on the low right corner for example freeze the camera view while animation is still running. The progress of the task steps can be seen on the top of the user interface (UI). On the bottom, instructions for the task steps are visible. By using arrows on the bottom of the UI, users may proceed to next step or go back to previous one. The system also includes exploded images of the hydraulic control unit and few guidance videos. However, these were not used during this study.

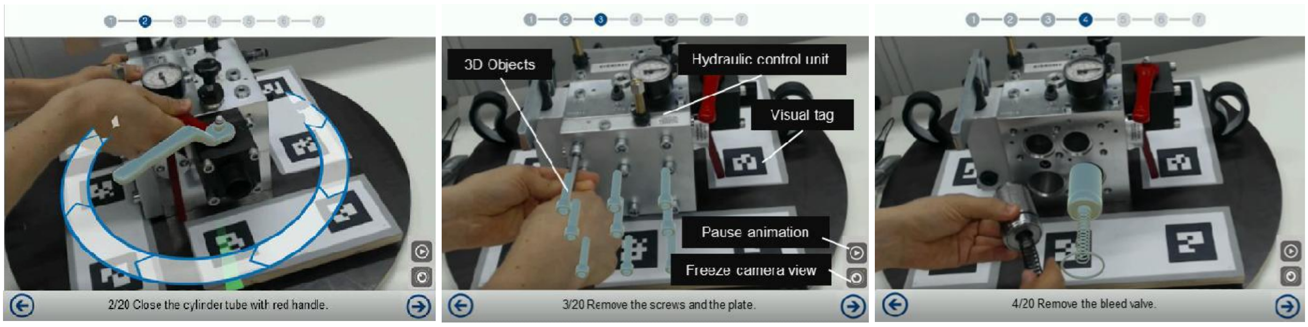

Figure 1: Screenshots of the augmented reality system user interface on a tablet device.

3.2 Participants

Seven (male) participants took part to the study. The average age was 45 years and the range was 20-62 years. The participants are working in an industrial company and they have different roles related to maintenance and training: three maintenance persons, two training experts, head of maintenance, and senior specialist in maintenance development. They had experience of actual maintenance work from 0 to 39 years (M=9,5 years). Two of the participants had done the test maintenance task before and five had not done it before. Two of the participants had some experience of the AR systems, three participants knew the AR term and two participants did not have any previous experience of AR.

3.3 Data Collection and Analysis Methods

Approaches for evaluating exposure to risk factors for MSDs include self-reports, observational methods and direct measurements [11]. Self-reports from workers can be used to collect data on workplace exposure to both physical and psychosocial factors by using methods such as interviews, questionnaires and diaries [11]. Simple observational methods for recording and assessing workplace exposure are such as Ovako working posture analysis (OWAS) [25], National Institute for Occupational Safety and Health lifting equation (NIOSH) [43], Rapid upper limb assessment (RULA) [35], and Rapid entire body assessment (REBA) [21]. In addition, there are a wide range of direct methods that rely on sensors, which are attached to the worker for the measurement of exposure (e.g. electromyography (EMG)). This study focuses on the use of self-reports (interviews, questionnaires) to gather user point of view to the research topics, and observational method REBA to reveal the exposure to risk factors in used postures. REBA was selected because it identifies neck, trunk, leg, arm and wrist postures.

Test execution was recorded with a video. All different AR system usage postures were screen captured and categorised. From the main categories the postures were evaluated with the REBA. In addition, participants claimed if they felt physical load in five point Likert scale, and were interviewed if they had any HFE issues during the task performance.

The HFE studies were complemented with UX, user acceptance and safety evaluation. UX and user acceptance were studied with a questionnaire. The questionnaire included smiley faces for overall UX (five point Likert scale), overall experience adopted from the Questionnaire for User Interaction Satisfaction (QUIS) [7] and adopted user acceptance questions of the Technology Acceptance Model (TAM) [12]. Concerns related to safety were studied by asking the participants if they had any safety concerns when thinking about using the presented AR system in actual industrial work.

The participants' demographics were collected with a questionnaire and participants signed a consent form. Participants' performance were observed in the test situation and later from the video recordings. Interviews were recorded with audio.

3.4 Test Procedure

First, participants were informed of the project topic, a consent form was signed and demographics were collected. Then participants received an introduction to the task they were going to perform and how to use the AR system. The maintenance task took around 20-30 minutes. During the task, participants read instructions from the AR system and then performed the maintenance task accordingly. After the task, the participants filled in the questionnaire and answered to the interview questions. Tests were executed in two locations (office rooms) but the setup was same in both. When operating with the hydraulic control unit the users wear thin oil protective gloves and used tools such as hex head wrenches and needle nose pliers. The hydraulic control unit was on top of the office table which is approximately at the same height than in the real environment.

The maintenance procedure included overall 13 different phases and the participants were able to go forward and backward between steps by using the control arrows on the low left and right corners (see Figure 1). Firstly the participants were guided to close the main pipe with the red knob. Then the user dismantled a plate and inspected and cleaned essential parts related to the control unit functionality. After the inspection and possible cleaning, the parts were assembled and the main red knob was turned to the open position.

4 Results

4.1 Human Factors and Ergonomics Evaluation

Three different tablet handling postures were recognized: two hands, one hand and on top of the table. Within these three groups

Figure 2: Identified postures.

Posture	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Final REBA score	1	4	3	4	5	3	2	6	4	2	3	5

Table 1: Final REBA scores for postures.

different body postures were identified. Figure 2 summaries identified postures. Two hands posture was used when selecting next steps on the guidance. Participants adopted one hand grip when the instructions guided them to turn around the platform under the hydraulic control unit. The tablet was put on the table when doing the actual maintenance work. When the tablet was on the table many participants checked the animation which was still running on the tablet (they used freeze feature). In the stepwise instructions there was one step which animation was not clear. If participant was standing on posture 1 they did not see well what the animation meant. If they moved AR system on the side of the hydraulic control unit they were able to see the step better (posture 4 and 5). While observing participants it was seen that many of them adopted quite different working postures.

In total 12 postures were evaluated by using REBA (Table 1). Postures were evaluated only from the right side of the body. Final scores were between 1 and 6 (M=3,5). In REBA scoring 1 means negligible risk, 2-3 low risk (change may be needed), 4-7 medium risk (further investigation, change soon), 8-10 high risk (investigate and implement change) and 11+ very high risk (implement change). Six postures were under value 3 which means that the risk is small. Other six postures were above it but still the risk was at a medium level. In these cases further investigation is suggested and changes may be needed. These postures included body twisting (posture 2), working upper arms raised (posture 12) and large bend in the trunk (postures 4, 5, 8, 9).

The participants said that the use of the tablet device did not have an effect on working postures at least in this test setup. They felt that it did not help nor worsen the task performance. They said that the handling of the tablet was easy. During the maintenance task there is room to put the tablet down in real environment but they wondered that what if there is no room to do that. In addition, it would not be good to put the tablet on the floor while doing the maintenance task. Some were also afraid that they would drop the tablet or it would get dirty from oil and grease. One participant also wondered that sometimes the tablet can be blocking the view to something important. For the claim "I didn't feel any physical load" three participants strongly agreed, three agreed and one was neutral.

4.2 User Experience and Acceptance

Overall UX of the AR system was positive: four of the participants were really happy and three were happy with the system (in five point Likert scale). In addition, overall reaction to the system was positive (Table 2). Participants felt that the system was wonderful, easy, adequate power and stimulating. They also felt quite satisfied with the system. Participants' answers spread

Terrible							4	3		Wonderful
Difficult							1	4	2	Easy
Frustrating						1	4	2		Satisfying
Inadequate power							2	3	2	Adequate power
Dull							2	2	3	Stimulating
Rigid						2	3	1	1	Flexible

Table 2: User experience of the AR system.

more in the flexible-rigid line. This was due to the reason that the instruction were in step-by-step way, and participants were supposed to follow the order.

User acceptance of the system was good (Table 3). The participants agreed that the system was easy to use and easy to learn to use. They saw that using the AR system would make their work easier, information would be easy to find and the information was seen trustworthy. The participants agreed or felt neutral regarding whether the AR system would support faster task performance or improve the quality of work. They agreed or felt neutral whether they would like to use the system in the future. One participant disagreed whether the system provided all information needed. However, others positively agreed (5) or strongly agreed (1) this statement.

Participants said that the user interface was good (e.g., buttons were at right place). They also thought that the size of the tablet could be optimized (now it was quite big but the information was well visible), and maybe it could be useful to use only one hand (e.g., smartphone or handle in the tablet).

4.3 Safety Issues

The participants did not feel that there would be any safety risks when using the AR system. They said that if machines are shut down in the engine room and maintenance persons are paying attention to the instructions nothing should happen. One participant was more concerned of the risks towards the tablet device than other safety risks ("what if it is dropped"). In addition, they said that the working with AR system does not differ so much from working with paper instructions when considering safety issues. Participants even suggested that the use of AR system could improve the safety because instructions are followed in systematic order. In addition, the use of AR can be safer than talking in the phone to get help. However, participants said that

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
The system was easy to use				4	3
It was easy to learn to use the system				2	5
I didn't feel any physical load			1	3	3
Using the system would make it easier to do my job				5	2
Using the system would enable me to accomplish tasks more quickly			2	4	1
The use of the system would improve the quality of the work			1	4	2
The system provided all the information I needed		1		5	1
It was easy to find the information				4	3
I was able to trust the information I received				2	5
I would like to use the system in the future			1	5	1

Table 3: User acceptance.

the use of this kind of AR system does not take away the maintenance technicians responsibility to be careful and to have situational awareness. As a neglect, the AR system can provide wrong feeling of confidence to the maintenance technicians. In addition, the AR system instructions do not tell the maintenance technicians if they have made an error. Participants also mentioned that diversion of attention might be a challenge. The AR system is quite capturing and it is possible that a technician does not pay attention to the signals in the environment. It is also an additional tool that technicians need to share their attention with. In addition, the animation is time bound and requires attention for certain amount of time. With paper instructions it is easier to look somewhere else anytime. The participants said that one safety issue is if the tablet is dropped in a critical environment (and how to proceed if instructions are lost).

5 Discussion

Based on the results, it can be said that the AR system was well accepted and the user experience was positive. The participants adopted different AR system holding postures as well as different body postures (e.g., bending, crouching). Some of the postures may lead to higher MSD risk.

The participants adopted three different kind of AR system holding postures: with two hands, with a one hand and the tablet on the table. When the tablet was on the table the participants turned they head or bent their trunk to see the information on the tablet. This could be a challenge if core tasks require high level of visual attention [31]. When holding the tablet with both hands, the participants bent and twisted their neck and trunk to see the information through the tablet. The use of both hands is not always possible and might need "making place" to use the system [31]. The participants adopted one hand use when they needed to perform a task and look the guidance at the same time (e.g., one hand is holding the tablet and the other one is rotating the platform). This kind of one hand approach was mainly applied for a tablet-based AR system in [1]. However, in their study, there was no freeze the view or pause the animation commands which in this study made possible to put the tablet on the table. When designing AR-guidance it is important to consider to what kind of working postures AR system design decisions may lead. In addition, the consideration of the AR system's suitability for core maintenance tasks and to working environments is needed. Ferreira and Höök [16] highlight, that it is important to design for bodily experiences in HCI field.

Higher REBA values were identified when twisting the body, raising upper arms or when bending the trunk a lot. However, these postures were not hold for long periods of time and therefore, they are not considered such a risk. When using tablets traditionally (without AR) for long time, it is suggested to use adjusted postural support [5].

In the stepwise instructions there was a step which animation was not clear when standing. If participant was standing on posture 1 they did not understand the animation well; from that posture it was difficult to see to which physical counterpart the animation was related to. If they moved AR system on the side of the hydraulic control unit they were able to see the step better. This lead to posture 4 and 5 which could provide higher MSD risk. In addition, this took more time to perform the current step. Therefore, postures could also affect performance. According to Colley et al. [8] users who stood further from the poster were able to perform an AR search task faster than users standing closer to the poster. To decrease both the MSD risk and the effect on performance AR systems' tracking should work from natural body postures and angles: users should be able to see AR guidance by using same type of angles or logics throughout the task.

While observing participants it was obvious that many of them adopted quite awkward working postures. In general, participants who were familiar with maintenance tasks due to their professional background, used better postures. This may be due to training or their work experience. This highlights the importance of training. Gavish et al. [18] found out that AR training systems need longer training time compared to video-based training. This may be due to the novelty of the AR technology. In the future, in addition to teaching ergonomic working postures in core maintenance tasks to maintenance technicians, the recommended postures while using AR systems need to be taught.

In this study, sometimes participants' posture improved when they used the AR system. For example, their trunk was bended when unscrewing bolts during the maintenance task (like in posture 8) but their body was stretched up when they used the tablet (posture 1). Therefore, it can be said that if the core task postures are poor it is good that the use of AR system interferes these occasionally. In this way, in some situations, the use of AR systems could improve the overall HFE. When designing AR systems the approach could be how to use AR systems to decrease the overall musculoskeletal load during the task performance.

User experience and user acceptance of the AR system were positive. In the HFE evaluation, one step in the animated guidance was difficult to understand. This usability problem led to poor posture with some participants. It is possible that users adopt awkward postures to cope with usability problems. Therefore, it is important to adopt human-centred design [24] principles already in early design phases.

Based on the results, there can be different safety issues that can be discussed within the use of AR system. Some participants were concerned of the "safety" of the tablet: it should not be broken and it should tolerate the harsh industry conditions. According to [2], maintenance environments have often noise, poor lighting, dust, grease and/or hot temperatures that make the working environment more challenging. Another viewpoint to AR safety is that one participant said that the use of the AR system could improve the safety and quality of the maintenance work by forcing maintenance technicians to perform the task in the same way. It would not be possible to forget a step which could possibly lead to safety risk when starting the machine. This is in line with the results of de Crescenzio et al. [10] who agree that AR has potential in reducing errors due to procedure violations, misinterpretation of facts, or insufficient training. AR system could also improve safety for example by visualising alerts [28],

[29], workspaces in human-robot cooperation [34], [36] and evacuation routes in buildings [40]. Another viewpoint to safety is that an AR system can be so capturing that the worker's situation awareness could decrease. This may lead to safety risks for the maintenance technicians (e.g., falling and impacts). Kristoffersen and Ljungberg [31] agree that some inspection and engineering tasks need a high level of visual attention to avoid danger.

According to [23] the identification and evaluation of the body postures can be a challenging work to do. In this study, the postures were evaluated only from the right side and only one video camera was used for the recording. Therefore, it is possible that the minor body changes were not identified (e.g., wrist twist). In addition, the small number of participants could have had an effect on the results.

6 Conclusions

The use of augmented reality (AR) technologies is increasing in industry. Therefore, it is important to consider human factors and ergonomics (HFE) in addition to user experience and user acceptance issues when designing AR systems.

This study identified what kind of postures users adopt when using a tablet based AR system during a maintenance task. The study showed that users adopt varied kinds of postures. The users selected their postures based on the view to the augmented information and the target object. In addition, the work experience and the profession of the user seemed to influence on the postures. Even though some of the adopted postures may increase MSD risk, postures were maintained short periods of time and therefore, they were not severe to well-being.

Based on the results, it can be said that the AR system was well accepted and the user experience was positive. However, the participants saw some safety concerns related to using the AR system but were mainly concerned if the tablet could be used in the harsh maintenance environments.

The findings of this study could be used to improve HFE of the AR system use in industrial maintenance settings. In the future, this topic should be studied with different kind of AR systems (head-mounted display, tablet/smartphone and projectors) to acquire more information regarding the HFE issues in AR system use.

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