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Operators perspective on augmented reality as a support tool in engine assembly

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Augmented Reality (AR) has shown its potential in supporting operators in manufacturing. AR-glasses as a platform both in industrial use are emerging markets, thereby making portable and hands-free AR more and more feasible. An important aspect of integrating AR as a support tool for operators is their acceptance of the technology. This paper presents the results of interviewing operators regarding their view on AR technology in their field and observing them working in automotive engine assembly and how they interact with current instructions. The observations and follow-up questions identified three main aspects of the information that the operators looked at: validating screw torque, their current assembly time, and if something went wrong. The interviews showed that a large amount of the operators were positive towards using AR in assembly. This has given an insight in both the current information interaction the operators do and their view on the potential in using AR. Based on these insights we suggest a mock-up design of an AR-interface for engine assembly to serve as a base for future prototype designs.

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Keywords: augmented reality; engine assembly; operator**Nomenclature**

AGV	Automated Guided Vehicle
AR	Augmented Reality
ARSG	Augmented Reality Smart Glasses
HRC	Human Robot Collaboration

1. Introduction

The fourth industrial revolution will stand to change how we manufacture products. It will allow more dynamic flows of information and thereby enable swifter changes in production [1]. This will change the work tasks for operators drastically, who will have to handle more product variants and more frequent updates of work tasks. Industry 4.0 will also likely lead to larger responsibilities for operators. One solution to handle this is to implement information systems that can give operators

needed information. Augmented Reality is one type of technology that might be used to support future operators [2].

AR is defined by Azuma et. al. to have the following characteristics: combining real and virtual objects in a real environment, running interactively and in real time, and aligning real and virtual objects with each other [3]. According to Azuma et. al. [3], AR can potentially apply to all senses and in this paper the focus is on visual AR specifically. AR has been shown to be able to increase efficiency in assembly tasks by giving information in context, thereby simplifying interpretation of data and reducing time and errors in doing so [4]. Implementations of AR can be categorized into three categories: head-attached, hand-held and spatial [5]. Rapid advances within head-attached solutions, specifically regarding Augmented Reality Smart Glasses, ARSG, has made this type of implementation a suitable platform for assembly support [6]. Therefore this paper limits itself to ARSG and when AR is mentioned in the rest of this paper in regards to the study and conclusions it implies ARSG.

While AR has made much progress in different fields, it is still struggling to reach the factory floors [7]. Handheld devices limits operators effectiveness, head-worn displays are heavy and limited in focal depth and resolution, and large screens take up space [7]. Smart glasses are however becoming increasingly lighter and getting better technical functionality [6]. Wang et. al. found that there are limitations in current AR systems in regards to assisting complex assembly processes [4]. One of the issues they identified as currently limited was intuitive user interfaces.

This paper focuses on the operators' perspective on using AR to support assembly tasks. The aim of this focus is to gain a better understanding of industrial operators as interface users to facilitate more intuitive user interfaces in the future. The operators' perspective is analyzed through observations of interaction in actual assembly to get a better understanding of the current situation. It is also analyzed through interviews that both complement the observations by giving the operators a chance to give a deeper explanation of their view. The interviews also gives an insight in how much the operators trust AR technology. This is relevant since user trust of an information system will affect the user's efficiency when working with it [8, 9].

This paper is a continuation of our previous work within assembly support for operators, which has focused on evaluating different AR support systems from an operators perspective and the technology's suitability for guiding operators through HRC assembly [6, 10, 11]. This paper focuses directly on operators themselves to observe their behavior and interview them regarding their views.

2. Case study

This section describes the layout of the factory and the operators' assembly tasks, how data was collected, how the operator observations were setup, how the operator interviews were setup, ethical considerations, and possible error-sources and how they were remedied.

2.1. Layout and assembly tasks

The interviewed and observed operators are all from one section of engine outer assembly of the Volvo Car Corporation engine factory in Skövde. There are four assembly lines, each with eight sequential stations placed in a U-formation. The engines are transported on Automated Guided Vehicles, AGVs, from station to station and stops at a specific point at each station. Each operator follows one engine from the first to the last station. After the last station they move to the first station where a new engine waits for them. Figure 1 gives an overview of one such U-formation with 8 stations.

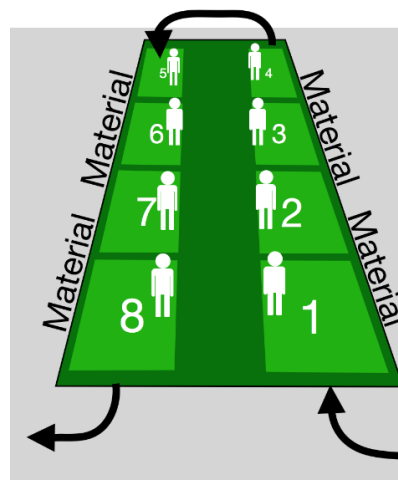


Fig. 1. Overview of an assembly line.

Each station is equipped with a monitor displaying station specific information. The monitors are all mounted above the engine at its fixed position. The most common information displayed is feedback on which screws and bolts to use and the results from the screwing machine whether the screwing process was of sufficient force or not. Figure 2 shows a detailed view of the instructions available for the operators. The left-most instruction contains detailed instructions for each step, the middle instruction shows possible specific details to check, and the right-most instruction is a digital screen that gives feedback on the operator's progress based on data from the production system. The screen shows the operator available time left on the current assembly cycle and how many screws that had been fastened with the right torque for instance. If the operator went beyond available time or if incorrect torque was used on a screw, the system gave this feedback to the operator.



Fig. 2. Close-up of instructions available for the operators.

2.2. Data collection

Two data collection strategies were used, observing the operators while performing their assembly tasks and interviews. One researcher performed all observations and interviews.

2.3. Observation setup

The goal of the observation was to gather quantitative data about how the operators interacted with current information systems. It was executed by following an operator during one lap of assembly. One lap consisted of 8 stations from 1 to 8 as in figure 1. Operators were asked to consent to the observation before proceeding and none declined. The observer placed himself as to avoid being in the way for the operator while still being able to see where the operator was looking. For each station the number of times the operator looked at the monitor or other information systems was counted by subjective observation of the operators gaze. When the operator looked for approximately half a second or more in the direction of an instruction (a computer screen, lit lamp, or a piece of paper with instructions) or interacting with another person directly connected to work performance and when the gaze was roughly half a second or more it was counted as an observation. Time spent looking was not recorded or measured.

After following an operator for one lap, and if it did not disturb production, he or she was informed about what had been observed and were asked if he or she generally looked often on instructions and what things he or she looked on.

2.4. Interview setup

The goal of the interviews was to gather a deeper understanding of the Operators' views on the need for information in their current work environment as well as their views on other information systems.

The interviews were semi-structural and individual. Each participant filled in a consent-form that informed them of the general goal of the data-collection: to gain knowledge in how operators view instructions in their work and how they currently interact with them. The extended purpose of creating a more efficient learning of new instructions and allowing for a more dynamic production was also explained. They were also given the option to provide an e-mail address if they wanted to know more about the results of this study. All interviews were audio-recorded to facilitate deeper analysis afterwards.

The interview questions were: age, how many years they have worked with assembly in a factory, how many years they have worked at their current position, how often there are changes in their tasks in production, how the company informs about the new tasks, if the operator complements the information in any way, how often they check up things in documentation (with the follow up questions: what they check then, how easy it is to understand, if it is easy to find), the operator's view on being able to do personal adjustments, how the operator would design the information flow if he or she had free hands, and if they had any other ideas or thoughts based on what had been brought up in the interview.

2.5. Ethical considerations

Operators' work in assembly is stressful [12]. Each operator has an individual RFID-tag that the use to login to each station. Any errors in assembly can therefore be tracked down to individual level. While this means operators are used to being

monitored this can also be a source of stress due to constant observation and measurement of performance. It was therefore emphasized by the data collector to the operators that the purpose of the data collection was for research of new technologies to display instructions and that the data would not be connected on an individual level.

During the observations they were not told what was being observed until afterwards when the purpose of the observation and what was being observed was revealed. No operator declined being observed which greatly simplified data collection.

All interviews started with the person being interviewed being presented a consent-form that informed about the purpose of the study, that the interview would be recorded and they had the right to abort the interview at any time with no motivation needed. Who had access to the recording was stated as very limited university staff. This was not more precisely specified since who would analyze the data was not determined at the time of the interviews.

2.6. Potential error sources

The observer made sure to place himself as to be out of the way for the operator while maintaining a good field of view of the operator's work. This meant moving in an assembly line while simultaneously making observations. This combination of structured subjective measurements and an active environment can have had a negative effect on the accuracy of the data. Video-recording the operators in production was not deemed feasible due to permissions needed and integrity. This was in part remedied by having one data collector and following an observation protocol, thereby reducing the risk of inter-measure discrepancy. The observer has also previously worked with industrial assembly for one year and was thereby used to this form of environment. The observation data from the first day was used to learn what could be feasibly observed and was not used in analysis.

3. Results

This section summarizes the results from the observations, summarizes the results from the interviews, and presents an AR-design based on the previously mentioned results.

3.1. Observation

A total of 35 observations were done. 19 observations were done on males and 16 on females. Two observations (one male and one female) were incomplete since there was a break before completing a full lap and one observation (female) was incomplete because of the shift ending. Of the 35 observations, 24 gave comments after the observation about what they look at when looking at the instructions in general in their daily work. The most common (10 operators looked at this) was checking the torque on screwing stations. The second most common (9 operators looked at this) was assembly time, and the third most common (8 operators looked at of this) was checking when something goes wrong. A full list of the

operators' self-reported reasons for looking at the instructions are shown in table 1.

Only two observations were done of an operator interacting with another operator related to their task. In one instance a colleague showed that an assembly piece had been moved to a more efficient position. In the other instance the operator wanted to verify with a colleague that a certain assembly piece were to be used. Social interaction was frequent but not measured. Interaction with signs was in the form of "pick-by-light", a system where a lamp would light up to indicate which detail to assemble at a specific product. The light would switch off when an RFID-tag held at the operator's wrist came close to the light.

No statistically significant patterns could be observed based on gender or experience regarding how often operators looked at instructions.

Table 1. Operator observations (self-reported)

View on AR	Male	Female	Total
Torque of screwing machine	5	5	10
Assembly time	4	5	9
Something goes wrong	2	6	8
Learning new steps	2	2	4
Must look at 240	1	2	3
Deviations from normal	2	0	2
Forget themselves	0	2	2
"When it's needed"	1	1	2
When production stops	0	1	1
If RFID tag does not react	0	1	1
More when interrupted	0	1	1
Automatically check in beginning or end	1	0	1

3.2. Interviews

A total of 28 interviews were held. The interviewed operators were chosen from the same group as the observed operators and some operators were chosen for both observation and interview. The first five interviews had a different set of questions and was used mainly as a test of the questions. The remaining 23 interviews had a modified set of questions based of the result from the first five. In the first group, 3 of the operators were male and 2 were female. In the second group 13 were male and 10 were female.

At the end of each interview the purpose of the study and the technologies involved was explained. Each participant was asked if they knew of the term "augmented reality" and it was known by 6 of the operators. Based on their reactions when the technology was explained and how it could affect their future work a large amount in both groups, 4 of 5 and 17 of 23, audibly exclaimed positive interest. Examples that was interpreted as positive are (translated from Swedish) "It sounds very interesting, of course I would like to see how this goes.", "Shit, how cool!" and "That would have been something." Two of the operators showed positive interest in the technology but expressed concerns that they did not think the management of

the company would like to spend the resources to invest it. But since they showed positive feelings regarding the technology in itself they were counted as positive.

Of the remaining operators, 6 showed no clear reaction to the possibilities of the technology and one operator expressed concern. The concern was (translated from Swedish) "God how creepy.". She expressed this when augmented reality was explained by using the example of a digital green arrow following a pen in its movements. The results can be seen summarized in table 2.

Table 2. AR acceptance.

View on AR	Male	Female	Total
Positive	12	9	21
Neutral	4	2	6
Negative	0	1	1

3.3. AR-design

Since the operators showed a clear interest in using AR and since AR can simplify distribution and presentation of assembly instructions it is of value to further investigate how AR can be used as support for the operators in their work. The current design is limited in that the screens are mounted in a specific position which limits from which angles the operators can see the screens. This has been solved in the current layout but is a limiting factor in where tasks and information regarding tasks can be placed. Based on the presented observation and interview data we have created a design suggestion for how an AR interface could present information to the operators.

Figure 3 shows an engine from an operator's point of view. Figure 4 shows an example of how instructions could be shown to an operator in one assembly step. The operator is to place the detail that is marked blue in the position that it is seen on figure 4. Then two screws are to be fastened with the correct torque. The blue marking in the middle highlights the current detail to assemble. Two bolts have been attempted to be fastened in this example where the first one (top right corner of the blue marking in the middle) is highlighted green, indicating a correct torque. The second bolt is marked red, indicating incorrect torque. In the current system, operators can see correct torque via a green/red lamp on the screwing machine or alternatively how many

Checking torque of screws was the most common reason for the Operators to check instructions according to their own view. The red highlighting also shows an example of how an error can be displayed to the operator. Checking if something went wrong was one of the second most common reasons to check instructions. The other second most common reason to check instructions was time, how much time the Operator had left on the current cycle. This AR-design presents information that the operators state is the most important to check and it is presented in similar colors and design as the current information systems that they use. It is possible that this design will not be effective in actual assembly but these two factors makes this design a good basis for future empirical studies.



Fig. 3. Unaltered view of an operator at one of the engine stations.

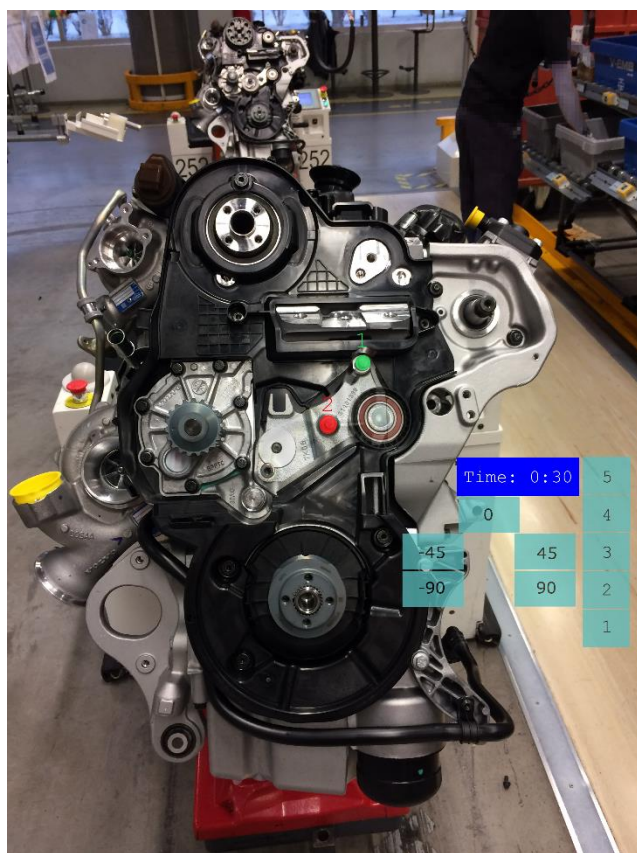


Fig. 4. The same as figure 3 but with the suggested AR interface added.

4. Conclusions

A high number of the interviewed operators showed positive reactions to augmented reality in connection to providing support in their work, indicating a high acceptability among the Operators regarding the technology.

Observations done showed that operators look on instructions mainly to check screwing torque, assembly time and if something went wrong. The suggested AR-design uses this as a base as to what operators find as important information to display.

The local managers for this section of production were pleased with the results and insights from this evaluation. The data helps the managers what positive values the operators see and which threats they see. What is mainly lacking from their perspective is comparative data that can be gained from tests on a prototype to show more concrete increases in efficiency.

The analysis of the observations done indicate better understanding of to how create intuitive user interfaces for operators and how to assess operator acceptance of AR. Furthermore, the operators view on AR as an information platform can support when estimating operator readiness and willingness to adapt when using this technology and thereby help in strategical decisions regarding further use of AR.

4.1. Future work

Although the gathered data is comprehensive it is limited to one factory so it would be useful to extend this data in the future to more factories to account for possible differences in cultures between companies and factories. The suggested layout of information, while relevant to the operators according to their answers and from the data gathered from observations, is just a mockup. The gathered data is based on self-reported acceptability however and needs to be validated further in a more concrete setting. To fully validate its usefulness for the operators a functioning interface needs to be developed. It is unlikely to get permission to test such an interface in real production, at least in earlier stages of testing. A testing environment with similar tasks being performed could provide a suitable test-case and would further validate such an interface design. While actual production would be an ideal environment to prove that the technology is ready, it might be less optimal for first tests. The first iterations are likely to disrupt production too much. More suitable would be to have a test-environment with similar tasks but with less critical cycle-times.

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