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How Do We Support Technical Tasks in the Age of Augmented Reality? Some Evidence from Prototyping in Mechanical Engineering

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How Do We Support Technical Tasks in the Age of Augmented Reality? Some Evidence from Prototyping in Mechanical Engineering

Completed Research Paper

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Abstract

Industrial sectors like mechanical engineering currently define themselves primarily through their product business. However, a change can currently be observed. Instead of continuing to engineer products for maximum reliability, solution systems are developed that leverage their performance from services such as maintenance. For these, information supply is an essential factor, since the underlying products are becoming more complex. Additionally, these products are integrating information and communication technology, which can supply technicians, e.g. with actual condition data. To be able to use this information, technicians need service support systems (SSS) that yet exist on mobile and simple wearable devices. This article reports from the development of an SSS-based on augmented reality glasses. The developed system was used to support a LEGO assembly task and evaluated with the Task-Technology Fit model. The result shows that AR glasses can be used for the information supply of technicians but still need further development to allow for adequate service support.

Keywords: Augmented Reality, Service Support System, Task-Technology Fit, Pretotyping, Design Science Research

Introduction

The market in Mechanical Engineering (ME) is being assessed primarily on the basis of product engineering competencies of its participants (Ulaga and Reinartz 2011). Manufacturers therefore compete in the development of new features and the improvement of products in terms of performance and cost-efficiency.

In the course of this optimization, however, there are also disadvantages that have to be considered: For example, the more cost-efficient use of materials can lead to a reduction in robustness and the improvement of reliability through the implementation of early detection and prediction technology can increase the design complexity of a machine. In order to master the various interdependencies and achieve sustainable performance improvements, mechanical engineering tends to develop systemic solutions that include product-related services (e.g. maintenance) in addition to products and thus achieve the overall quality of performance through a "value bundle" of products and services (Baines et al. 2013). The principle of such "Product-Service Systems" is widely accepted in research and practice (Tukker and Tischner 2006) and produces digitally connected heirs such as "Industry 4.0" from a production-centric perspective (Lasi et al. 2014), "Smart Service Systems" from a service-centric perspective (Beverungen et al. 2017) and "Cyber-physical Systems" from a technical perspective (Mikusz 2014). The advancing development of information systems that are located between product and service is thus an essential driver for the progress of systemic solutions in ME and promises to enable information-based service offerings such as predictive or preventive maintenance (Wiedemann et al. 2019). At the same time, however, the service technician, as an executive expert, also plays an increasingly important role in the business model of the mechanical engineering company, since error-free operations evidently depend not only on the early prediction or detection of a fault, but ultimately on the timely execution of countermeasures. Considering the increasing product complexity on the one hand and the increasing importance of services as a solution component on the other, technical work by service technicians is being understood as an information-intensive task. Against this background, the information support for technical service operations is gaining in importance and underlines research efforts for the explication, serialization and transfer of knowledge.

New technical options therefore connect to a general goal that intrigued research on information systems for decades, namely the adequate informational support of after-sales-services, through which competitive advantage is to be achieved (Ives and Vitale 1988; Lele 1997). But where are we and why aren't we there yet? An underlying theoretical problem has been the ongoing (re-)location of the boundary between human work (and its information needs) and (available) information support in the provision of services, which e.g. delivers on the automated simplification of tasks and the provision of context-specific information (Kammler et al. 2019). This in turn has led to the emergence of a specific class of information systems: "Service Support Systems", which originally were discussed in the field of decision support systems, but gain in importance with the advent of mobile and wearable devices (Matijacic et al. 2013). With each development stage of such technologies, the integration and use of information systems in work processes become more seamless (e.g. freehand use in bimanual activities) and information presentation is being improved (in extent and quality). Consequently, new technologies and the empowerment they provide to their users motivate further research.

Augmented Reality (AR) glasses represent another shift in this field, as they enhance seamless integration into work processes and the display of complex and extensive information. Although AR glasses recently attracted attention with the release of Microsoft's HoloLens and several other devices, the technology behind the glasses is known in research since decades. A major step towards marketable versions, however, was the emerging ubiquity of enough computational power and the opportunity to process large amounts of visual data in a reasonable time. By means of that, AR glasses interpret the current physical environment (e.g. via a depth sensor) and integrate virtual objects via the display of the glasses. Users consequently perceive the illusion of information systems that can be located in a physical environment and, for instance, be pinned to a certain position on a wall. Literature provides us brightly colored visions of AR in working processes. Also, some prototypical implementations evidently show the application of certain devices for certain processes. Still, there is little knowledge on AR-based service support systems for technical service tasks. We therefore ask:

RQ: Are Augmented Reality Glasses an adequate Support System for Technical Service Tasks?

Answering this question is an interesting step forward for the scientific discussion in several respects. On the one hand, a theoretical contribution is made to the decomplication of knowledge-intensive services and enable the delivery of tasks for less-educated workers. For example, the level of detail of digitally retrievable information can decide whether a technical manual requires existing specialist knowledge or can also be carried out by laypersons as "self-service". In this sense, a SSS can be regarded as a "knowledge interface" between humans and machines and serve as an object of investigation for partial autonomy in information systems. On the other hand, answering the research question contributes practical knowledge about whether and how AR can be used advantageously in field service processes. Our report from a 1-year research project is structured as follows. Section two gives a short introduction into our studies' application field in Mechanical Engineering and current research advances in AR technologies. After that, we explain our research process, the choice of methods and the insights we strived for. All results of our 5-step development process are then briefly outlined in section 4. Concluding, we evaluate the developed prototype through an experimental application in section 5. Section 6 and 7 discuss the insights we gathered from our research and outline future research needs.

Fundamentals

Service Support Systems in Mechanical Engineering

Technical customer services (TCS) in mechanical engineering are characterized by a high level of knowledge intensity. This is primarily caused by the complexity of the machinery, which already consists of a large number of mechanical and electrical components and is often configured according to individual customer requirements, thus covering a wide range of possible variants. As a consequence, the complexity of service provision also increases and, in addition to the basic mechatronic training of service technicians, requires practical experience and application knowledge of the respective machines. In order to be able to support technicians in the process and to contribute to the fast and high-quality execution of services, the requirements for an information system were investigated and mapped in a mobile service support system (Daeuble et al. 2015; Matijacic et al. 2013). In practical use, however, it quickly became apparent that a number of typical activities had to be carried out with both hands, so that the freehand use of the support system gained in importance (Niemöller et al. 2017). As a result of this finding, more and more Head-Mounted Displays (HMD) in the form of Smart Glasses have been researched to implement service support systems that meet the new requirement. But parallel to the efforts to integrate information technology more seamlessly into the work process, the amount of available, relevant information is also increasing and poses new challenges for the adequate information supply. For example, modern machines have a large number of sensors that record data on the current operating status and display it as a machine history. The development of future support systems is therefore based on the dilemma that on the one hand ways have to be found to provide information with as little interference as possible, while on the other hand an increasing amount of information has to be shown. In conclusion, new approaches for support systems are still demanded, which can select context-relevant information, compress it and visualize it with low disturbance effect for the technician.

Augmented-Reality-based Information Systems

In the context of information systems, the term AR has long been used to refer to Smart Glasses-based HMDs (e.g. Berkemeier et al. 2019). Although some characteristics of AR are met by Smart Glasses, the ongoing evolution of the technology reveals which capabilities AR provides beyond the static presentation of little information. The principle idea of HMDs exists already since the year 1963, in which Hugo Gernsback presented with the so-called “television goggles” an initial prototype of a portable display (Oppermann and Prinz 2016). Three decades later, Ivan Sutherland introduced the first functional HMD that could display 3D-objects in space (Sutherland 1968). The current notion of AR represents a new development in the field of HMDs, characterized by the representation of virtual, interactive (3D) objects in real space. The reality of the user is thus enhanced by virtual information (Azuma 1997). This context-sensitive integration of virtuality and reality is made possible by devices that capture the environment via sensors. To this belong mobile devices, which combine virtual and real environment on the display via software development kits such as Apple's ARKit or Google's ARCore, as well as HMDs such as Microsoft HoloLens, which capture the environment via depth sensors and cameras and fade 3D content into the field of view. Using a semitransparent display, 3D content can then be shown and interacted with in real-time. While the first versions of these devices still had a low Usability due to high weight or a low Field of View (FOV), current devices offer the potential to be used in industrial applications. For example, in industrial assembly procedures, which are most often based on paper or projector systems, the amount of information that can be shown via the AR glasses of the worker increases. New application scenarios also arise in the medical environment, where AR glasses can be connected to a magnetic resonance imaging scanner in order to display and interact with overlays during surgeries in real-time (Mojica et al. 2017) or to facilitate the dosing of tablets (Przybilla et al. 2018). In addition to new application areas for AR glasses, the modular structure of AR-based information systems is being investigated (Berkemeier et al. 2019). Accordingly, the choice of cloud infrastructure, internet connections, use of edge computing and the actual device class have an influence on the performance of the system (Chen et al. 2017).

Research Approach

Design Science Research as a Basal Methodology

In order to answer our research question, we choose a construction-oriented approach, since so far, few practical examples for the use of AR in field service tasks are known and most of them still have prototype status. Newer design-oriented research methods are subsumed under the Design Science Research (DSR) Methodology, which aims at the deductive application of knowledge and inference of insights through the construction of prototypes. The result emerges on both a practical and a scientific level (Hevner et al. 2004). From a theoretical perspective, the repeated evaluation thus contributes to continuous validation against practical requirements and to the inductive derivation of findings (Sonnenberg and vom Brocke 2012). From a practice-oriented perspective, transparent development processes and the generalization of developed prototypes achieve knowledge formation in the sense of “projectable“ artefacts, i.e. transferable between different application cases (Baskerville and Pries-Heje 2014; Berkemeier et al. 2018). An essential aspect of DSR research is the creation of uniform development paths, which has led to a variety of more general or more specific proposals for discussion. Among these, the procedure model according to Peffers (2007, p. 54) has attracted considerable attention and has become a widely known approach due to its broad application in corresponding literature.

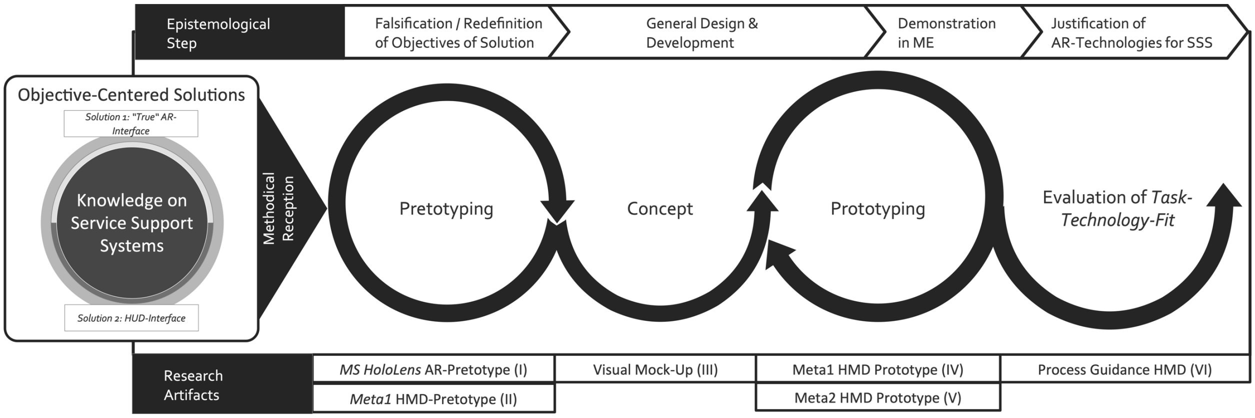

Figure 1. The Research Approach we adopted from Peffers et al. (2007)

We implement Peffer's comprehension of a Design Science process as the underlying structure of our work and see the results of each phase as both, a prototypical research artifact and an epistemological step towards the answer of our research question (cf. Figure 1). In doing so, we follow the assumption that the two outlined, essential development directions of the AR-based Service Support Systems (SSS) are to be understood as “objective-centered solutions”. According to Peffers et al., an objective-centered solution, “could be triggered by an industry or research need that can be addressed by developing an artifact” (Peffers et al. 2007, p. 56). In addition to this type of initiation, according to Peffers et al. further entry points are also conceivable (e.g. design- & development-centered initiation), which are set against the scientific reception of existing artifacts. It would also be possible to pursue such an approach which would narrow the design process down to a single artifact. However, one goal of our work is the preliminary validation of underlying objectives, which are to be understood as the result of the availability of new technologies (“technology push”) rather than the basic demand in the market (“market pull”).

Epistemological Steps, Methodical Reception and Research Artifacts

Step 1: Falsification and Redefinition of Objectives

Our first epistemological step towards the answering of our research question is the falsification and redefinition of the design objectives. Falsification is a recognized mechanism of epistemology that can be used to systematically test premises and artifacts. Such approaches attempt to disprove existing knowledge and thus identify erroneous knowledge at an early stage. Within Design Science, there are various corresponding methods that are intended to open up "misfits" between the field of application and the design object at an early stage of development. Some may be familiar with the concept of the minimum viable product (MVP). An MVP is a working product, stripped down to its core functionalities (Savoia 2011). The expectation towards an MVP is that it offers the maximum acquisition of knowledge with the least amount of effort (Ries 2009). However, to fulfill this expectation, a lot of energy and resources be invested in collecting and analyzing information (Ries 2009). A more lightweight approach can be found in the concept of *Pretotyping*, which also aims to find out whether a product is needed or will be used on the market. Through a fast, cost-effective and rough mockup of the product, the idea of the product is tested. Therefore, the pretotype does not have to be functional. The pretotype is used to test the "initial appeal and actual usage" through "simulating its core experience" (Savoia 2011) and promises the quick identification of the "right set of features and user experience" (Singi et al. 2015). Whereas the MVP and pretotype both aim to answer the question if the product is a product that has an actual demand, they are opposed to one another concerning their principal idea: While MVPs are developed to identify a suitable approach that can be further developed, Pretotyping strives for fast fails that extend the knowledge of the developer on sound features. This in turn also means, that the recovery is fast as well and therefore allows to restart quickly with new knowledge. Pretotyping is especially useful to make immediate decisions about whether an investment is worthwhile, or the initial idea should be disregarded due to the lack of actual demand (Savoia 2011). We follow the pretotyping approach of Savoia (2011) to test simple instantiations of the alternative visualization concepts for AR glasses and redefine the existing objectives of our research. Section 4.1 introduces two pretotypes we have built to learn the differences and hurdles of both concepts.

Step 2: General Design and Development

Testing the product idea with a pretotype is a step before building a prototype. After the need for the product has been established, a subsequent prototype can help to understand the usability, actual usage and how to implement the functionality. For the prototyping, we used a visual mock-up that outlined the service support system. We then applied the agile development method SCRUM[1] to implement a functional system. We chose an agile approach since the market for HMD-based AR is very dynamic and technical advances were to be expected. This expectation was confirmed during the development process by the release of a new version of our HMD. We thus decided to enhance our prototype for the novel HMD and constructed a Mark 2 prototype that benefited from new interaction mechanics, higher resolution and processing power. The prototypes are illustrated in section 4.2 and 4.3.

Step 3: Demonstration of an Application and Justification of AR-Technologies for SSS

As a third epistemological step, we strive for the practical applicability as well as the theoretical justification of AR technologies for Service Support Systems. It turned out that the evaluation of our prototype in an industrial environment is extremely difficult, since various industrial safety regulations (e.g. Explosion Protection Directive, Directive on Health and Safety Protection of Workers) must be met. We thus decided to evaluate the eligibility of such systems for more general assembly tasks that do not require the industrial environment, though providing a sufficient number of experts: LEGO-models. During our experiment, the participants were asked to assemble an unknown LEGO-model with the help of our prototype. Subsequently, we surveyed the participants according to the Task-Technology Fit (TTF) model (Goodhue and Thompson 1995). We also applied the Affinity for Technology (ATI) scale (Franke et al. 2019) and evaluated the participants' knowledge of the tools used in the study to gather more detailed insights. We report on our results in section 5.

Development of the AR-based Service Support System

Falsification of Approaches: Located Displays vs. Head-Up Display

As outlined above, we "pretotyped" two instantiations of window-based AR applications to discover the suitability as an SSS in the service technician domain (cf. Figure 2 & 3). The fundamental idea of a window-

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[1] SCRUM is an agile software development approach. A detailed introduction is e.g. provided by Sutherland and Schwaber (2013).

based AR-application is to provide field technicians with information on virtual displays that are being located in the physical environment of the user.

Our first pretotype is based upon Microsoft's HoloLens, which is a well-known AR device that provides a considerable number of libraries and functions and thus facilitate the pretotyping step. The HoloLens captures the surroundings of its user through a built-in depth sensor. By utilizing the resulting depth map, the system is able to "locate" windows in a physical environment and thus "augments" the workplace by required information through multiple "located" displays (cf. Figure 2). A window-based design allows the simple presentation of convenient information material (cf. Figure 2), such as videos, pictures or websites. Furthermore, users may open and locate various windows to support their task optimally. In order to provide practically relevant information, we filled the windows according to Matijacic et al. (2013). The pretotype includes Process guidance (upper left), the access to annotated process models (upper right) and video instructions (bottom right), which reference to Matijacic et al.'s *display of complex information objects* and *proactive information provision* (2013, p. 12). Users interact with the application through a cursor, gestures and voice commands. In sum, the pretotype enabled us to test the presentation of different information types in a window-based format which can be located in the captured room.

Place pump cover, center and fix with screws

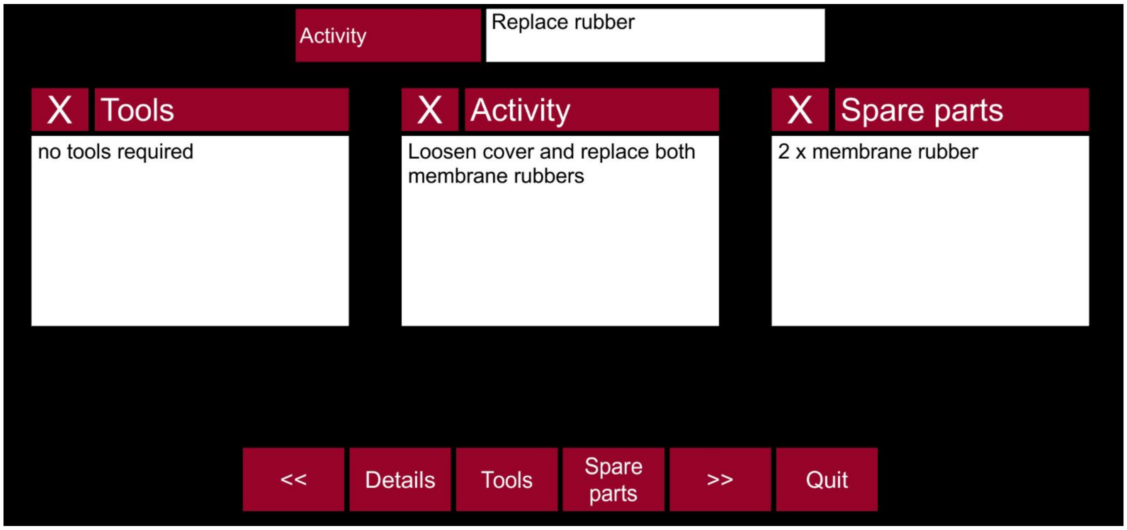
Now the cardboard sleeve is used again, as the left diaphragm protrudes. The screws should only be tightened hand-tight!

Figure 2. Pretotype I (Microsoft HoloLens) with Window-based Design

In order to follow our strategy and identify technology-induced failures early, we undertook field observations in a mid-sized company from Mechanical Engineering. A field technician was asked to use the system for a simple assembly task (fix of an electrical error) in the exhibition area. An essential benefit of AR-technology was recognized in the available "virtual space", that allowed for the locating of various information sources and – theoretically – the simultaneous access.

However, we found several technology-induced disadvantages that cast doubt on window-based AR. For example, the idea of an "infinite" display was quickly falsified for the pretotype, since the provided field of view required the user to look around often. The field technicians compared the effect to a torch that lights only distinct areas in a dark room. Moreover, the limited real representation in the field of view increases the cognitive effort of the technician. The technician has to keep in mind where he has placed windows and with what kind of content to capture all information. We observed a situation in which the field technician "forgot" yet located windows at his starting point in a conference room. The undiscoverable interface first led to confusion at the point-of-service and ultimately forced the user to either reboot the device or return and "pick up" the required window. The overlap of information and real objects turned out in our experiment as a further drawback of located displays (cf. Figure 2). Since the initial location of windows currently did not regard the physical environment, the field technician was compelled to relocate new windows manually to conduct his task. Additionally, turning to another working place at the machine shifted the angle between the device and the virtual displays and, again, forced the technician to relocate the windows.

In order to compare these results with a second approach to an AR-based SSS, we implemented a Head-Up-Display (HUD) pretotype that was realized with *Metavisions'* AR glasses Meta 1. With the designed HUD, we eliminated on the falsified objectives and provided static information displays to the user (cf. Figure 3) to reduce the searching and frequent placing of previously located displays and to avoid an overlap of information with real objects.



Replace rubber

no tools required

Loosen cover and replace both membrane rubbers

2 x membrane rubber

Figure 3. Pretotype II on Meta 1 with Window-based Design

Compared to Microsoft's HoloLens, the individual windows can be arranged in the field of view (FOV), but not located in the room. We observed that the design decision for a static arrangement lessened reposition activities and increased the intuitiveness and comfort of the system for users. The navigation bar has also been moved so that it can interact with the interface independently of isolated displays. In a field observation, it was determined that the FOV still causes overlaps between the interface and the working environment. In addition, a technician stated that it was necessary to adjust the amount of information in order to be able to respond to individual information requirements. The comparison of the pretotypes shows that the HUD variant is easier to handle in practical use although it does not use the full functionality of the AR glasses, i.e. to locate displays in a captured surrounding. Accordingly, in a next step the findings were transformed into a conceptual design, which forms the basis for prototype development.

Conceptual Design

Since HMD-based ARs have only recently been mass-produced, there are few analyses of requirements or design principles for assistance systems based on them (Dhiman et al. 2018). This complicates the design and development of such systems, since previous investigations in the field of mobile assistance systems have shown that the multi-perspective collection of requirements is of essential importance due to the complexity of maintenance and repair tasks (Matijacic et al. 2013). The results of pretotyping can only be regarded as indicative, whereas the detailed design has to be carried out e.g. by adapting design principles for similar devices. For this reason, we initially consolidated requirements and design principles that had already been collected for HMD-based support systems (Berkemeier et al. 2019; Niemöller et al. 2017). In a second step, the results were discussed in focus groups according to Kitzinger (1995) with service experts and users from ME and converted into a concept. As a result, the first conceptual design comprises a total of four essential features:

- **Process Guidance** includes the visualization of service processes (i.e. the activity to be performed) as well as navigation through process steps. For non-linear processes, such as error diagnoses (Metzger et al. 2017), decision situations will be mapped so that the user can influence the further process flow.

- **A Communication Interface** enables the transmission of audio and video streams, e.g. to the back office. Depending on the end device used, the HMD's video signal can be transmitted from the point of service.
- **Proactive Information** is being provided through the integration and processing of existing knowledge and context information. This includes, for example, information on spare parts, the bill of material, tools, or a history of previous service operations.
- **Real-Time Sensorics** enable the connection of the support system to a service object, so that real-time sensor data facilitates the diagnosis of fault conditions by the technician. Context-sensitive warnings indicate out-of-normal sensor values and provide recommendations for corrective actions.

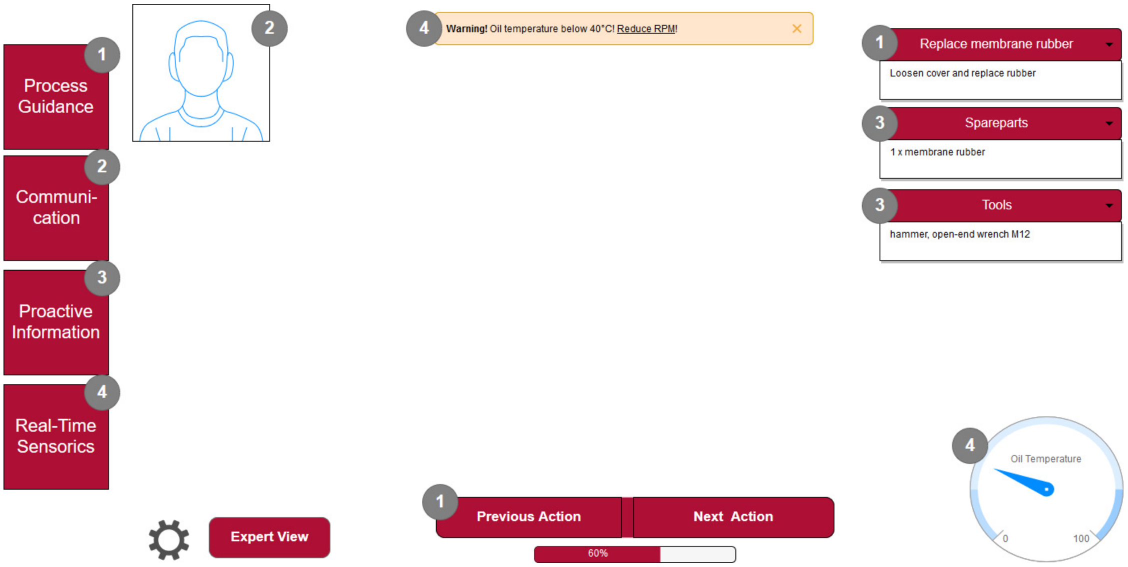
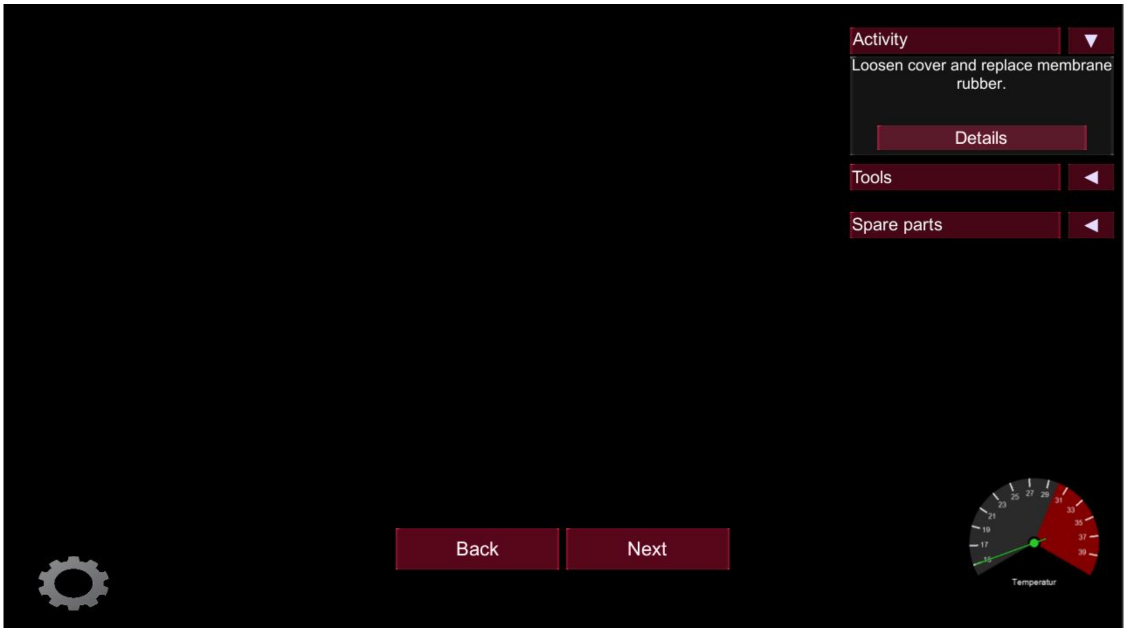

Warning! Oil temperature below 40°C! Reduce RPM!

Figure 4. Conceptual Interface of an AR Service Support System

The falsification of competing objectives led to the utilization of AR glasses as a static HUD, which does not respond to ambient changes (cf. Figure 4). All information windows can be minimized by the user to allow for individual information needs. Moreover, we follow Berkemeier et al. (2019) in the view that a modular architecture can prevent the functional overload of the support system and at the same time foster the agile development of the prototype.

Prototyping

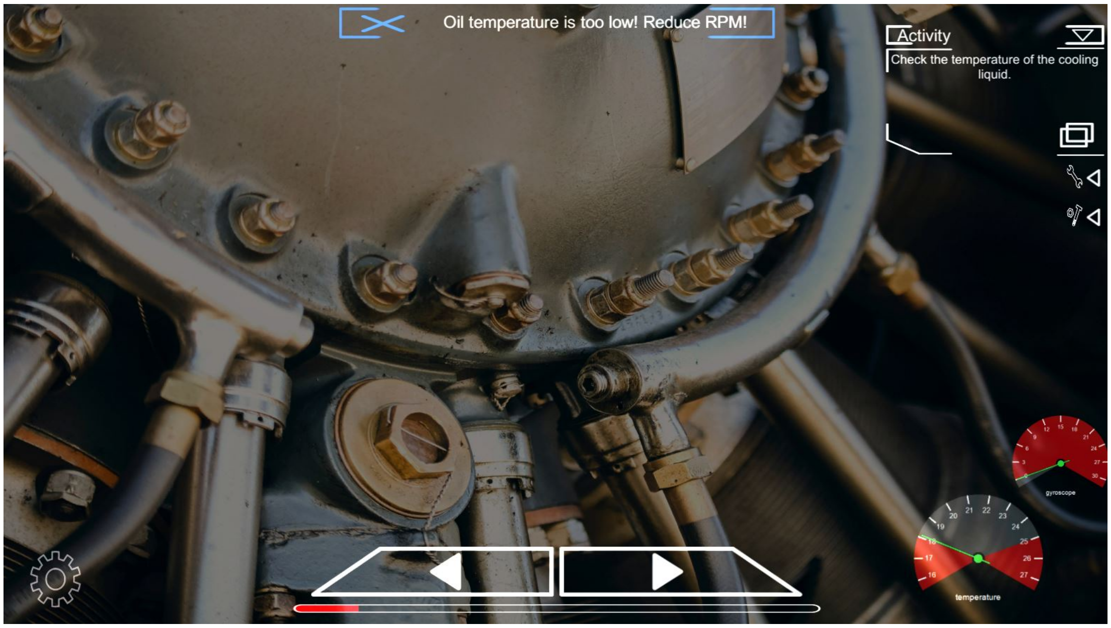
Due to the limiting Integrated Development Environment (IDE) of Microsoft's HoloLens, we decided to implement the prototype of the concept on Meta 1, for which additionally a successor with a market-leading 90° FOV had already been announced at the time of development. The development was carried out as an agile process on the basis of SCRUM with a total of eight sprints. Each sprint had individual HUD modules and their required backend infrastructure as its object. For example, the proactive provision of information proposed by Matijacic et al. (2013) requires, in addition to the surface in the HUD, an information structure that can select and display the corresponding information context-adaptively along the work process (Varwig et al. 2017; Kammler et al. 2019). In addition, the visualization of sensor values requires a connection to a corresponding real-time streaming infrastructure, which was simulated with a Bluetooth multisensor (Texas Instruments Sensortag) for our prototypical implementation. Figure 5 shows the implemented Meta 1 prototype.



Loosen cover and replace membrane rubber.

Figure 5. Prototype on Meta 1

The first prototype was presented again to the experts involved in the development of the concept. Further requirements were collected and integrated into a second iteration on Metavision's Meta 2, which was released in the meantime. Besides the advances of the display (e.g. FOV, resolution), the tracking system was also significantly improved by means of better sensors. While the total weight has increased by approx. 40%, the carrying system is made more stable by further mounts. These technical changes could already mitigate some of the falsified objectives (e.g. torchlight effect). Nevertheless, there were some further requirements by the experts that were included for the second prototype. Due to changing service situations like lighting conditions, a feature was added that enables the adjustment of the coloring.



Oil temperature is too low! Reduce RPM!

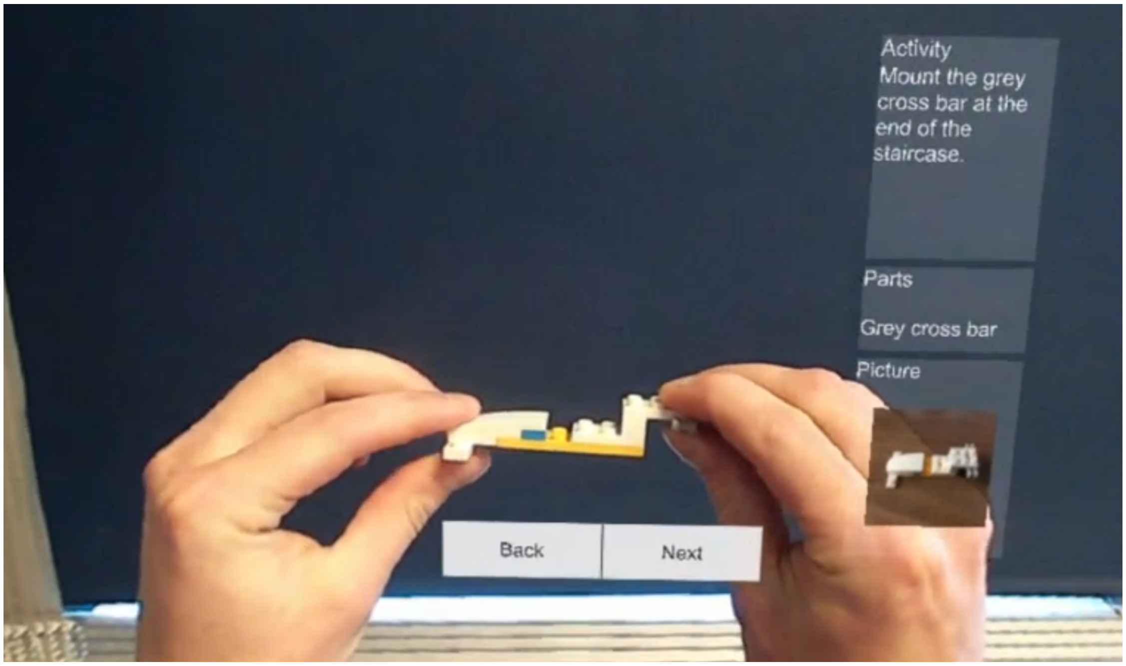
Check the temperature of the cooling liquid.

Figure 6. Prototype on Meta 2

Although the FOV was increased in comparison to Meta 1 and HoloLens, the display area was not sufficient for a comprehensive integration of the sensors, so that the process guidance and real-time sensors were adjusted. Sensors and individual activities were therefore linked in a database following Kammler et al. (2019) in order to display the sensor values that a technician needed. In addition, field tests have shown that context-related warnings overload the interface when critical sensory levels are reached. For the second prototype (Figure 6), the display time of warnings was reduced and a history was implemented that tracks finished service tasks.

Functional Evaluation of the Prototype

In order to design a feasible evaluation, we focused on one feature instead of all features and evaluated process guidance. Therefore, the prototype was reduced by removing the sensor streaming, the communication and parts of the knowledge base and simplified the design to information blocks. Consequently, the user has only access to the current activity, spare parts and a picture of the activity carried out and navigate through the process (cf. Figure 7). To simulate a simplified process that represents the assembling of a component, a LEGO model was designed with an 11-step-assembly-process. First, the structure of the interface was initially explained to all participants (n=29). During the experiment the user had to assemble the model with the help of the support system. After the experiment, we conducted a questionnaire-based survey. The questionnaire consists of four parts: (1) Knowledge on Lego and AR, (2) the ATI scale (3) the standardized TTF Questionnaire and (4) open questions about the prototype.



Activity
Mount the grey cross bar at the end of the staircase.

Parts
Grey cross bar

Figure 7. Evaluation of the simplified prototype on Meta 2

(1,2) Expertise of the Participants

Overall, the participants were familiar with both, LEGO and AR (cf. Figure 8). Regarding LEGO, the analysis revealed a median at *"I know Lego and have already used it extensively"* ($\tilde{x} = 4$). The analysis of the participant's AR experiences showed, that most of them already were able to try out AR for a short time ($\tilde{x} = 3$).

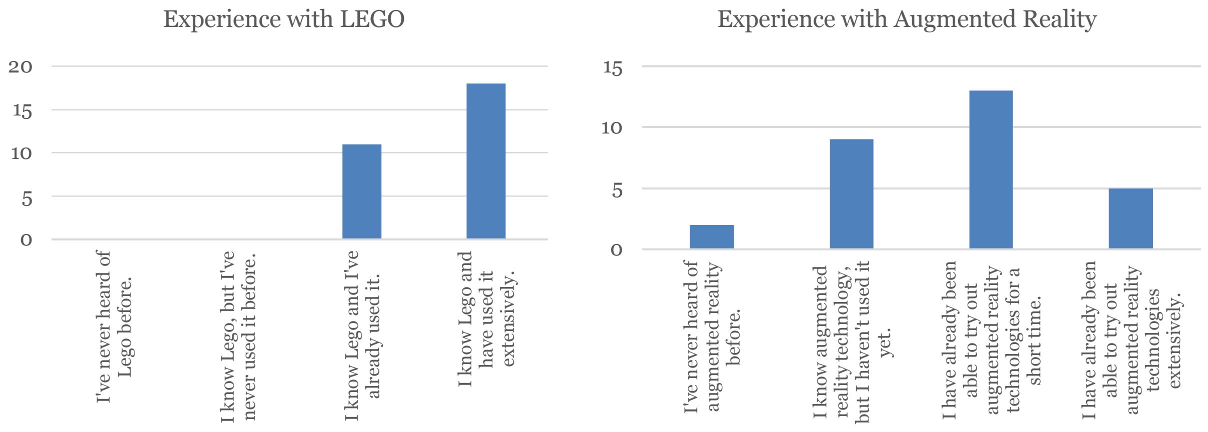


Figure 8. Previous Knowledge of Participants

The Affinity for Technology Interaction (ATI) Scale (Franke et al. 2019) is a suitable instrument which measures the individual tendency to interact with (new) technologies. Based on nine statements, which are evaluated on a 5-point Likert scale, the affinity of the user is evaluated with regard to personal resources for interaction with technology. For the participants in our experiment, an average ATI value of 3.946 ($\sigma^2 = 0.8147$) could be determined (cf. Figure 9).

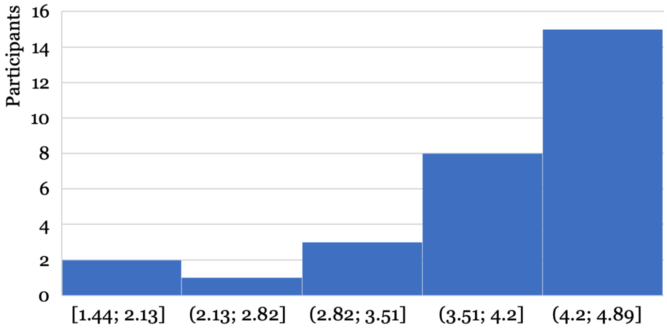


Figure 9. Histogram of the Results of the ATI Questionnaire

(3) Task-Technology Fit

The TTF can be used to check the suitability of a technology to perform a specific task (Goodhue and Thompson 1995). Goodhue and Thompson argue that the fit between technology and task is crucial for a person's individual performance. Since then, the model has been extended (e.g. Dishaw and Strong 1999) and applied to various areas such as E-Commerce (Klopping and McKinney 2004) and Security Trading (Ende 2010). Although the model was originally developed for an organizational context instead of individual application systems, recent studies show that TTF is suitable for both specific technologies and specific tasks (Gebauer et al. 2010). For this study, we follow the questionnaire presented in Goodhue (1998), which contains 24 questions recorded on a 7-point Likert scale from which the TTF is derived for 12 constructs in total (cf. Table 1). For example, it is surveyed whether the data is presented in a readable and understandable format. The participant can choose in seven degrees between "do not agree at all" and "fully agree" and thus give a tendency whether the technology has a negative, none or positive effect on the execution of the task. The questions were adapted in wording to the AR use case. The development of the prototype has shown that with AR glasses issues such as the limited FOV or overlapping information limit the user in the execution of his task. Therefore, we formulated our hypothesis as follows:

> *H_0: Process assistance with AR is disturbing the execution of assembly tasks.*

After the experiment, the mean ($\bar{x}$) and the standard deviation ($\hat{\sigma}$) were calculated of the overall TFF, i.e. the average scores of all 24 variables. Furthermore, a t-test was conducted in order to test the null hypothesis H_0: $E[x] \leq 4$, which indicates a lack of suitability of the technology. The individual constructs were treated in the same way by averaging the scores of appropriate variables to ensure independence of the data (cf. Table 1).

Table 1. Results of the TTF Survey

	Key Figures			H_0	
	Refer. Quest.	$\bar{x}$	$\hat{\sigma}$	*t-value*	*p-value*
TTF	24	4.4468	0.3424	6.9065	0.00000***
The Right Level of Detail	2	5.7241	0.7269	12.7738	0.00000***
Accuracy	2	4.2586	0.8087	1.7222	0.04803*
Compatibility	3	2.3908	0.9883	-8.7684	1.00000
Locatability	2	5.6207	1.1851	7.3643	0.00000***
Accessibility	2	5.7241	0.7972	11.6473	0.00000***
Meaning	1	5.3103	1.3121	5.3779	0.00000***
Assistance	2	4.9828	1.0647	4.9706	0.00002***
Ease of Use of Hardware and Software	2	5.2931	1.1916	5.8438	0.00000***
System Reliability	2	3.7241	0.7390	-2.0101	0.97293
Currency	2	4.2069	0.8075	1.3797	0.08929
Presentation	2	5.3966	1.0384	7.2428	0.00000***
Confusion	2	2.1897	1.0213	-9.5455	1.00000

For the overall TTF, we see that the p-value is below 0.0001 and therefore significant. This leads us to reject the hypothesis that the AR device for process support harms doing the work. However, when looking at the separate constructs in more details, we see that the p-value for *Compatibility*, *System Reliability*, *Currency* and *Confusion* is not significant with $\alpha = 0.05$. We can therefore not disregard the hypothesis for these constructs. In order to identify whether the individual ATI has an influence on the assessment of the support system, the tests were again determined with subsets for (a) ATI ≤ 3 and (b) ATI > 3. For participants with a low ATI, the hypothesis H_0 can still be rejected for the overall TTF ($t=33.0$, $p=0.0000$). However, only the constructs *The Right Level of Detail, Locatability, Accessibility* and *Assistance* are significant as well. The hypothesis cannot be significantly rejected for all other constructs. For subset (b), however, H_0 can be significantly rejected for the overall TTF ($t=5.6580$, $p=0.0000$) and eight constructs in total. The comparison thus shows that even for persons with below-average ATI, the technology is not regarded as a restriction on the execution of the assembly task. The comparison of the groups shows that the higher the technology affinity of the user, the better the fit between task and technology. From this it can be assumed that for the beneficial use of an AR process guidance, users with a low ATI should first be familiarized with the technology. This result is confirmed by the qualitative evaluation, too.

(4) Qualitative Evaluation

A downside of pre-structured tests is the often-missing opportunity to receive individual unstructured ideas and notes from the participants. For this purpose, the participants were asked three open questions after the experiment had been carried out.

Q1: Where do you see strengths and advantages of the Augmented Reality process support?

Q2: Where do you see weaknesses and disadvantages of the Augmented Reality process support?

Q3: Would you design aspects of the prototype differently? If yes, how?

For each question, all statements were thoroughly inspected, and the relevant information was marked. The marked phrases were then clustered according to the information they held. In the following step, all phrases of one cluster were summarized to one more general statement. The summaries were bundled into statements that dealt with the technology and the implementation of the software. A category “other” was also introduced for a few outliers. For Q1, the answers could not be separated into technology and implementation. The statements intertwined technology and implementation too well in order to make clear separations. Therefore, for Q1 the last step was left out. Notice that the percentages do not add up to 100% since participants were able to give multiple answers to each question. 26 out of 29 participants gave an answer to Q1. Out of all participants that answered, nine people (34.62%) state that the time saving aspect is a great advantage of the process support with AR, which corresponds to our finding that an AR process guidance does not disturb the assembly process. Two participants each stated more specifically that this process support system reduces training time and time for gathering the necessary information. Six participants (23.08%) see the visual support as an advantage. Similarly, five participants (19.23%) that answered the question appreciate that the information is directly in their visual field. Being able to work with both hands while receiving instructions from the AR device is seen as an advantage by five participants (19.23%). These responses show the relevance of AR devices for the support of bimanual activities. The intuitive operation was also named by five people (19.23%). Two participants explained it as experiencing an easy success. Overall, the answers to Q1 confirm the assumption that AR represents a potential for SSS.

Q2 was answered by 22 participants of 29. There were 34 remarks made about the technology and handling the technology, whereas only six criticizing comments were made about the implementation. One participant expressed their worries about data security which was categorized under the heading ‘other’. Concerning technology, eight participants (36.36%) criticized the unprecise and lagging tracking of the AR glasses. Five participants (22.73%) were bothered by blurry visuals. Some mentioned difficulty reading the projected text or blurriness when tilting the head. Similarly, four participants (9.09%) who answered the question were bothered by the restricted field of view. Four participants (18.18%) felt the AR glasses were too big and heavy and one participant pointed out difficulties for people wearing glasses. The same number of participants said the technology was generally not developed enough. Other concerns were insufficient processing power, missing haptic feedback, incomprehensibility of how to use the technology, cumbersome operation, questionable ergonomics. One participant mentioned the technology is not useful for people with short arms and another participant presumed that technology acceptance might be difficult. Overall, it can be seen that the Meta 2 used in the test does not yet meet the requirements of the participants with regard to interaction and presentation. The comparison with the evaluation of the HoloLens pretotype shows that the mentioned aspects (e.g. restricted FOV, blurry visuals, ergonomics) also occur with alternative devices. There was less criticism concerning the implementation of the software. Merely two participants criticized that the user may neglect independent thinking while working with the system. Other disadvantages were only mentioned once each. They include that the information was not detailed enough, hands are necessary for the operation of the software, glasses are not useful in all working conditions. One participant rejected the prototype in general. In contrast, another participant felt no disadvantages for this type of task.

20 out of 29 participants gave answers to question Q3. There were nine of the suggestions for improvement were aimed at improving the technology and the interaction with it. 18 suggestions were made for improving the implementation. Almost half of the remarks toward technology (4) asked for an improvement of the interaction with the buttons and display. One person suggested using speech recognition for navigating the system. Although this function is technically feasible, practical applications have shown that speech recognition is particularly difficult due to ambient noise at the service object. Two remarks were made toward improving the wearing comfort of the glasses. One participant mentioned improving the blurry visuals and another one would appreciate smaller and faster technology for the task. Most suggestions were aimed towards the improvement of the presentation of information. Five of the answers (25%) were suggestions towards making the visual presentation even clearer. Visually highlighting new information and building blocks or giving more perspectives (3) of the building blocks would improve the experience in the participants’ opinion. New forms of presenting information were suggested by three people (15%). Concrete suggestions were to use videos instead of pictures and text, providing information in a 3D model and present the information as a visual model. Participants also made suggestions for the presentation of text and pictures. Two participants (10%) suggested integrating the image and textual information or allowing a flexible placement of the tiles.

The evaluation has shown that the participants generally perceive AR process guidance as a helpful support system. The participants' comments basically confirm this. At this point, the technology in particular is criticized as insufficient in terms of presentation, interaction and ergonomics. While some functions such as speech recognition are already available for AR glasses but not necessarily practicable, others such as haptic feedback or a larger FOV cannot currently be implemented. In connection with the ATI of the participants, it can be seen that the higher the personal commitment for interaction with AR, the performance advantages increase. Despite the rather small number of participants, some findings can be identified for the development of future assistance systems and the further development of AR.

Table 2. Summary of the Findings from the Open Questions

Subject	Key Statement	Mentions[2]
Strengths and Advantages	Perceived time savings in service execution	9
	Extended visual support (e.g. images of the assembly)	6
	Information provision in the user's field of view	5
	Hands-free use and support of bimanual tasks	5
	Generally intuitive usability of the system	5
Weaknesses and Disadvantages	Insufficient precision of gesture tracking	8
	Blurry visuals	5
	Limited field of view	4
	Poor ergonomics and wearability	4
	General immaturity of the technology	4
Diverging Design Concepts	Usage of a mature technology with better interaction options	9
	Improved interaction mechanisms (e.g. with buttons)	4
	Improved clarity of information provision	5
	Extended use of media (i.e. videos or 3D-models instead of pictures)	3

Discussion

During our research, we were interested in ways to enhance SSS with AR technology. Based upon two pretotypes we relativized current design objectives and approached a two-stage prototype. We found that some technical shortcomings currently hinder the practical use of "true" augmented reality applications. Such is, amongst others, the overlapping of the information system and the actual workplace and the continuous need to remedy the information systems' position. Furthermore, our first pretotype revealed a torchlight effect, where users were searching for located displays of their information system. We argue that this phenomenon is an effect of insufficient hardware, namely the currently small FOV of AR devices. We thus decided to set up a HUD design that utilizes the already existing hardware and adds benefit to the working scenario of field service technicians. That is, compared to mobile support systems, the advantage of free hands during (bimanual) technical tasks and, compared to wearables such as Smart Glasses, an extensive display that allows for the use of multiple features simultaneously. Following the idea of "projectability", we tried to adopt design knowledge from other support systems for the AR-based application and, in turn, now provide conceptual modules that can be communicated for other devices. During the research, however, it turned out that this basic assumption is not enough to design an entire system. We found this effect especially for software features that rely on unique hardware propositions of AR glasses, for which, up to now, little scientific evidence or implementation guidance exists. A tangible example is given by the sensor feed in the bottom right corner of the HUD. To visualize real-time sensor data, we implemented a meter-design that holds up to 3 sensor values. Although this feature was well accepted during our field tests, we encountered practical use cases that would require an overview of at least 10 sensor values at once. Current visualization methods do not provide any guidance on how to deliver such complex information without implementing a classic "dashboard", which, then again, suffers from overlapping with the workplace. We therefore endorse Olshannikova et al.'s recognition of the need for all-new visualization approaches that utilize technological opportunities (Olshannikova et al. 2015). Other fruitful fields were identified in the design of unified interaction patterns, the fusion of real objects and virtual information and the opportunity to change visualization preferences along changing application scenarios. Although the field of AR-based support systems is advancing, we argue that further research is required to understand the adequate design of such and to deliver broadly applicable features. In addition,

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[2] In order to increase the reliability of our results, we limited our conclusion to statements that were mentioned by three or more distinct participants.

with the application of TTF we were able to show that AR Glasses increase the individual performance of the users during the execution of assembly tasks. In combination with the ATI, it is shown that especially for users with low technical affinity, training in the use of assistance systems might be advantageous, so that the use of resources for interaction with the technology does not inhibit the increased performance. This observation is confirmed by the comments of the participants, for whom interaction and presentation in particular have been criticized. In this context, for example, new concepts for interaction with AR support systems must be developed that go beyond gestures and speech input.

Current Limitations

Our study is limited in the utilization of AR glasses. Even though our prototype utilizes AR glasses to provide a new support system, the technical opportunities are not completely exhausted yet. Our evaluation indicates that the HUD we developed fits technical assembly tasks such as the assembly of a LEGO model. However, more research is necessary to shift to a new generation of support systems. For instance, larger and less homogeneous user groups with a smaller affinity for technology could be considered in order to reaffirm our results on a broader basis. Also, the quality of the results from LEGO-experiments is called into question, since they would not reproduce the complexity of real processes. Although our results contradict this, there is still the possibility that AR devices are unsuitable for practical use. Repeated LEGO experiments with varying process difficulty would be an opportunity to test the robustness of our results. Yet, the goal for future research should be field experiments on genuine TCS-processes, once the devices meet the regulatory requirements such as ATEX. Also, the study at hand does not consider the economic dimension of AR-technology although it is an important factor for its practical relevance. All AR setups we developed, implied costs of more than 2500€ in total. While this price on the one hand might originate from the novelty and scarcity of such devices, its value-added (especially in comparison to cheaper devices) is yet uncertain. Some studies yet provide insights on the "return of investment" of AR devices. Still, the authors add for consideration that intangible benefits of AR may justify the costs (Oesterreich and Teuteberg 2017). This uncertainty factor was recognized during the introduction of information systems also, for example, in the health sector (Dranove et al 2014). Such calculations base upon the assumption that AR glasses are conceived as a technical investment. However, Microsoft currently works on the interception of this cost-driven uncertainty with its pricing model for the upcoming HoloLens 2. Businesses will have the option to rent the device for 125$ per month. In doing so, the company approaches economic barriers with a new business model. Moreover, our study does not investigate the effect of so-called "onlookers ", i.e. persons who see the use of the technology, but do not use it themselves. Although they have an effect on the actual technology usage due to social influences (Sergeeva et al. 2017). The introduction of the Google Glass, neighboring type of technology, in 2012 showed that this effect can be present. Therefore, further research is needed in order to explore the acceptance of AR glasses in society.

Conclusion & Outlook

Our study strived to understand how technical tasks can be supported in the age of AR. We found multiple drawbacks that question the practical applicability of such technologies at date. Still, we were also able to implement a service support system that utilizes the AR glasses Meta 2 that achieved a positive TTF during an assembly experiment. While various steps to the successful design and implementation of an AR-based service support system remain undone, we argue that the general technology provides a fruitful direction for future research. The perspective that so far "only" known features of SSS have been implemented does not seem like a novel scientific finding. However, the insight that the technical potential for information processing and visualization is far from exhausted is promising and opens up exciting new research directions for the visions mentioned at the beginning. Through our prototype we have also learned that AR-based support systems offer new capacities not only for service support, but also for primarily data-driven industrial systems such as "cyber-physical systems". If the joint further development and, ultimately, the integration of both developments succeeds, the prospect of deeper cooperative provision of services by people and machines might be more than realistic.

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