Scalable and responsive information for industrial maintenance work – developing XR support on smart glasses for maintenance technicians

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ABSTRACT

This paper describes the process and results of bringing responsive and scalable technical documentation to smart glasses to support industrial maintenance. Development and testing was done in four development cycles to discover how maintenance information can be delivered to smart glasses to support maintenance technicians. Test case was elevator maintenance, and several user tests were performed in a real or realistic environment by real maintenance experts. The concept of using smart glasses to view technical information during a maintenance task was received very well by the test users. This study confirms that DITA XML is a good candidate for the creation of technical information content for smart glasses, but information design is needed to ensure the scalability and usability of the information.

CCS CONCEPTS

• **Information systems~Document topic models** • Information systems~Information systems applications • **Human-centered computing~Mixed / augmented reality**

KEYWORDS

XR, AR, smart glasses, technical documentation, XML, DITA, html5, Information 4.0, industrial maintenance, field work, informed reality, assisted reality

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1 Introduction

The on-going fourth industrial revolution, Industry 4.0, is changing the concept of industrial work. Traditional industrial work has been characterized by tacit knowledge and a challenge to find skillful workforce especially in developing markets [9]. Digitalization, Internet-of-Things (IoT), smart devices and technologies, and growing connectivity radically change many industrial work roles [11, 12].

Fernández del Amo et al explain how the maintenance industry is facing new challenges as the maintained equipment base grows more complicated, is more scattered globally and has a longer lifecycle. As a result of this, maintenance business is growing in importance, and more focus is paid to the ways of getting support to the maintenance technicians [4]. Many times the maintenance tasks tend to be complicated and varied, and technicians need hundreds of instructions to perform the tasks in a safe and efficient manner. **Traditionally, technical information has been delivered on paper or as electronic prints, as embedded online helps or, more recently, through online portals or web services.** Online documentation has established benefits over paper-based documents: newest revisions are always available and can be accessed with smart phones and other handheld devices.

However, **industrial maintenance is often hands-busy type of work**. Users may be holding equipment parts and/or tools in their hands and, at the same time, need to check some information or get guidance on the task they are performing. Furthermore, the technician must wear personal protective equipment such as cut-resistive gloves. The maintenance assignment often contains tasks where users' hands get dirty and greasy. This setup makes user interaction with touchscreen-based smart phones difficult. Hence, we turn to XR, DITA and Information 4.0 to solve this challenge.

1.1 Key concepts

The following concepts are closely related to this study. As this study is interdisciplinary by nature, the key concepts are also related to different fields.
X Reality (XR) stands for extended reality, which covers all forms combining real and virtual elements, e.g. Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR). The XR field is expanding rapidly and XR technologies and XR devices are developing fast, and, therefore, the naming conventions are not fixed. Both augmented and mixed reality terms are used for systems representing information on smart glasses, even when the information is not spatially aligned with the real environment. When presenting information on screen without aligning it with the environment, the term informed or assisted reality is also used.

DITA (Darwin Information Typing Architecture) is an XML model and the industry standard for structured, modular writing. To facilitate the creation and delivery of information, DITA specifies three main topic types: concept, task, and reference. A concept explains what something is like or how it works, a task describes a procedure, and a reference is for presenting reference material [4]. Topics are stored in a repository and can be reused across different publications.

Information 4.0 is technical communication's answer to Industry 4.0, and makes it possible to implement, maintain, leverage and understand Industry 4.0 systems. In Information 4.0 the content is smart, and it can be assembled, transformed and rendered dynamically and contextually according to users' needs. [8]

1.2 Related work

Kaasinen et al presented the Mobile Service Technician 4.0 concept, where new practices and tools are introduced to support maintenance technicians for preparing for a maintenance visit, identifying equipment faults, performing maintenance tasks, receiving remote support from colleagues and reporting on completed tasks. These solutions utilize the industrial internet and new technologies to enhance maintenance technicians' work performance and satisfaction. [9] In recent years, technical advances have made it possible that the devices outlined in the Mobile Service Technician 4.0. concept, (e.g. smart glasses) have entered the consumer market [3]. As these devices are now more powerful and reasonably priced, they have great potential to be used on a wider scale in industrial maintenance to deliver technical information to support technician's tasks.

Industrial companies have presented several use cases where **maintenance instructions are displayed on smart glasses** [12, 15]. The concept has been validated: users are able to perform faster with a lower error rate [2, 7, 21], and even user satisfaction and feeling competent is increased [10, 23]. However, the smart glass market is full of different types of smart glasses: monocular, binocular, see-through, video-see-through, holographic, virtual retinal displays, and so forth. According to an extensive review on AR in industrial maintenance, development is still needed on smart glass technology even though the advantages for industrial maintenance have been proven. The high fragmentation among hardware, software and solutions also makes it difficult for industrial companies to select and develop AR systems. The same review also notes that authoring solutions and content management tools need to be developed for AR. [15]

1.3 Aim of this research

Due to the fragmentation and constant evolution of AR hardware markets, our focus was to **study how technical information best accommodates different devices**. Rather than testing certain devices and their features as such, we selected three different types of smart glasses that are commonly used in industrial AR applications. Additionally, as the needs and circumstances of the users vary, the information delivered to technicians must be in a format that works in different devices with different screen sizes, from personal computers to tablets, mobile phones and also smart glasses. This way, the same information can be utilized in all the devices. DITA XML is the industry standard for technical writing, and, therefore, we see it as a good candidate as the information authoring format for XR use. However, two challenges can be identified: 1. How to design and deliver that information so that it also supports hands-busy type of work in addition to more traditional reading modes? 2. How to create the content so that it can easily be updated and revised in a production setting?

To maintain a competitive edge in the highly competitive maintenance business, maintenance technicians need to perform their tasks efficiently. Therefore, in an industrial maintenance setting, **applications need to be intuitive and easy to adopt**. Companies do not want to invest too much time and money for the learning curve, and employees may not be willing to invest their time in learning if the application seems complicated. Therefore, the usability of the smart glass applications and the information delivered to these devices are in the focus of our research.

Many of the existing AR applications have been designed in such a way that the content has to be specifically tailored or manually authored for each use case and task [15]. However, we are aiming one step further and are researching ways to **bring instructions from the company's information system automatically available for the user according to Information 4.0 principles**.

2 Experiments

The aim of this research is to develop a working concept for smart maintenance aid for elevator maintenance, i.e. bring technical instructions to smart glasses. As no off-the-self solutions exist, we utilized the lean start-up method to test the usability of the concept iteratively and to develop it further. In the lean start-up method the core component is the build-measure-learn feedback loop. The phases of the loop are: idea (hypothesis), build (proof of concept), measure (evaluations), and learn (adjust). These quick learning cycles are repeated as many times as necessary. [17]

Our study consisted of four consecutive development cycles, which we call experiments. Each experiment consisted of one or more build-measure-learn loops. In the first experiment the proof-of-concept applications were implemented and tested on Vuzix 100 and Microsoft HoloLens. In the rest of the experiments the proof-of-concept applications were implemented and tested on ODG R-7 and HoloLens. An overview of experiments is presented in Table 1. Our main interest was the presenting and reading of content, and little effort was put on user interface design. All application user interfaces were implemented in English.

Table 1. Overview of the experiments

	Exp. 1	**Exp. 2**	**Exp. 3**	**Exp. 4**
Devices	Vuzix M100 HoloLens	HoloLens ODG R7	HoloLens ODG R-7	ODG R-7
User test task	install alarm phone	replace drive component	install alarm phone	replace drive component
Instruction location in evaluations	locally saved	web portal	web portal	web portal
Application	default web browser	separate viewer application	separate viewer application	separate viewer application
Number of test users	12	9	10	7

To develop and evaluate the concept, we selected conventional qualitative and participatory methods, which are known to reveal the behavior and perception of users. The selected methods were focus groups, focus interviews, think aloud, user observation and questionnaires.

2.1 Smart glasses used in experiments

Three different types of smart glasses were used in field experiments.

Figure 1. The devices used in field experiments from left to right: Vuzix M100, ODG R-7, and HoloLens.

Vuzix M100 are monocular video-see-through smart glasses with a small display on the side of the user's view (Figure 1). They are equipped with a speaker and a camera. There are control buttons for user interface, and the device supports voice control.

ODG R-7 are binocular video-see-through glasses (Figure 1). With ODG R-7, the content is tied to the display, i.e. the content is always visible regardless of head movements. This means that the content moves with the display when user turns their head.

Microsoft HoloLens are binocular-holographic glasses (Figure 1). With HoloLens the user had two possibilities for interaction with the application UI: speech and gestures. The available gestures were HoloLens standard features (pinch and bloom). Speech commands consisted of a predefined vocabulary such as "next", "previous", and "scroll down". Spatially aware devices, such as Microsoft HoloLens, allow the system to present information on spatially arranged windows, which can be moved around in the desired physical position. This means that the windows do not move with the head movements when user turns their head.

2.2 Experiment 1

Use case: maintenance field worker performing hands-busy type of task, getting instructions on head mounted display with no internet connection
User test task: maintenance task for installing alarm phone components
Devices: Vuzix M100 and HoloLens

A simple QR code reader application was developed for both devices. With the applications the user was able to scan a QR code (Figure 2) and the correct instruction was opened automatically in the browser.

Figure 2. User scanning the QR-code to start the instruction (HoloLens on the left, and Vuzix on the right).

After Experiment 1 was completed, Vuzix M100 was updated to Vuzix M300, and we no longer have the M100 available. Figure 3 shows an instruction retrieved from the web portal using the default browser on Vuzix M300 glasses. It might appear slightly different from the browser view of M100 that was used in Experiment 1.

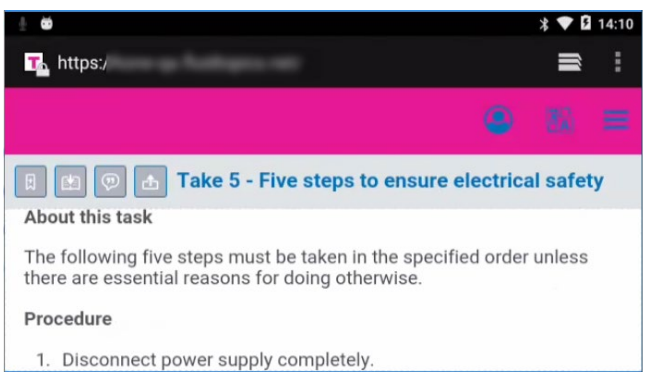

Figure 3. Instructions retrieved from web portal with default browser on Vuzix glasses.

The user tests were conducted at a real equipment in Hyvinkää, Finland. Twelve users evaluated the proof-of-concept applications without performing actual maintenance tasks. Four of them were female and eight male. They had expertise in industrial maintenance, technical documentation, X reality, documentation IT architecture, maintenance analytics and maintenance applications. They had little or no experience of augmented reality and smart glasses, except for one user. All of them were native Finnish speakers. After testing, the users answered a questionnaire, where they were also able to give free-form comments. All users were also verbally asked for free comments after the test, and the comments were written down.

During these evaluations the users had the equipment under maintenance visible and could compare the maintenance instructions against the real components, but they did not physically perform the maintenance task. These evaluations lasted for approximately 15-30 minutes. Figure 4 shows one of these short evaluations in action with Vuzix 100 glasses.

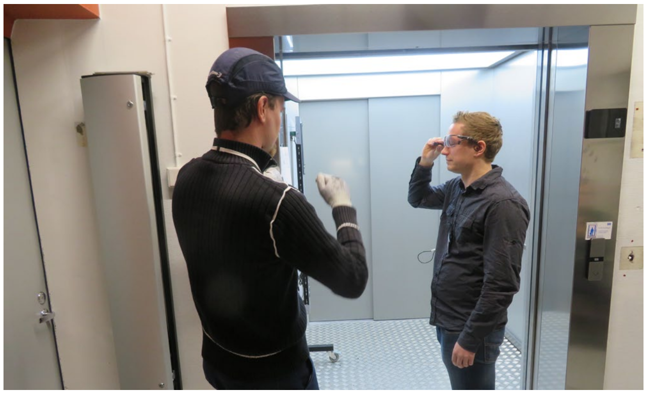

Figure 4. Short evaluation with Vuzix M100 ongoing.

One test user (maintenance expert) performed the complete maintenance task using the instructions on smart glasses. The completion of the first part of the task was done with Vuzix and took approximately 1.5 hours. Second part was done with HoloLens and took approximately 2 hours. With this user, we used user observation and the think aloud method. The user was instructed to comment on everything while working, and all the feedback and comments were written down during the test. The user test was also video recorded. Three persons observed the user test. Figure 5 shows the test setup. After the tests, the user answered the same questionnaire as other users, and he was also asked to give free-form comments.

Vuzix glasses were attached to a hardhat or safety glasses. HoloLens was integrated in a hardhat.

The original instructions for the task existed in FrameMaker format and had previously been published as PDF files. The instructions were in English. They were modularized and rewritten into DITA 1.2 XML format and stored in the repository. The modularized instructions contained 29 topics (18 tasks, 5 concepts, 5 references). The topics contained procedural and descriptive information and no tabular data. A total of 16 animations (.mp4) were linked to topics (2 in concepts, 1 one reference and 13 in tasks). Due to XML repository system limitations, animations were not stored in the repository. The XML content was exported from the repository, and references to animations were added to the XML files in a local hard drive. The files were then uploaded to the devices. In the process, references to animations were updated to follow the correct path in the device.

Figure 5. User tests in progress (Experiment 1)

In addition to the locally stored test material, the users were able to log into the web portal and search and open any instructions. These instructions were not formally recorded or analyzed.

2.3 Experiment 2

Use case: maintenance field worker performing hands-busy type of task, getting instructions on head mounted display from a web portal
User test task: maintenance task for replacing drive component
Devices: HoloLens and ODG R7

The learnings from Experiment 1 were taken into account when developing the viewer applications for Experiment 2. Most importantly, the amount of text visible in the application was optimized by changing the UI elements. Vuzix was replaced with ODG R7 as Experiment 1 showed that displaying this much information on the small screen of Vuzix was inconvenient for the users.

Figure 6 shows the HoloLens UI of demo application used in Experiment 2. In the middle we have *document window*, on the left *table of contents window*, and on the right *bookmark window*. When the user clicks the video in the document window, *video window* opens above the document window. *The information symbol* on top right corner of document window opens an *information window* above the table of contents window. The font size can be changed from the application settings before opening the document. There is no standard font size in augmented reality, as the relative size of the text also depends on how far from the user the text is placed.

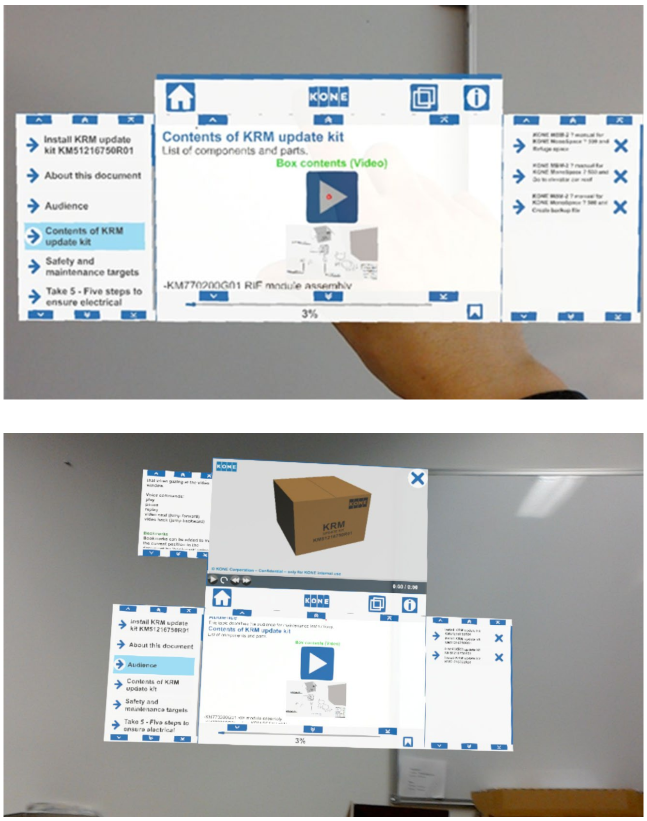

Figure 6. HoloLens UI, Experiment 2. Above application start view, below all windows visible

In Experiment 2, users typically placed the application windows in HoloLens in 1-3 meter distance from themselves. Font size was selected so that the users were able to read the text well and as much content as possible was visible. The user placed the UI on the side, e.g. on the elevator shaft wall, so that it did not cover the working area, yet was readily available when needed.

Figure 7 shows the application user interface used in Experiment 2. In ODG the application was divided into tabs. One tab had no content and the display was dark, i.e. the user was able to see the real world well through the display with the glasses on. When the content was displayed on ODG, the instructions for replacing drive component occupied a total of 33 pages.

The applications were developed in cycles of 1-2 weeks during a two-month period. Nine people were involved in testing the applications during the development phase. Three of these users were female and six males. All of them were native Finnish speakers. They had expertise in industrial maintenance, technical documentation, IT solution architecture and X reality. Not all users were involved in testing each cycle. Most of them were also involved in Experiment 1, so they were already familiar with the concept.

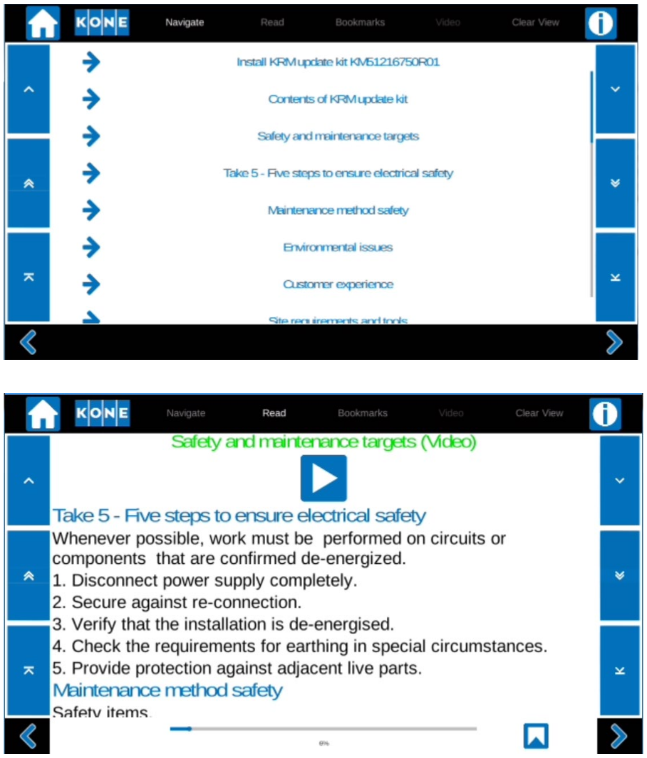

Figure 7. Screenshots of application user interfaces at ODG R-7. Above Navigate tab (Table of Contents), below Read tab (content).

The users tested the application for approximately 15-60 minutes in an office environment without performing the actual maintenance task. During the tests, users were observed and the think aloud method was used. Their feedback was verbally collected after the test, and notes were taken. The users tested the application mostly with the same content as in Experiment 1, but the users were able to select any of existing instructions from the web portal and occasionally other content was also used to get as much user feedback as possible.

A synthesis of comments was always used for the next software development cycle. The feedback focused on technical issues, UI, and the features of the application. In addition, users also commented use scenarios and possible use cases and safety issues.

After the proof-of-concept applications were ready, thorough user tests were conducted at an elevator simulator in Hyvinkää, Finland. One maintenance expert performed the whole maintenance task using both devices for half of the task. With this user we used user observation and the think aloud method to evaluate the user test. During the user tests, HoloLens was integrated in hardhats and ODG R7 was used with a hardhat.
The original component replacement instructions had been modularized into DITA 1.2 XML format and stored in the repository. The instructions were in English. The structured XML content was processed into HTML through DITA Open Toolkit and published in a web portal. A network connection was needed for this experiment. The instructions were accessed in the portal by navigating to the front page of the portal. Exact document name was needed to be able to fetch the correct instructions for the task. The modularized instructions contained 52 topics (24 tasks, 5 concepts, 23 references). No animations were included in the instructions. Tabular data was included in 12 topics (11 references, 1 task). The application was also able to scan a QR-code and automatically retrieve the desired instructions.

2.4 Experiment 3

Use case: maintenance field worker performing hands-busy type of task, getting instructions on head mounted display in multiple languages
User test task: maintenance task for installing alarm phone components
Devices: HoloLens and ODG R-7

The viewer applications of Experiment 2 were further developed in Experiment 3. The user interface and the functionalities of the application were improved based on learnings from Experiment 2. In addition, some minor bug fixes were made to the software. For example, horizontally split text lines were fixed and totally visible. Navigation inside the application was improved.

Ten different people were involved in testing in this experiment. Seven of them had maintenance-related roles (maintenance technicians, maintenance troubleshooters and maintenance managers), two maintenance training-related roles and one competence development related role. Nine of the testers were male and one female. All participants were native German speaking. User tests were carried out in class room environment in Hannover, Germany, and user feedback was collected in group discussion after testing. User observation was also used during the testing. English instructions from Experiment 1 were saved locally in the devices. Additionally, test users were able to retrieve German content from the web portal. Each user was able to select the instructions they wanted to test, and the used instructions were not formally recorded or analyzed.

2.5 Experiment 4

Use case: maintenance field worker performing hands-busy type of task, getting localized instructions on head mounted display
User test task: Real maintenance task for replacing drive component using guidance
Device: ODG R-7

For this experiment, no changes were made to the application, but the content was adapted to better suit smart glasses use based on the learnings from previous experiments. One of the major learnings was that wide tables do not work well when viewed with smart glasses. The original instructions for the maintenance task were in PDF format. The original instructions were heavily based on tabular data and, during the modularization process into DITA 1.2 XML format, the information was rewritten to remove some of the wider tables. The topics were stored in the repository. The modularized instructions contained 58 topics (27 tasks, 22 concepts, 9 references). No animations were included in the instructions. Even after the modularization process, 18 topics (8 concepts, 8 tasks, 2 references) contained tabular data.

User evaluations were carried out in training facilities with an elevator simulator. The environment was identical to a real situation; the task was performed in an identical way as it would be done in a real situation.

The users were all German speaking and all content used in this field experiment was in German. In the first part, the application and instructions were tested by seven people in maintenance-related roles without physically performing the maintenance task. In the second part, maintenance experts used the system for a real complicated maintenance task (replacing a drive component). One user performed the actual maintenance task and other maintenance experts followed the work. One extra pair of smart glasses was available, so one maintenance expert was able to follow the instructions on glasses while the other performed the maintenance task (Figure 8).

Figure 8. A maintenance expert is performing maintenance task using ODG R-7. Another one is following the work and instructions on ODG R-7.

User observation and the think aloud method were used in both parts of the user evaluation. After the second part, the maintenance experts gave their feedback in a group discussion, and notes were taken. When the content was displayed on ODG, the instructions occupied a total of 126 pages.

Test was combined with an AR remote assistance user test. At the end of the maintenance task, another application was used to get remote assistance for parameter settings. However, description of that part of the experiment is out of scope for this publication.

3 Results

The user tests were carried out by a diverse team of experts in field maintenance, industrial XR, technical documentation, and extended team of IT backend systems and software development. Three different smart glasses were used (Vuzix M100, HoloLens, and ODG R7) in four different experiments. Proof-of-concept applications were tested by a total of 22 different people as some users were involved in several experiments. Three user tests were carried out in a real or realistic environment by real maintenance experts. Figure 9 shows maintenance expert working with HoloLens in experiment 1.

Figure 9. Maintenance worker using smart glasses (Experiment 1).

General attitude among the test groups was positive towards using technical information in smart glasses. Many users commented that they would prefer XR-based guidance to traditional paper manuals, provided that the information is usable, the application intuitive to use, and devices technically advanced enough. They showed general enthusiasm to utilizing XR-based guidance, especially to check a short task or a technical detail related to it. Some users still preferred to use their mobile phone to read technical information, and, to overcome the hands-busy issue, to “use a piece of gum to stick it somewhere and watch a video”.

3.1 Devices and user interfaces

Test users gave much feedback regarding devices. As a general remark we can conclude that **the hardware still needs to be improved before it really is applicable for this kind of industrial use**. A see-through display is in some occasions too opaque, and the user cannot see the real environment. On the other hand, sometimes it is difficult to see the display in bright light. With a small monocular display, many users need to close the other eye to see the display, and changing the focus between the working environment and the display is unergonomic and inconvenient. Very small displays such as Vuzix are not well-suited for reading a large amount of information, and it seems that these kinds of devices are suitable for checklist type of information. Battery life is also an issue as an external power source complicates smart glass use: The cable connected to e.g. power bank cannot hang freely, but must be under clothes for safety reasons. Large, heavy devices such as HoloLens are not suitable for field use because of the weight and the fact that the device blocks the user’s field of view.

User experience and user interface design for smart glasses is needed. In the first experiment, some of the instructions were retrieved directly from the web portal and viewed with the device default browser. The view was cluttered with navigation-related toolbars and very little room was left for the actual instruction texts (see Figure 3). Users commented that it was difficult to understand and follow the instructions as a very small amount of text was visible at one time. Therefore, for further experiments the viewer applications were developed to maximize the amount of text visible in the smart glass view.

Users also gave feedback regarding the viewer application UX and UI design (Experiments 2-4). For example, with HoloLens they would have liked to easily position windows and move them in the desired position. Some users also desired the possibility to “wipe application windows away” and easily “recall them back to the view”. Users also commented on application features. Especially in Experiment 2, the users were asked to give feedback on technical details of the application and to test the functionality.

Non-native English speakers had problems using voice commands in English. In addition to unclear pronunciation, the commands were also not recognized due to background noise and echo. There was some lag with sound commands, which frustrated users. Many users preferred gestures to voice, but commented that this is due to voice commands not working as they expected. Users also commented that the UI user interface should support hands-busy type of actions, and voice commands, if working properly, would support this.

3.2 Technical information

As the content was not designed to be displayed on a small screen, most topics were too long and step lists were difficult to follow due to the large number of steps. Topic length resulted in content not fitting on the screen and frequent scrolling was required from users in Experiment 1. Scrolling is necessary when the information to be displayed does not fit on the screen and overflows from immediate view. Table 2 defines the number of words and task topics for the content that was analyzed in these experiments. Even though the average number of steps is reasonable, the longest step list contained 49 steps, which was extremely difficult to follow. Admittedly, this step list would be difficult to follow even on paper.

Table 2. Average number of words in topics and number of steps in task topics. Same content was used in Experiments 1 and 3.

Experiment	Average number of words in topics	Average number of steps in task topics
1	65,3	6,7
2	134,4	7,3
3	65,3	6,7
4	158,5	13,7

In the first experiments, users had problems in understanding where they were within the instructions (position inside the current document and location in the documentation hierarchy). Users also noted a need for bookmarking. These problems were taken into account in application development in Experiments 2 and 3. To avoid the scrolling problem, users could browse by pages and had the possibility to go by chapters or move to next chapter or section title. A simplified bookmarking functionality was also built into the application. From the menu icon, the user could always return back to the main menu.

The test content included a large number of tables. Tabular data fit poorly on small screens and required horizontal scrolling. In many cases, test users just scrolled past the tables without reading them, looking for tasks and step lists.

In the first experiment, videos and animations were not clearly distinguishable as something that can be started. They were indicated with a grey box only, and users did not know that they could start video playback. This was improved in Experiment 2 by adding a clear play icon to playable objects. When users knew how to start an animation, stopping it proved problematic. The users had problems in understanding where they were within the video, if the video was going to end soon, or if there was still a long part to be seen. As a solution, a progress bar was added.

Both English and German content was used in the experiments, and both languages worked in a similar manner from the delivery point of view.

4 Discussion

General attitude towards using technical information in smart glasses was positive in our user evaluations. However, to utilize smart glasses in industrial maintenance, further development is needed for devices, their user interfaces, and in the design of technical information.

4.1 Devices

The best way of utilizing smart glasses in industry depends on the field of industry and the type of operations. If we compare smart glass use cases on assembly line and in equipment maintenance, there is one fundamental difference. On an assembly line, the location is fixed and the same tasks are performed frequently, whereas in equipment maintenance, the worker is constantly moving from one equipment to another in geographically different locations, and the tasks to be performed vary considerably. Therefore, the smart glass concepts are different. On an assembly line one can have a dedicated application on glasses. The glasses can be in kiosk mode where only that specific application is running. When the assemblers enter the specific spot on the assembly line, they grab the glasses and follows instruction on glasses. When they complete the task, they put the glasses back on the charging station, and this way the glasses are always ready for the next user. As the worker is moving from one location to another in equipment maintenance, the charging of the devices has to be considered. Probably an external battery, i.e. power bank, is needed to ensure that the device is enabled during the whole work shift. As the need for information is not always predictable, the device should always be ready for use at once when the need arises. Current battery life and UIs do not support this.

With many maintenance tasks, the technician’s both hands are holding tools and parts while they are performing the task, and in this situation hand gestures cannot be used. On the other hand, operating the device UI, launching the application, and selecting menu items can be performed with gestures. **As the use situations vary and users have individual preferences, multi-modal user interface is advisable.** Prilla et al compared handheld touch device and head gestures in hands-busy type of health care context. They show that also head gestures support this kind of use scenario. [16] Therefore, further research of complimentary user interaction methods would be beneficial.
One point worth mentioning is that the maintenance worker needs guidance or technical information only every now and then and not constantly. Therefore, **the user interface should be intuitive and easy to remember to avoid the technology cost overrunning the gains**. Businesswise one additional challenge is the cost compared to use hours: If the smart glasses are used only seldom, is the cost too high? The cost becomes more acceptable if the smart glasses are used for several purposes. One additional use case is remote assistance, and the glasses could also act as a mirror screen for the smart phone. Another possible approach would be to have the smart phone as the processing unit and have the wearable display connected to it.

Tasks vary in equipment maintenance, and the technician does not perform the same task repeatedly. Therefore, it is essential that the smart glass application provides instructions for several different tasks, and the technician can then easily select the appropriate instructions.

Developing and testing augmented reality in a real context and environment is challenging in many aspects. Perhaps two dominant questions are related to **occupational safety and costs**. You cannot compromise safety and, therefore, the testing should also be safe. Testing several devices and creating applications for all of them is expensive. One solution to overcome the problems is to **simulate augmented reality and smart glass use in virtual reality** as suggested by Burova et al. [5].

On very small displays such as Vuzix **it is important to squeeze the information in as compact a format as possible**. The application of the minimalist approach and minimalism heuristics [22] offers one way to compress the instructions, and controlled languages such as Simplified Technical English [1] generally restrict the length of sentences. Further research is needed to validate these approaches with the use of smart glasses.

IoT sensor data is used more and more in industrial maintenance to implement preventive and predictive maintenance. The core of this approach is to carry out the necessary maintenance actions only, and perform them at the optimal time. This means that the combination of tasks performed at each maintenance visit differ from each other. In order to serve the maintenance technician, the instructions need to be dynamically composed based on this combination. Contextually relevant dynamic information content is composed of relevant information topics and, and through that, tailored for each maintenance visit and task.

4.2 Technical information

Armfield et al note that “professional and technical communicators, with knowledge of visual design, minimalism, structured authoring, and user experience, are crucial for the development of content required for AR” [3]. As the mixed reality technologies develop further, **more focus needs to be put on designing the content so that it fits the users’ needs instead of automatically converting old existing content**. User-centered design is the main principle of technical communication in the more traditional delivery channels [11, 18], and this principle also holds true when the information is delivered through XR devices.

To move the content from traditional delivery channels to XR, many researchers recommend that textual elements are reduced and images and icons are used instead [20]. Some researchers suggest that there might not be a need for text at all [9]. Researchers also recommend the use of authoring templates or frameworks to create standardized content for AR applications [6, 13, 14]. While the automated process from text or 3D models to images through templates may seem like an efficient and cost-effective mode of operation, there is not much evidence that images alone carry over all the needed information. On the contrary, it has been established that language facilitates a more explicit meaning of what is being communicated than images, and leaves less room for interpretations [5]. In industrial maintenance with a zero accident tolerance policy, we cannot leave the correctness of the interpretation to the user but **ensure unambiguousness with the correct ratio of text and accompanying images**. This issue needs to be further investigated to establish guidelines.

Content and style is separated in DITA, and, therefore, information can be delivered in a scalable and responsive format, supporting devices of different sizes. However, even when content is modularized, **traditional topics tend to be too long and do not work as such in AR applications**. As already seen in the scope of our experiments, scrolling is not desirable when viewing content on smart glasses. Sanchez and Wiley have investigated the effects of scrolling on learning and concluded that especially with individuals with lower working memory capacity, scrolling affects learning negatively [19]. Studies on scrolling have focused on PCs and smart phones, but in the test setup with smart glasses, the negatives effects of scrolling were amplified for the following reasons: 1. The screen size is considerably smaller than with a PC and most handheld devices, resulting in frequent overflow of content. 2. When the used devices are controlled with voice commands, it is clear that speech recognition is not yet sophisticated enough. Many test users had problems with the commands “scroll down”, “scroll up”, resulting in content scrolling too fast past the desired point and the user having to scroll the other way again. Constant scrolling back and forth caused frustration and hindered task completion. Further research is needed to establish guidelines for the ideal length of topics and step lists and ways to overcome the scrolling issues.

As DITA topics have a standardized structure, they can be utilized in the creation of standardized content for AR. Furthermore, as information typing is also a feature of DITA, each topic type already has a specific primary objective which allows for **certain kind of information to be targeted for delivery to AR applications**. For example, it is possible to deliver only task-related information to the AR application and leave the rest of the information to other delivery channels. In this study we established that reference information, in many cases in form of tables, fits poorly on smaller screens. However, the role of reference information on smart glasses needs to be studied further. In our field experiments, we were able to use both English and German and can conclude that this is a language-independent system. Therefore, if localization is done in XML, we can use any target language to easily deliver localized content to smart glasses.

When the number of possible tasks is increased to accommodate for the maintenance of the whole equipment or equipment base, it is not viable to manually design and hardcode each set of instructions for smart glass use. Therefore, **it is of crucial importance that the instructions are delivered from a documentation repository, and the content adaptation for smart glasses is performed already in the backend system**. Consequentially, no design or configuration is needed in the smart glass application. Even though the content used in our experiments was converted from other formats (FrameMaker or PDF) to XML, the current authoring format and the industry standard is DITA XML and no conversions are needed. However, as evidenced by our experiments, the format alone does not mean that the content is suitable for smart glasses as such.

5 Conclusions

Even though smart glass devices and applications can display the instructions in more visual and interactive ways, it does not remove the need for textual information in the instructions. Instead, **the message is conveyed most reliably with a mixture of text, graphics and videos or animations**. Moreover, when the content is designed for mobile use with small displays, it does not only support use in smart glasses but also works in a variety of different devices including smart phones, smart watches or other wearable displays.

We have established that **the concept of using smart glasses to deliver maintenance instructions to technicians is well-received** and a validated concept. In a production setting, it is important that existing technical information can be utilized, but **information design and compression and shortening of topics** is needed for usability reasons. Additionally, **further development is needed on devices, user experience, and user interface design**. To advance the use of XR technologies in industrial maintenance and other similar hands-busy type of professional use, there is a need **to develop an explicit list of UI and usability heuristics for XR context.**

Industry 4.0 and new technologies are offering new and exciting ways to support the work of maintenance technicians. Smart maintenance support will help the maintenance technicians to perform their tasks more efficiently and in a safer way. Most importantly, **proper information design and well-designed information delivery support the maintenance technicians to perform their tasks by providing context-sensitive information in an easily understandable format**.

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