Introducing Augmented Reality-Ready Head-Worn Displays to Support Workers on the Shop Floor of a Car Production Line

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***Abstract*—In this paper, we present an approach to directly instruct workers in the quality check division of a car production line. We simulated the complete manual functional check of a car to test the possibilities of using one selected binocular optical See-Through Head-Worn Display. Furthermore, we chose one subtask to be Augmented Reality-supported to get an impression of the capabilities of this technology in this application area. Also, we tested a finger-worn input-device, representing the type of "close to the body"-input-devices. For the whole implementation we applied the Human Centred Design Approach as described in ISO 9241 - 210. We evaluated the application with four workers from the selected division. Even though we could not implement all requirements exactly as they were requested, the participants responded positively to the selected Head-Worn Display, the finger-worn input modality and the augmentation we provide.**

Keywords–Augmented Reality; Interaction Device; Head-Worn Display; Shop Floor; Production Line.

I. Introduction

Modern Head-Worn Displays (HWDs) have the power to show information directly on site where they are needed while keeping both hands free to execute tasks. Also, due to the rapid development of miniaturising high performance hardware, they have the capability to display sophisticated content when it is needed. Since the late 1980s, visually extending the real environment with virtual content is part of scientific research and also made its way into popular culture. The so-called Augmented Reality (AR) was exemplified in many areas like medicine, eLearning or user navigation. Another promising field of application is the support of workers. From the very beginning, maintenance, repair and assembly were strategically identified as key application fields of AR [1]. It also can be split up into remote support and automatic on-site support. While the first is establishing contact to an expert of the field and therefore is highly flexible, the latter is based on analysing and modelling work-flows to display supportive instructions whenever they are needed.

This automatic on-site support is less flexible as it only can access formalised knowledge, usually generated for each use case, but it especially is able to support people in work areas with low flexibility and high production rate. One prominent example of such a work area is the conveyor belt of car manufacturers, where cars are assembled and quality checks are performed. In this area we conducted our study on how AR can support workers performing quality checks after the assembly of vehicles. While AR was difficult to established with the available hard- and software, we could identify that overcoming direct interaction with the HWD (i.e., using the buttons on the HWD itself, e.g., on the glasses temple) is crucial for the success of these devices.

The work presented in this paper is structured as follows: In Section II, we present related work. In Section III, we describe the results of the analysis of the current work flow. In Section IV, we describe the implementation of the application, including the interviews conducted to validate and/or make design decisions. The results of the final evaluation are presented in Section V. In Section VI, our findings are summarised and conclusions are drawn.

II. State of the Art

Today, many AR systems are using HWDs, hand-held computers or smart phones, i.e., small devices including at least one camera and one kind of graphical display. In the context of worker support where hand-free is critical, however, HWDs are significantly advantageous. In many aspects, HWDs are similar to Head-Mounted Displays (HMDs). According to [2] the main difference is that HWDs can be put on like a normal pair of glasses while HMDs usually require the user or an assisting person to adjust the position of the display, for example via adjusting screws on the frame or head straps. Typically, HWDs function with the support from either a mobile or a wearable computer. Since the first device in 1968 [3], HMDs have gone through tremendous changes for maturation of resolution, refresh rate, Field of View (FoV), etc. The new generation of HMDs, the HWDs, are lightweight and almost like a normal pair of glasses, instead of their bulky predecessors. All of these devices come along with their own powerful computing unit, while older devices often need to be attached to a desktop-PC to be able to offer AR-features. This development is mainly based on the fast progress in the miniaturisation of high performance electronics. With the ability to function as wearable computers, modern HWDs broaden the field of application for AR, due their higher level of mobility.

Recently, car manufacturers have started supporting employees with smart glasses instead of mobile devices. For example, smart glasses now are a part of standard equipment's at Volkswagen in Wolfsburg, Germany [4]. Opel also has a virtual assistant called "Smart Helper" [5]. The importance of AR in the production environment was emphasised through the

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work of Meixner et al. [6] in which AR is portrayed as one of the most important technologies of user interaction evolution in future industrial environments. The AR-support offers instructions and guidelines at different levels to help users to achieve their tasks while minimising errors and increasing safety [1]. Moreover, AR also has been applied in providing remote expert support and environment interaction [7]. Rauh et al. use HWD to support workers in the quality check division of a German car manufacturer [8] displaying instructions and documentation in the Field of View rather than paper-based. The aim here was to enable any worker, independent of his/her expertise in this task to increase performance. The work showed that in general HWD have the capacity to optimise workers' performance in the selected application area. Loch et al. could show that compared to video assistance a worker supported in AR performs significantly better in terms of error rates in manual work tasks [9]. This is an important finding considering that the flexibility of a human worker is needed to be able to offer customised production services for customers.

With the specific intention of supporting workers in industrial production environments, several projects proposed designs and frameworks where AR is employed to fulfil these visions. Both projects MOON by AIRBUS Military [10] and the AR Framework for Maintenance Tasks by Re et al. [11] share similar goals of delivering 3D assembly work instructions via smart phones and tablets. Even still struggling with tracking technology and needing further development, these works have shown promising results of AR usage over productivity. In 2002, Tschirner et al. presented a welding helmet equipped with video See-Through technology to augment the welders field of view with multiple information, based on his/her current task [12]. Besides a feasibility study to assist workers while fix broke weft yarns of a industrial waving machine Kerpen et al. identified effects of the current trend of digitisation in factory environment on the worker and the portfolio of his/her tasks [13]. Among others, they predict a easier and faster access to machine related data, a higher flexibility of the work organisation and the need of increased IT-skills.

Wijesooriya et al. make use out of the increased accessibility in a prototype using AR to visualise machine status data on site [14]. Maly et al. developed an AR system for maintenance and collaboration with a robot [15]. During the ARVIKA project [16], head worn AR-based solutions for industrial applications have been developed. The project had brought AR into attention of many players across multiple areas. Related to the ambition of this work, Eissele et al. describe a system which successfully combines "multiple reality stages" (i.e., AR, Mixed Reality, Augmented Virtuality and/or Virtual Reality) to decrease assembly-time and error-rate [17]. Potentially related to the usage of a combination of multiple levels of virtual environments, according to the authors the actual strength of their system may be in highly complex tasks. Another prominent example is AR in Smart Factories (in terms of "Industry 4.0"), as described, e.g., by Paelke [18]. By using AR instructions, users without experience in the selected task were able to successfully implemented assembly tasks in down-scaled model factories. The positive outcomes of this work had encouraged further tests and investigation in a real production environment for better applications.

Aside the industrial application areas, AR shows great potential in many other areas. For example, Delft University of Technology had run a project for distributed collaboration in crime scene investigation [19]. The system allows a field investigator, equipped with a HWD, to work with an expert in distance via video stream, voice communication and a shared interactive 3D model. The work displayed promising outcomes in improving mutual understanding between investigators, fastening data exchange, as well as time management. Furthermore, medicine is another interesting domain for AR. In [20], Mentler et al. discussed several use cases in medical practice employing smart glasses. These use cases cover from triage, diagnosis to surgery. Despite the limitation of current technologies, health care experts had shown their interest for the usage of HWD.

Since AR has the power to decrease error rate and also documentation efforts, e.g., by detecting if a task was executed successfully or with errors, we believe that if this technology is introduced in the right way it can increase efficiency. In the described study we introduced a AR-ready HWD for selected work tasks and compared the direct interaction with the device (i.e., using the interaction elements on the glasses) with a clicker device (i.e., a remote control with the same buttons as the glasses). While AR turned out to be problematic due to the diminished amount of trackable features in the selected environment, feasible interaction with HWD-based systems seems to be a key feature for the users we talked to.

Figure 1. The customised layout of the Hoerbiger Smartcontrol PDA hand-held terminal as used in the described setting.

III. ANALYSIS

We conducted the presented work on the shop floor of a German car manufacturer in the final check division of one car manufacturing line. In contrast to the assembly division, the tasks in this subsequent division require higher flexibility from the workers. Several varying automatic and manual tasks are executed, based on the car's configuration, among others to ensure the product quality. To further understand the work tasks and the environment, we analysed both as described in this section.

A. Environment

We selected the initial start-up and functional check division, which is the first subdivision of the final check division. This selection mainly is based on the fact that we already executed previous projects in this division in which we made good experiences with the flexibility of the workers. In this division, there is a greater amount of manually executed task, for which the workers need to be instructed and guided than in other divisions. Also, workers need to be mobile to execute these tasks. Finally, the workers are already instructed by a hand-held terminal, which they also use for documenting the test results. In this division, the vehicles still are on the conveyor belt. The lighting conditions, which are important for object detection in camera images, are good and consistent. For instructions and documentation of the progress Hoerbiger Smartcontrol PDA hand-held terminals (see Figure 1) are used. The unused hand-held terminals are placed on a desk, where they can be charged. Like all other important tools they are located aside the conveyor belt so workers can reach them in short walking distance.

B. Work Tasks

We selected observation and self-exploration as the methods to analyse the current work flow in this division. For observation, we watched workers while they were performing their tasks. We could ask them questions, as long as they were not interrupted in their work flow. For further questions, one employee from the technical plant support and development also was available, standing next to us. After the observation, we shifted to the rework division (located after the final check division) to experience the work on our own without risking to delay the manufacturing process or affecting the production quality by wrong performing. In this division, defects can be corrected. Due to the diversity of issues, the vehicles no longer are standing on a conveyor belt but are parked in a reworking area. We performed one exemplary functional check task flow here. In the following, the context of use and further results of this initial analysis are listed.

The workers perform manual functional checks, like verifying the bearing play of the steering wheel on each vehicle, while the vehicle is connected to an automatic functional test system. Some of the tasks of the automatic functional test system require the worker to collaborate with the system which is displayed on the hand-held device, while others are performed autonomously. Each vehicle is completely checked by one worker who shifts to check the next car when finished with the current one.

To start checking the car, initially the worker scans a bar code which among others is printed on a A4-paper attached to the windscreen. To do so, the worker pushes the scan-button of the hand-held terminal which enables its bar-code-scanner. If the scan was successful, the hand-held terminal requests the according functional checks from the back-end application and displays them in a list. To start one functional test, the worker selects it by pushing the list item on the touch screen, the hand-held terminal requests the work flow. To enable the testing system performing automatic functional checks, the worker connects the car to a test control unit which also is identified by scanning the attached bar-code. After the test control unit was identified and connected successfully, the functional test starts. In the beginning, various automatic tests are performed. This is indicated by black font colour on white background (see Figure 1). The worker is observing the automatic tests until the background changes to yellow. The systems stops performing until the worker executes the requested input (e.g., pushing a switch) or confirms that the test was performed manually by entering the result (i.e., ‘OK’ or ‘not OK’, represented by the +/- buttons in Figure 1). While automatic and manual (or collaborative) tasks alternate the worker is moving around and through the car counter-clockwise. After the last test was executed the worker removes the test control unit.

IV. Implementation

For the implementation we defined the requirements on the software solution. Afterwards we designed Mock-Ups which we validated by interviewing five (respectively four) employees of the car manufacturer. Three participants were employees working in the selected division while the other two (respectively one) were engineers of the technical plant support and development. After redesigning our Mock-Ups we developed one prototype.

A. Requirements

For developing an example application instructing the workers using AR, we concluded the following requirements as *must-have*:

a) Replacing the Hand-Held Terminal: The selected HWD shall completely replace the hand-held terminal for the selected tasks. It has to offer all the necessary features to successfully perform complete functional tests. As we aim to evaluate the general usage of AR in this environment and the user feedback, no connection to the test control unit or the back-end-system is needed. It is sufficient to simulate one exemplary functional check.

b) Hands-Free Operation: The biggest disadvantage of hand-held devices is that they blocks at least one of the worker’s hand if it is not put aside. To overcome this problem, the application shall be hands-free (as long as no interaction with the device is necessary).

c) Improved Training: While previous projects mainly focused on text-based worker instructions and served as documentation system, in this project we intended to observe the capabilities of AR-ready HWD. We are aiming for using AR to support novice workers in their training phase. For demonstrating this capability some input elements from the cockpit shall be selected. The selection will be made during the development phase.

d) Ease of Operation: Using the application shall be as simple as possible and new users shall be able to use the device quickly.

e) Similar Appearance: To minimise the training phase for experienced workers, the visual design shall follow the visual design of the hand-held terminal application as long as it not requested differently by the participants in the analysis or any evaluation. The existing design shall be used as starting point and be enhanced together with the workers.

f) Bar-Code Scan: The bar-codes shall be scanned by using the HWD‘s camera to identify the car. As stated above, loading the work flow will be simulated.

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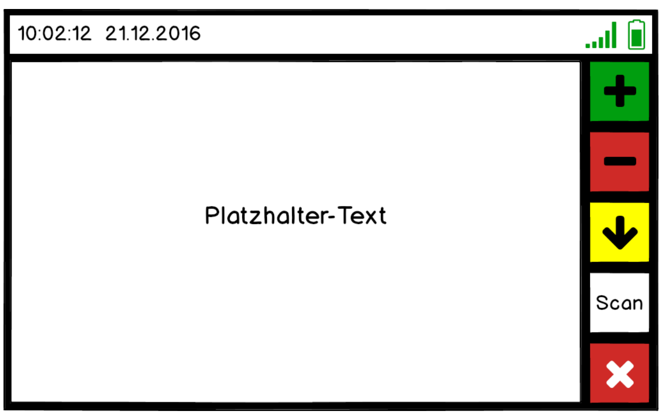
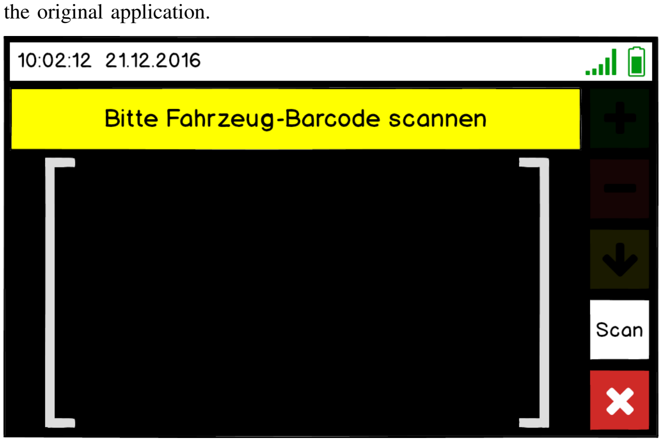
g) Interface to Load Work-Flow Data: The application shall be able to interpret XML-based test-files to simulate different work flows.

Within this definition phase we also discussed other requirements. As the project was limited to four months we decided to classify them as *nice-to-have*. These requirements are: 1. *Saving the protocol* to be able to review the single tests. Also, they should be exportable to a computer. 2. *Configure input modalities* should be possible to reconfigure the interaction-concept. This on the one hand would enable the workers to personalise the interaction to their needs and preferences and on the other hand would simplify extending the features of the application. 3. *Offering an exchangeable work flow parser module* to ensure the application to be compatible with future plant control systems. 4. *Extending the use of AR* for more than one training scenario. This can be for example augmenting another task or also superimpose the workers' view with navigational instructions, for example, using arrows to guide them from task to task. 5. *Skilled workers should be enabled to work more independent than novice workers* by adjusting the Graphical User Interface (GUI). Therefore, the application has full access to the camera, it generally is able to detect the execution of tasks, and also to determine the skill level of each worker.



(a) The instruction screen Mock-Up. Buttons and labels follow the design of the original application.



(b) The scanning screen Mock-Up. Unused Buttons are greyed out.

Figure 2. Initial Mock-Ups for both types of screens.

B. Design

Based on the analysis we identified two basic screen layouts. One for scanning tasks, and one for instruction and documentation. We decided to choose a consistent structure for both to reduce the cognitive workload when switching from the instruction screen to the scanner screen. This is based on the assumption that the worker will be able orientate himself/herself faster on two similarly structured screens.

We designed Mock-Ups of both screens as shown in Figure 2. In Figure 2 (a), the instruction screen is displayed containing five interaction elements (Buttons) on the right and a text-area ("Platzhalter-Text") for displaying instructing text. Above that area the date, time, WiFi signal strength and battery load are shown in a status-bar. The scanner screen, shown in Figure 2 (b), also contains the two required interaction elements on the right. The black area on the left is transparent and functions as viewfinder, because we plan to use the camera to scan bar-codes. Above the viewfinder-area the user is instructed to scan the vehicle's bar-code ("Bitte Fahrzeug-Barcode scannen"). On the top again there is the status-bar.

As described in the ISO 9241 - 210 Standard [21] we evaluated the Mock-Ups together with stakeholders (here: workers from the division and the engineering department), which should establish usability and ensures that we, the developers of the application, do not misunderstand the current work-flow or requests by the stakeholders. The Mock-Up evaluation was performed in a conference room located in the same building as the plant. We initially introduced the project idea and the selected HWD to each of the five participants. Also, we offered the participants to stop whenever they feel to do so and clarified that all personal data will be treated confidentially. Some of the participants already participated in a predecessor project where we evaluated the HWD Google Glass XE in the same set-up.

We prepared an icon test to validate the identification of the used icons and all other GUI-elements. The participants were asked to put on the HWD and describe all elements they can see as detailed as possible. Also, they were requested to explain what they think the element stands for. The results of icon test are listed in Table I. Except the *WiFi Signal Strength* icon all elements could be identified as expected. The high identification rate most probably results from reusing the layout of the elements from the hand-held UI.

TABLE I. RESULTS OF THE 'ICON TEST'.

Icon	*Identification Rate*
Date / Time	5/5
WiFi Signal Strength	3/5[a]
Battery Load	5/5
Text Area	5/5
Button *OK*	5/5
Button *Not OK*	5/5
Button *Repeat*	5/5
Button *Scan*	5/5
Button *Cancel*	5/5

[a] Two participants could not identify the icon correctly.

Afterwards we showed the participants 41 screens representing one possible example of a functional check. Each screen was displayed for one second and the participant was asked to stop the forwarding when he/she thinks based on this screen an active action is necessary. He/she then was asked to

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TABLE II. RESULTS OF THE QUESTIONNAIRES. [a]

(a) The Mock-Up	*P1*	*P2*	*P3*	*P4*
...is well structured (++) / confusing (--).	++	++	++	++
...offers acceptable (++) / unacceptable (--) Field of View size.	--	++	++	++
...shows instruction text in sufficient (++) / insufficient (--) font size.	++	++	++	++
...does (++) / does not (--) offer all features to fulfil the task efficiently.	++	++	+/-	++
...gives sufficient (++) / insufficient (--) feedback on user input.	++	++	++	++
...does (++) / does not (--) follow a consistent interaction concept.	++	++	++	++
...can be learned in little (++) / long (--) time.	++	+	+	++
...does (++) / does not (--) allow to switch between task easily.	NS	++	+/-	NS
...does not (++) / does (--) force the user the interrupt his work.	-	+	++	-
(b) The Head Worn Display				
...simplifies (++) / impedes (--) orienting in space.	-	--	+/-	+/-
...does not (++) / does (--) show reflections above the display.	--	++	++	++
...is easy (++) / hard (--) to operate.	NS	++	+	++

[a]P = participant, NS = not specified / answer not definite.

describe which action needs to be performed. All screens were classified correctly and the necessary actions were derived.

To gather general information about the structure and appearance of the application and also about critical points (we experienced in previous projects) of the HWD, we handed out questionnaires. We used semantic differential to find out which statements the participants rather agree to. Unfortunately, participant 5 had to leave earlier due to other obligations and could not fill in the questionnaire. Hence, this evaluation phase was performed with four participants. The results, as well as the translated statements of the both questionnaires are presented in Table II. When the answer was not clear we did not count it.

Because we recognised that the first participant did not use the free text section of our questionnaire, we decided to add a short discussion about the Mock-Ups and the questionnaires to find out further details, among others that the bright white text-area stresses the eye. Participants suggested to increase transparency of the area or move the text-area to the top (similar to the scanner screen). Also, switching from near to far distance focus was experienced to result in double vision and for some participants the screen appeared blurry in the upper left corner.

All participants were very open and showed interest in the HWD. Some of them asked questions about the device or compared this experience with the one from Google Glass XE. All agreed that the AR-ready HWD ODG R-7 is more suited to the selected use case.

Based on this evaluation we reviewed our current status and decided to change the GUI-Layout as follows:

- Two participants were not able to identify the WiFi Signal Strength icon, even though this icon already is used in the GUI of the hand-held terminal. We assume that this information is of minor priority for the execution of the work tasks. Hence, we decided to not implement the WiFi Signal Strength icon.
- All five participants stated that the text-area is too big, three even experienced it as disturbing. We decided to move the text-area to the top, similar to the scanner screen (cf. Figure 2 (b)).
- Two participants stated that the upper left corner of the screen is blurry. The manufacturer offers replacement nose-pads for their HWD, which can be bought in different sizes. But still, if the device is not sitting perfectly on the nose, for example because the worker hits it unintentionally, the corners might be blurry again. We concluded that it is better to not display any information in this area. Hence, we decided to centre date, time and battery load in the status-bar.

C. Prototype

To increase to possibilities regarding AR, but also to simplify the manipulation of AR context for future use, we decided to use Unity Editor with the Vuforia AR SDK to implement the application. Another reason for this selection is Vuforia's 'native' support of the selected AR-ready HWD, which among others means that the framework has all necessary specifications to set-up a suitable scene for this particular HWD.

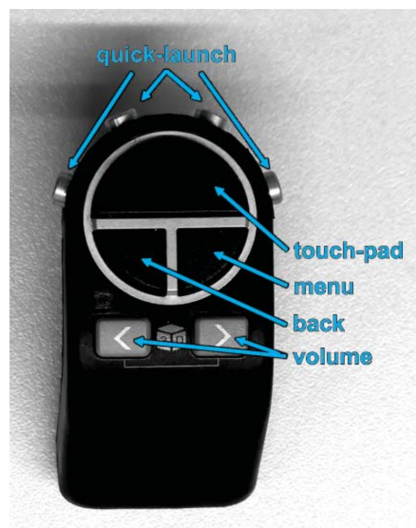
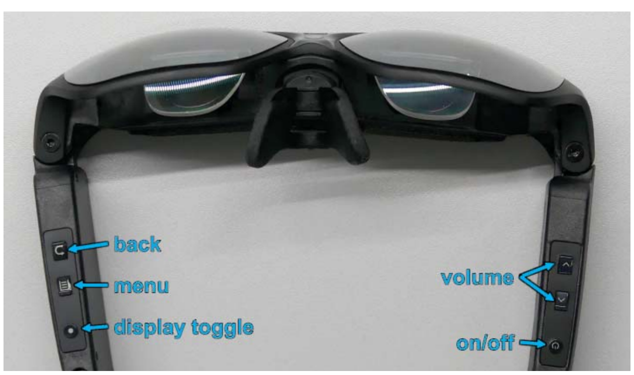


Figure 3. The Reticle Speed Mouse, a finger-worn input-device, with its standard button assignment. The size of the device is about 82 mm * 27 mm * 36 mm and can be put on one finger with the ring-strap on the backside of the device.

In previous projects, we already analysed input modalities of HWDs and their suitability for the context of a factory environment. In the selected environment, there is a moderate noise level randomly interrupted e.g., by floor-borne vehicles passing by. This prevents using voice commands without directed microphones and additional noise cancelling. Also, we did not want to intervene with the cooperative work environment by forcing the workers to talk to devices instead of communicating with the other workers from their group. Finally, most voice command frameworks use servers to analyse the spoken text and send back the transcription. This would require to enable internet access for the HWDs and therefore allow the operator of these servers unrestricted access to any voice close to the HWDs. Due to privacy and confidentiality concerns this currently is not an option.

We also evaluated hand-gesture detection frameworks and concluded that even in the selected environment with very consisted lighting conditions the tracking was too unstable to guarantee a sufficient detection rate. We assume that with a camera-technology which is able to detect depth information the tracking would be stable enough. Unfortunately, the selected HWD ‘only’ has a high resolution colour camera. Furthermore, non-visual gesture-tracking technologies detecting the muscle tension are available, for example the Thalmic Myo armband. Based on our experience the stability of the tracking with these technologies depends on too many variables (e.g., the skin resistance) to use it in this set-up.

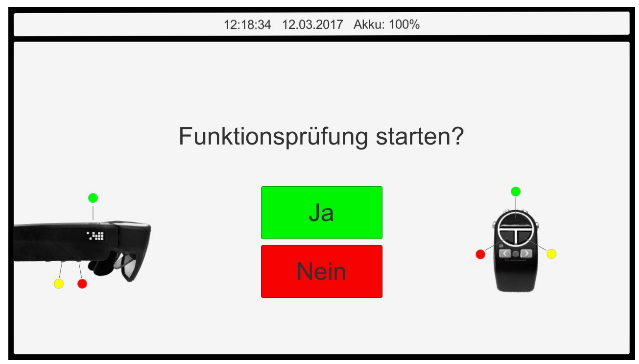
(a) Front of the ODG R-7 with the touch-pad. Between the lenses is the camera and above a flash-led.



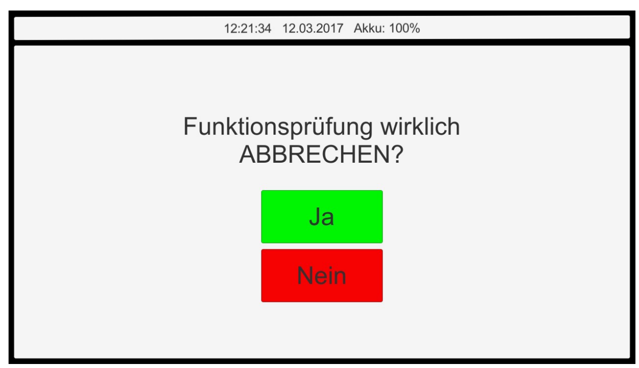
(b) Bottom view of the ODG R-7.

Figure 4. The standard button assignment of the used HWD.

Both devices (the Clicker and the HWD) offer a touch-pad (clickable), a back-button, a menu-button and buttons for increasing and decreasing volume. In addition the Clicker offers 4 quick-launch buttons and a 9-Axis Inertial Measurement Unit (IMU) for 3D gesture detection. These gestures usually require sweeping motions to be detected stably, which is not possible e.g., when sitting on the drivers seat, so we excluded this option. Furthermore, we decided to use the same five buttons on both devices. While a touch-pad click will mark a task as ‘OK’, clicking the back-button will mark it as ‘not OK’ and the menu-button will repeat the task. We assigned all buttons in the order of appearance on the GUI (top to down). As shown in Figure 3, the selected buttons on the Clicker are not labelled and as shown in Figure 4 (a) and Figure 4 (b) the labels on the HWD are not visible to the user when wearing the device. Hence, we expect that overwriting their functionality with new ones is not critical. Especially, for the back-button, which can be misinterpreted as repeat button, this is important. Furthermore, the workers will use the device with the developed application only, so they are not confronted with another assignment of these buttons.



(a) Initial screen. The worker is informed about the key assignment and can start the functional check by pushing the touch-pad either on the HWD or on the finger-worn input-device.



(b) Cancel screen. The worker is asked if he/she really wants to cancel. He/she can confirm by pushing the touch-pad or undo by pushing the back-button either on the HWD or on the finger-worn input-device.

Figure 5. Further Screens of the App-prototype.

Finally, we decided to work with the buttons and the touch-pad of HWD and a ‘Clicker’, a finger-worn input-device (cf. Figure 3). We are aware of the potential disruptive character of the Clicker, but compared to a hand-held it does not occupy the whole hand and here it serves as mean to compare direct interaction and remote interaction with the HWD.

We decided to use long click on the menu-button (‘repeat’) for cancelling the task (as depicted in Figure 7). Furthermore, we recognised that we never need the scan function when a functional check is performed and also do not need the mark as ‘OK’/‘not OK’ function outside of the checks. We decided to reuse the menu-button for scanning.

TABLE III. RESULTS OF THE EVALUATION OF THE PROTOTYPE. [a]

Question	*P1*	*P2*	*P3*	*P4*
Do you understand the interaction concept of the HWD on the start screen?	no[b]	yes	yes	yes
Do you understand the interaction concept of the finger-worn input-device on the start screen?	yes	yes	yes	yes
During automatic tests: Do you see all icons and understand what they mean?	yes	yes	no[c]	yes
Can you cancel the tests by long pressing the ‘repeat’-button?	yes	yes	yes	yes
AR: Do you see the green arrow?	yes	yes	yes	yes
AR: Does the arrow point on the right element?	no[d]	no[d]	no[d]	no[d]
AR: Is the arrow displayed double?	yes	yes	yes	yes
Please rank which of the devices you would prefer working with. [e]	2,3,1	3,2,1	1,2,3	3,2,1

[a] P = participant, [b] ”Problems to find ‘repeat’-button”, [c] ”Wearer of corrective glasses, Field of View of the HWD too low”, [d] ”Only after closing the left eye”, [e] ”1 = hand-held terminal, 2 = AR-ready HWD, 3 = AR-ready HWD + hand-held controller

To finish the program flow, we added two screens: One informing the workers about the key assignment and enabling them to start the tests (cf. Figure 5 (a)) and the other one to confirm cancellation of the test (cf. Figure 5 (b)).

As stated above, we also wanted to explore the potential of AR in this set-up. As a first step we selected four buttons of the dashboard (Figure 6). These have been selected, because they are standard elements of the passenger compartment. Hence, they are available in all vehicles manufactured in this manufacturing line.

We experimented with the tracking capabilities of the Vuforia Augmented Reality SDK. Our first attempt was to take a photo of the selected buttons and use it as a so called image target for the image feature detection algorithm of the SDK. Due to the mainly black appearance, we did not manage to get stable detection, even when using a high resolution camera. Second, we dismounted the whole dashboard element to scan it with the Vuforia Object Scanner Smart phone application, which generates a point cloud. Because we only needed the front of the element and we were not able to remove unneeded points we could not apply this technology as well. Last loading a 3D-Object provided by the car manufacturer currently is not possible with the selected framework. Hence, we decided to put an image target (‘Vuforia-Stones’) above the buttons and adjust the position of the arrow to point on each button as shown in Figure 7. We are aware that this is not an applicable solution for everyday business, but it gives an impression of what AR-support might look like in future systems.

V. EVALUATION

To evaluate the prototype, we focussed on three factors. First, we wanted to investigate if the GUI and its elements, especially those we changed, are interpreted correctly. Second, the selected input concept could not be tested with workers by now, even though it is an important factor. The focus here is on the interaction with the HWD and the finger-worn input-device and whether the introduction of the key assignment on the start screen (cf. Figure 5 (a)) is sufficient or not. Third, we simulated an actual functional check to allow testing whether the selected HWD is suitable for supporting workers. Also, we wanted to test how the workers respond on the AR support.

We simulated one functional check in the reworking area. Four workers from the initial start-up and functional check division volunteered, two of them were already participating in the design evaluation-phase. We introduced the HWD and the general usage, especially to those participants who did not

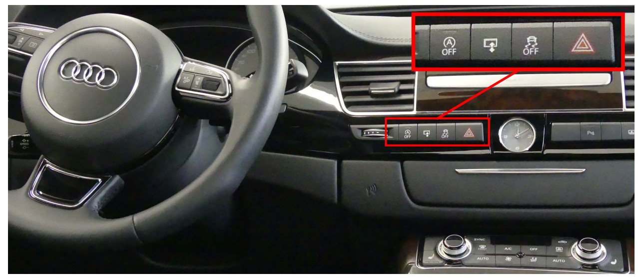


Figure 6. The selected element of the passenger compartment: Buttons in the dashboard.

work with it before, followed by the purpose of the evaluation and the planned procedure. Also, we informed the participants that all personal data will be treated confidently and that they can cancel the evaluation whenever they want.

The evaluation was split in two parts. In the first part, we handed out the HWD only and asked the participants to put it on. They were asked to describe how they understand the instructions (i.e., the key assignment) shown on the start screen and then start the functional check (by pushing the touch-pad). While the automatic tests were simulated the participants were asked to describe the elements on the screen to verify that they could identify all of them correctly. When a manual or collaborative task was displayed the participants were asked to start performing it. The participants could not perform the tasks completely as they were working on a real vehicle which already was tested and set up completely. When an AR supported screen was displayed we furthermore investigated the visibility of the AR content (arrow, cf. Figure 7). In the second part, we gave the Clicker to the participants and asked them to do the test again. We did not further investigate on the GUI or the AR feature. The purpose of part two only was to experience the usage of the finger-worn input-device (representing ”close to the body-interaction).

The results are listed in Table III. Summed up, we found out that the selected HWD might cause problems for spectacle wearers. This is a very common problem with this kind of devices as two glasses have to fit on each other. Especially, wider spectacle frames lead to problems. Furthermore, all participants could not instantly perceive the 3D object correctly. They saw it duplicated and on the wrong position. Based on our own experience this issue is solved after a longer period of use, when the users get used to this new experience. It is important to be aware that this also temporarily can cause eye pain, headaches and other symptoms due to the strain on the eyes, which should be taken serious. The wrong positioning also can be a result from displacing the image target slightly.

In a short discussion with each participant, directly after finishing the two parts, we asked for their impressions and points of critique. Also, we asked them for ranking which of the three possibilities they would prefer for their daily work: The hand-held terminal, the HWD or the HWD with the Clicker. The ranking is shown in Table III. Three of four participants prefer the HWD or the combination of HWD and finger-worn input-device over the Hand-held terminal. Only participant 3 prefers the hand-held terminal, most likely due to the issues he/she had with the HWD and his/her corrective glasses, which he/she emphasised in the following discussion. As in previous projects (with other HWDs) the participants pointed out that having both hands free to perform their tasks is a great facilitation. Furthermore, we got the following feedback: All participants stated that the display is too bright.

Figure 7. An overlay from an App screen-shot on a picture of the used image target (‘Vuforia-Stones’) attached to the vehicle’s dashboard, to demonstrate what the worker sees through the HWD.

One participant suggested to not use background colours but only colouring the test white and yellow and reducing the button size. One participant suggested to move the keys to the left temple of the HWD. One participant was concerned about confusing the OS-‘back’-button and the application-‘repeat’-button, i.e., the key assignment. About the finger-worn input-device one participant said that might damage the car and another participant stated that pushing a button unintentionally is very likely. Two of the four participant stated that the image of the HWD dangles when walking. Also, two of the four said using the device tires the arms and puts a high strain to the nose and head, due to its high weight of about 175 g. This is why the participants doubt that they can use the HWD a whole work shift (8 h). One participant suggested to try head gestures to interact with the HWD.

VI. Conclusion

In this project, we developed an application for work instruction and documentation in the initial start-up and functional check division of a car manufacturing line of a big German car manufacturer. This prototype included an AR feature simplifying the guidance for the workers. We followed the Human Centred Design Approach as defined in ISO 9241 - 210 [21]. The prototype was evaluated by four participants working in this division. The aim of the project was to develop a proof-of-concept. A study with more participants is pending to gather quantitative data verifying the presented results and potentially reveal further perspectives on the prototype.

While the design of the application was easy to understand for all participants, some problems with the selected HWD occurred. Wearers of corrective glasses can be limited in the usage of this device. Also, we found out that while two-dimensional GUIs do not cause bigger problems for the users, three-dimensional objects (for the AR feature) could not be perceived adequately. All four participants stated that the selected object is not placed correctly and reported double vision. During our work with the device, we found out that these symptoms disappear when the eyes learn to focus on the objects, but this risks causing eye strain. Except one participant, who struggled with the combination of the HWD and his/her own glasses, all participants selected the HWD over the hand-held terminal. Two out of these three participants preferred input via an additional finger-worn input-device while one preferred input via the buttons of the HWD itself.

Participants who already took part in the evaluation of a HWD not capable of supporting AR in the same division stated that the AR-ready HWD is more suited for this use case. Also, even though all four participants struggled with the AR feature and limits of the selected AR framework all participants responded positively to this feature.

Furthermore, testing the finger-worn input-device gave us some insights on potentials and limits of ”close to the body”-interaction in this use case: If tailored to the use case, interaction with different types of systems could be facilitated. To not disrupt work-flows the interaction either should not require any hardware to be worn, be based on hardware which can be worn unobtrusively or be in-cooperated in the workers clothes. We aim to explore this device type for use cases like the one described in this paper in future work.

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