Full shift usage of smart glasses in order picking processes considering a methodical approach of continuous user involvement

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Cornelia Sophie Murauer

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Max Murauer,

Nerina Pflanz,

Serena Striegel &

Florian Mesz

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The opinion is only the opinion of the PhD candidate, not necessarily the one of the BMW Group.

For better legibility gender-specific language was omitted and the generic masculine was used without intention to discriminate against the gender of any study subject.

Abstract

Smart factories, in which processes are partially or completely automated and digitalized, are the future. Automobile production is also currently undergoing said change towards 'Industry 4.0'. While the degree of automation is very high in car body construction due to the use of robots, the degree of automation in logistics varies depending on the process. By contrast, in transportation processes, such as the use of tugger trains, autonomous transport systems or forklifts, automation is at a very advanced stage of development. In picking processes the employee continues to be at the center of attention due to his flexibility in movement sequences and grasping. Assistance systems such as smart glasses, smart watches or scanner gloves can nevertheless support employees and provide process improvements. The present research project focuses on the use of Augmented Reality (AR) technologies, in particular the usage of smart glasses in manual man-to-goods order picking processes. The required information for order picking is displayed in smart glasses in the picker's field of view. In scientific research, their usage has been tested primarily under laboratory conditions. I subsequently identified a research gap investigating a full shift usage of smart glasses under real industrial production conditions. For this reason, the present PhD thesis includes a full shift field study, which examines the impact of the smart glasses usage in order picking processes on the employee and the process. As a first step, a process for shop floor employee involvement in innovation projects based on Rogers' 'Diffusion of Innovations' will be developed. Afterwards, the suitability of workstations for AR-usage will be evaluated using the Rasmussen skills-rules-knowledge-framework. In addition, an objective procedure for classifying individual activities into Rasmussen's framework will be developed. After selecting the test workstation, which contains most of the process steps supportable by AR-technologies, I will compare scanning mechanisms for the interaction with the warehouse management system. The core of the research project is a full shift field study with 23 employees in automotive assembly supply, which examines the impact of a smart glasses usage on the number of errors, the error types, the task completion time, the attention, the subjective strain, the visual fatigue of the employees and the likelihood of symptomatic occurrence of simulator sickness. In contrast to most existing studies, the field study is conducted in real production in accordance to the rhythm of the assembly line. The test system is connected to the warehouse management system. Employees interact with the warehouse management system with the aid of a scanner. The age range of the participants represents the regular workforce. Besides that, I will select a smart glasses hardware, which enables the inclusion of corrective glasses wearers. All the above points contribute to a test under real industrial conditions. As a basis for comparison serves the previous process, which displays the picking orders on a monitor attached to the target shelf. In this system a scan glove is used as interaction mechanism. The evaluation of the study results determine a time saving of 22% and an error reduction of at least 33%, depending on the error type. Due to these promising results, I explain further steps for series introduction. In addition, I discuss further potentials of the usage of data glasses in order picking processes.

Kurzfassung

Smarte Fabriken, in welchen Prozesse teilweise oder gänzlich automatisiert und digitalisiert sind, sind die Zukunft. Auch die Automobilproduktion befindet sich derzeit in diesem Wandel hin zur „Industrie 4.0“. Während beispielsweise im Karosseriebau der Automatisierungsgrad durch den Einsatz von Robotern sehr hoch ist, ist er in der Logistik prozessspezifisch unterschiedlich ausgeprägt. Bei Transportprozessen, wie dem Einsatz von Routenzügen, fahrerlosen Transportsystemen oder Gabelstaplern, ist der Entwicklungsstand der Automatisierung sehr weit fortgeschritten. In Kommissionierprozessen hingegen steht der Mitarbeiter durch seine Flexibilität in Bewegungsabläufen und im Greifen weiterhin im Mittelpunkt. Der Einsatz von Assistenzsystemen wie Datenbrillen, Smart Watches oder Scanner-Handschuhen kann dennoch Mitarbeiter unterstützen und Prozessverbesserungen hervorrufen. In dem vorliegenden Forschungsprojekt steht der Einsatz von Augmented Reality (AR)-Technologien, insbesondere der Einsatz von Smart Glasses, in der manuellen Mann-zur-Ware Kommissionierung im Fokus der Betrachtung. Dabei werden dem Mitarbeiter die zum Kommissionieren benötigten Informationen in einer Datenbrille im Sichtfeld angezeigt. In der Wissenschaft wurde ein Einsatz vor allem in Laborstudien getestet. Eine Studie über eine volle Schicht im industriellen Kontext wird als Forschungslücke angegeben. Aus diesem Grund beinhaltet die vorliegende Doktorarbeit eine Feldstudie im Vollschichtbetrieb, welche die Auswirkungen der Nutzung von Smart Glasses in der Kommissionierung auf den Mitarbeiter und den Prozess untersucht. Als ersten Schritt wird ein Prozess zur Mitarbeitereinbeziehung in Innovationsprojekten am Shop Floor basierend auf Rogers „Diffusion of Innovations“ erarbeitet. Im Anschluss wird ein für den AR-Einsatz geeigneter Arbeitsplatz mithilfe des Rasmussen-Modells menschlichen Verhaltens ausgewählt. Dazu wird ein objektives Verfahren zur Klassifizierung einzelner Aktivitäten in das Rasmussen-Modell entwickelt. Nach der Auswahl des Arbeitsplatzes, welcher die meisten durch AR-Technologien unterstützbare Prozessschritte enthält, werden Scan-Mechanismen zur Interaktion mit dem Warehouse Management System verglichen. Kern des Forschungsprojekts ist ein Vollschicht-Feldversuch mit 23 Mitarbeitern in der automobilen Montageversorgung, welcher die Auswirkungen des Einsatzes von Datenbrillen auf die Fehleranzahl, die Fehlerart, die Durchführungszeit, auf die Aufmerksamkeit, die subjektive Beanspruchung, die visuelle Ermüdung der Mitarbeiter und eine mögliche auftretende Simulatorkrankheit untersucht. Im Gegensatz zu den meisten bereits existierenden Studien erfolgt der Versuch im Realbetrieb unter Einhaltung des Produktionstakts. Dabei wird das Testsystem an das Warehouse Management System angebunden. Die Interaktion wird durch den Mitarbeiter selbst und nicht über einen Wizard-of-Oz-Ansatz durchgeführt. Die Altersspanne der Teilnehmer deckt im Versuch die gesamte Breite der Belegschaft ab. Darüber hinaus wird eine Datenbrillen-Hardware genutzt, welche die Einbeziehung von Brillenträgern ermöglicht. All die oben genannten Punkte führen zu einem Versuch unter Realbedingungen. Als Vergleichsbasis dient der jetzige Prozess, welcher die Kommissionieraufträge auf einem am Zielregal mitgeführten Monitor darstellt. Als Interaktionsmechanismus im bisherigen System dient ein Scan-Handschuh. Nach der Auswertung der Ergebnisse der Probandenstudie, welche u.a. eine Zeiteinsparung von 22% und eine Fehlerreduzierung von mindestens 33%, abhängig von der Fehlerart, nachweist, werden weitere Schritte zur Serieneinführung aufgezeigt. Darüber hinaus werden weitere Potenziale des Einsatzes von Datenbrillen in der Kommissionierung diskutiert.

Publications

Murauer N. (2019) Designing a User-Centered Approach to Improve Acceptance of Innovations on the Shop Floor Using Rogers' 'Diffusion of Innovations'. In: Bagnara S., Tartaglia R., Albolino S., Alexander T., Fujita Y. (eds) Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018). IEA 2018. Advances in Intelligent Systems and Computing, vol 825. Springer, Cham
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1 Introduction

1.1. Smart Factories

Manufacturing companies are currently faced with the challenge of shaping the transition from traditional flow production to a smart factory. The increasing digitalization of transport, storage, assembly and maintenance processes is also called 'Industry 4.0' or the fourth industrial revolution. The term 'Industry 4.0' can be traced back to the high-tech strategy of the German Federal Government, which describes the objective of a smart factory. While the first three industrial revolutions were only labeled as such in retrospect, the fourth was already called a revolution before its implementation. Figure 1 shows the development steps of the industry in the four phases Industry from 1.0 to 4.0, including the respective development stages in logistics [1].

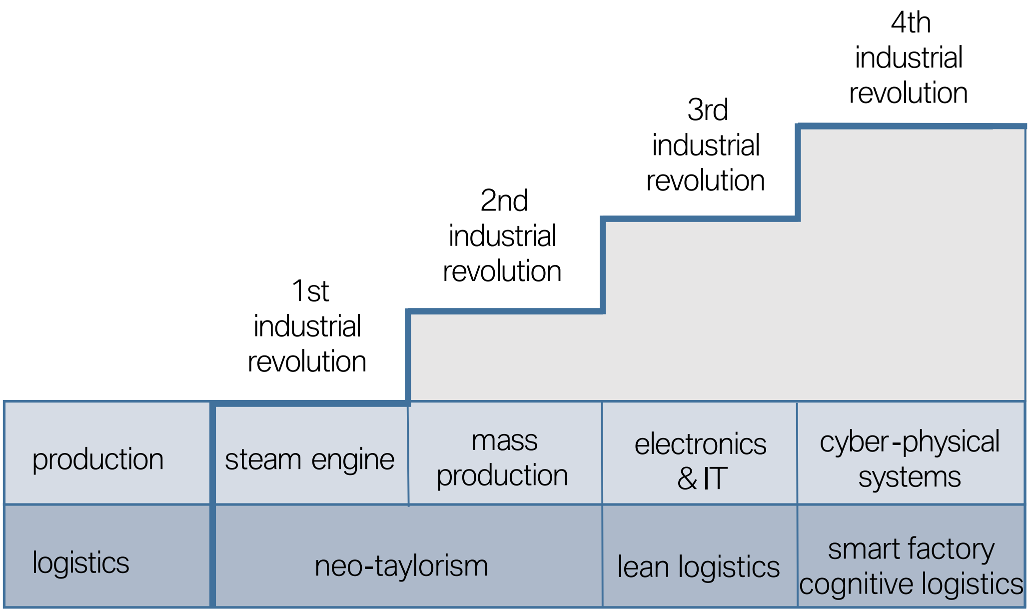

Figure 1: Four industrial revolutions in production and logistics, based on [2] and [3]

The first industrial revolution began in the 1750s with the development of the steam engine, which triggered industrialization and created the basis for industrial production. The second industrial revolution dates back to the turn of the 20th century, when Henry Ford introduced assembly line production and thus mass production based on the division of labor. In the 1960s the third industrial revolution started integrating electronics and IT. The fourth industrial revolution includes the development of so-called cyber-physical systems [1], or 'CPS'. These are defined as 'integrations of computation and physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa' [4, p.363]. Vogel-Heuser specifies individual characteristics of a CPS. CPS are based on sensors collecting physical data and on actuators consequently influencing real processes. Data, which is permanently collected, stored and evaluated, can trigger actions and reactions. Digital networks are used for worldwide communication between the physical and digital worlds. 'Multimodal human-machine interfaces' enable communication and control of the system with the workers [5]. As shown in Figure 1, logistics is also undergoing a major change towards logistics 4.0 [6]. In future logistical processes, the flow of material is organized and controlled by interconnected logistical objects [3]. The networking and interaction of previously uncomputerized objects is called Internet of Things (IoT). To convert transport boxes into smart boxes low investment costs are required [7].

In addition, smart shelves and smart boxes, can independently manage requests for inventory management and order replenishment. A cloud is used for real-time data traffic [6]. 'The classic, RFID-based 'internet-of-things', as invented at the turn of the millennium, gets eyes, ears, arms and legs' [6, p.616]. 'Swarms of autonomous vehicles', which are also capable of loading and unloading containers or pallets, are used for transport [7, p.177]. While many intra-logistic processes will be fully automated in the future, 'the humans play an essential role [in order picking processes], among other things, due to its flexibility and the ability to handle different objects easily' [8, p.1]. Nevertheless, a variety of assistance systems, which can become part of the Internet of Things, offer the possibility to support the worker in achieving one of the most important goals in order picking, the 'zero-defect picking' [9]. An upcoming mobile device offering a high potential for worker support are so-called smart glasses. These show virtual information in the user's field of view and thus partially overlap the reality. This technology is referred to as Augmented Reality. In literature there are already some investigations in the field of smart glasses-supported order picking. Nevertheless, large parts of its usage, especially in industrial environments, remain unexplored. In my PhD thesis, I focus on the usage of smart glasses in the industrial order picking context. In the following chapters I first explain the theoretical background of Augmented Reality technology and of order picking processes. Subsequently, I will discuss already conducted studies and define the research gap.

1.2 Augmented Reality

Since the introduction of Nintendo's smartphone and tablet game Pokémon Go in 2016, smartphone-based Augmented Reality became mainstream. The user interface shows the player's GPS-based real-time-localization on a map. He moves in his real world environment and tries to catch virtual so-called Pokémon [10]. The game caused a worldwide hype and became the third most downloaded iphone app after snapchat and facebook messenger in 2016 [11]. In the following, the theoretical basics of Augmented Reality are explained in detail.

The term 'Augmented Reality' (AR) is based on Caudell and Mizell's research on head-up displays in 1992 [12]. A uniform definition of the term does not exist [13]. Augmented Reality (AR) refers to the display of virtual information in the user's field of view [12], which are presented appropriate to the situation in the context of the real world [14]. These virtual elements can be 'digital information […] (text, picture, movie, etc.), interactive elements or (3D-) animations' [15, p.19]. Tümler extends this definition, which focuses on visual augmentation. He also includes the augmentation of audible, haptic, olfactory and gustatory perception into the term [16]. Nevertheless most studies address visual Augmented Reality [16]. According to Azuma Augmented Reality bases on the following three characteristics:

- Combination of real and virtual world
- Real-time interaction
- 3D-registration [17, p.356].

While Azuma excludes 2D overlays from his definition, [13, p.11] name 'AR in the narrow sense' with regard to 3D overlays with location dependency and 'AR in the broader sense' with regard to textual information (2D overlays). Another wording for this difference is 'context-sensitive' for visualizations with tracking and 'context-independent' for visualizations without tracking.

The distinction between reality or real environment, Augmented Reality, Augmented Virtuality and Virtuality or virtual environment depends on the percentage of computer-based elements. Milgram shows in his 'Reality-Virtuality Continuum' the range between real environment and virtual environment [18], see Figure 2:

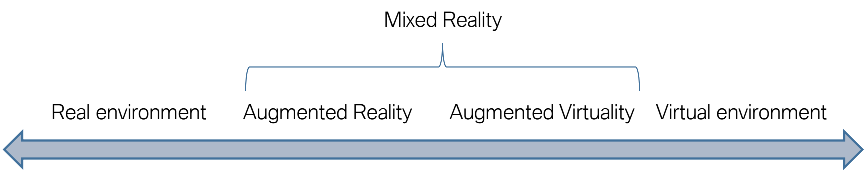

Figure 2: Reality-virtuality continuum [18]

Milgram's Continuum is framed by the real environment on the left side, in which no virtual elements are integrated, and the virtual environment on the right side, which is defined as a fully computer-based world. In-between real world and virtual world are mixed, which is referred to as 'mixed reality'. In Augmented Reality the proportion of real elements is significantly higher than the proportion of virtual elements [18]. 'AR supplements reality, rather than completely replacing it' [17, p.356].

Focusing on visual AR, several visualization tools are usable. As a first categorization, we distinguish between mobile and stationary solutions [19]. Stationary AR-tools can be projectors, head-up-displays or monitors [19]. Mobile AR-visualization 'describes the situation-specific display of computer-generated information on user-portable display devices positioned in the field of view, which do not impede the processing of primary work tasks' [16, p.12]. Mobile visualization tools can be divided into two subcategories depending on the positioning of the tool on the user's body: head-worn and hand-held devices [20]. Head-mounted devices (HMD) are primarily smart glasses that have either a transparent or non-transparent screen in the user's field of view. Hand-held devices are mainly smartphones or tablets. There are also publications offering head-mounted or hand-held projection solutions, like for example [21], but these are in the minority. Head-mounted devices include on the one hand displays, which are attached to helmets, caps or other racks, and on the other hand smart glasses, which provide virtual information in a transparent display in the user's field of view. Figure 3 shows an overview of different visualization devices.

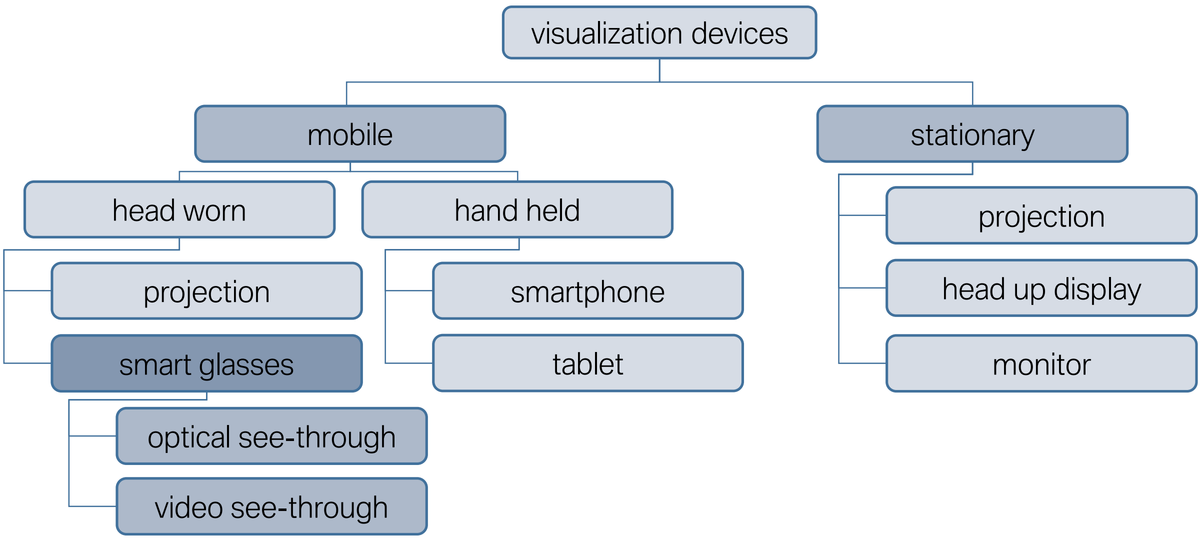

Figure 3: Overview of visualization devices based on [19], [20] and [21]

Regarding the visualization technique two methods are common [22]:

- Optical See-Through (OST)
- Video See-Through (VST).

Optical see-through means the presentation of virtual elements on a half-transparent display, which allows an optimal view on the real world through the half-transparent layer [23], see Figure 4. Video see-through is a video-camera-based method. The camera streams the view on the environment and the computer adds virtual elements to this video-stream [22]. According to Tümler video see-through HMDs are not suitable for industrial use for work safety reasons [16]. Hence we focus in this research project on optical see-through AR-visualizations.

Figure 4: Functionality of OST-HMDs, based on [17]

Augmented Reality technologies, as well as head-mounted displays, have increasingly evolved in recent years. Many of the publications underlying this thesis were written in 2008 and 2009, for example [16] [19] [24-30]. Around this time AR first became part of the so-called Gartner Hype Cycle. The Gartner Hype Cycle describes the maturity of various innovative technologies every year. According to Gartner innovations always pass through the same phases. An emerging technology is initially hyped, but cannot show the necessary degree of maturity for long-term use. Therefore, it cannot fulfill the high expectations. This 'Trough of Disillusionment' is the current status of HMD-based AR, while smartphone or tablet-based AR more advanced. An increase of the curve can only be achieved with the first practical applications [19]. Figure 5 shows the positioning of AR on Gartner's hype cycle since it was first mentioned in 2008. While the time to reach the Plateau of Productivity was forecast for more than 10 years in 2008, it has not yet been reached in 2017.

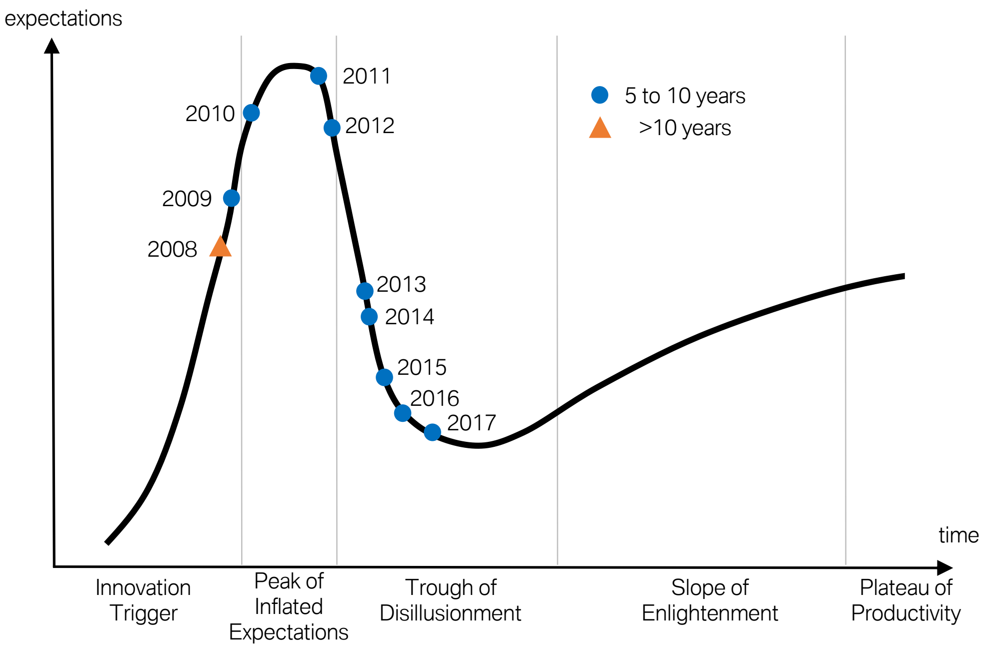

Figure 5: Development of Augmented Reality on Gartner's Hype Cycle, based on [31-40]

With the increasing hype of the technology, the number of companies producing HMDs on the market also increased. But analyzing the market, there is a lack of adequate hardware for reaching the Plateau of Productivity.

HMDs can be subdivided according to their construction design into monocular and binocular HMDs [19], in addition to the subdivision according to the type of visualization (OST and VST). Most studies before the peak of inflated expectations used mainly two systems: a Microoptical Clip-on [14] [41] and a Microvision Nomad ND2000 HMD [16] [19] [28] [42]. These systems are based on a monocular display. Due to the hardware development of HMDs towards glasses-similar solutions without external batteries, cables and head-straps, the term 'smart glasses' instead of HMDs prevails. 'Smart glasses are equipped with a see-through optical display, which is positioned in the eye-line of human users' [43, p.1]. In this thesis I use both terms, HMD and smart glasses, as synonymous. Studies, which used monocular smart glasses like Google Glass or VUZIX Star 1200, are for example [44] and [45]. Syberfeld et al. present in their publication an overview of available smart glasses on the market [20]. Since the market is constantly changing, I recommend [46] to compare the data sheets of currently available glasses. My research in this research project underlines Gartner's assessment of technological maturity. When selecting a hardware, a compromise between performance and comfort must always be made. The most mature hardware in terms of performance is currently considered to be the binocular Microsoft HoloLens, while the monocular Google Glass offers the best wearing comfort. The use case-specific selection with different 'must haves' leads to a different choice of smart glasses.

Azuma's three characteristics of an AR-system explained above, contain not only a visualization device, but also real-time interaction. Several interaction techniques can be combined with smart glasses. Some studies investigating AR-use cases did not consider the interaction method and use a Wizard-of-Oz-technique for system control, for example [27] [45], because '[t]he interaction between human user and smart glasses is still encumbered and problematic' [43, p.2]. A similar approach to the Wizard-of-Oz-technique interacting on the participant's request took Kampmeier et al. [42]. Reif and Walch used speech recognition [25], whereas Theis et al. decided to use a portable PC attached to the belt [47]. In contrast, Tümler tested interaction by a forearm keyboard [16] and Wiedenmaier a mouse click [41]. Summing up, every predetermined action, whether haptic, gesture or acoustic instructions, can be used as input for an interaction with the system. Which technique is to be used must be decided specifically based on the advantages and disadvantages of the use case.

1.3 Fields of application

The use of Augmented Reality-technologies offers advantages to many different environments, use-cases and research disciplines, such as training, maintenance, education, museum guidance, architecture, medicine, navigation, tourism, archeology, games, entertainment [48], military [49], marketing [50] and industrial production [41]. In the following, I examine some areas of application. This is only a brief overview on commercial and industrial applications in order to understand AR-potential, rather than an exhaustive presentation of existing studies.

AR has already become part of our everyday life. Parking aids in cars extend the live video stream of the rear view camera with additional AR-auxiliary lines. Sports commentators use a similar principle in their analysis, with the difference being the situation is analyzed retrospectively. In football, for example, offside situations are explained by fading in a virtual line or tactics of the teams by virtually encircling and connecting individual players into three- or four-man backfield defense. Another example from the sports sector is the Peakfinder Alps app, which displays the names of the mountain peaks in the field of view to mountaineers. GoSkyWatch is the counterpart for the virtual display of constellations in the sky. Especially in the marketing of the consumer goods industry, AR-applications are increasingly being used to encourage customers to buy. Sephora Visual Artist uses a real-time camera image of the customer's face and face tracking to test different make-up products and hairstyles on the customer. For example, when the customer is satisfied with a lipstick color, it can be placed directly in the virtual shopping cart or the image can be sent to friends or posted. The basis of business of Mister Spex, an online seller of corrective glasses, also uses face-tracking technology for virtually testing different models of glasses. Through his new method the company became a serious competitor in optician business. The fashion chain Zara tested virtual shop windows in its AR-Studio Collection. Models run up and down virtually on the display of the smartphone or tablet that is directed at the shop window. The outfit of the model can be changed by the user. In this way, the fashion company can present not only 3-4 outfits on mannequins, but the entire collection in one shop window. In the furniture industry, IKEA has long offered the so-called Place App. The customer can virtually test and place new furnishings in his apartment. When purchasing the BMW 2 series from a car dealer, customers can virtually test the interior volume and additional products such as a bicycle rack with BMW Product Genius. All these apps described above are programmed for handheld devices such as smartphones or tablets. Due to the better hardware in comparison to smart glasses, the level of development of these apps is relatively advanced and apps could become mainstream. Smart glasses-based AR-apps, on the contrary, are predominantly tested in research and have not achieved a comparable everyday maturity. Subsequently, maturity is hardware dependent and the assessment of the Gartner's hype cycle includes AR on smartphones, tablets as well as smart glasses. For this reason it forecasts a duration of five to ten years until the reach of the Plateau of Productivity using all possible devices.

In the industrial context AR is mainly used for assembly, order picking and maintenance. In assembly, AR can in particular support assembly training. Employees receive step-by-step instructions, where and which parts are to be placed and assembled. Additional information, manuals or videos can be displayed. The integration of gamification elements rewards the learning success. In addition to training use-cases, AR also supports the assembly of complicated components or customer-specific products when the assembly steps are not routine activities. Furthermore, some publications deal with AR-instructions especially for disabled employees [51-54]. In maintenance workers receive additional information such as documents, real-time data or video-based instructions on a handheld device or in smart glasses. A target-actual comparison helps to remedy faults. In order picking processes workers see visual picking instructions in the field of view instead of using paper lists or monitors. This smart glasses-based order picking is called 'Pick-by-Vision' [28, p.17].

The following chapters explain order picking, picking methods and related work concerning Pick-by-Vision in detail.

1.4 Order picking

Order picking is part of production logistics taking the role of the supplier for the production. Goods pass through the goods receiving, warehouse and order picking before they will be assembled in the production [55], see Figure 6.

Figure 6: Order picking in production process, based on [55]

According to ten Hompel et al. 'order picking is a core element of intralogistics' [55, p.3]. 'The aim of picking is to compile partial quantities (articles) from a total of goods (assortment) based on requirements (orders)' [56, p.2] Goods, which were previously stored according to the specific warehouse system, are rearranged and prepared according to the (internal) customers' orders [57]. A special form of order picking is 'sequencing', which is very common in the automotive industry. Sequencing means preparing goods exactly in the same order as they are required at the assembly line. There are two possibilities describing the movements of workers and goods in warehouses: man-to-goods- order picking and goods-to-man order picking. In man-to-goods order pickings processes the picker moves between fixed racks or pallet cages collecting the required articles [28], whereas in goods-to-man order picking the worker staying at his position picks automatically delivered goods.

A large number of order picking systems exists for listing or displaying orders. Schlögl and Zsifkovits provide a good overview of the methods and their advantages and disadvantages [58]. Five common methods will be explained in detail:

- Pick-by-Paper
- Terminals
- Pick-by-Light
- Pick-by-Voice
- Pick-by-Vision.

Pick-by-Paper [45] describes order picking based on a paper list containing order specific information [19] [58]. It is the oldest picking method, but due to low investment costs nevertheless advantageous. The lack of real-time quality control and low flexibility regarding changes argue against this method. Furthermore handling the list does not allow hands-free work. A terminal refers to as electronical device showing the required orders in combination with an interaction tool [58]. Terminals can be stationary or mobile [19] [58]. Available hardware often additionally contains barcode scanners or label printers. Whereas the integrated scanner function avoids picking errors, it increases the weight of the mobile terminal. A disadvantage of mobile terminals are, similar to the paper list, the lack of possibility to work hands-free [58]. Stationary terminals on the contrary allow hands-free work, but due to the missing integration of a scanner, real-time quality control is not possible [58], except using a combination of an external interaction device with a stationary terminal. Regarding a Pick-by-Light system a stationary lamp and a confirmation button are attached to every retrieval box [19] [58]. The employee moves from one flashing light to another, reads the required amount of goods on a display next to the lamp and confirms the pick using the button [58]. Pick-by-Light systems are investment intensive, but allow user-friendly guidance through the process. In addition, errors can be detected and remedied at an early stage using the interaction button. Pick-by-Voice provides order related information though acoustic instructions. Voice commands serve as interaction method. Positive aspects of Pick-by-Voice are the flexibility, the support of hands-free work and short training period for novices. Compared to Pick-by-Light, the required investment is significantly lower. A negative aspect of Pick-by-Voice is the permanent monotonous acoustic announcements, which can disturb employees [58].The term ‘Pick-by-Vision’ was invented in research project at TU Munich [28] [58]. This method includes ‘all systems using HMDs to support the order picking process’ [28, p.17]. Further Pick-by-Vision can be subdivided into two types [28], similar to Mehler-Bichler’s classification into ‘AR in the narrow sense’ and ‘AR in the broader sense’, which is explained above [13]. Schwerdtfeger names ‘Pick-by-Vision (2D)’ for textual context-independent information and ‘Pick-by-Vision (AR)’ for a tracking-based context-sensitive information [28, p.17]. Using AR-technologies at an order picking workstation provides a reduction of errors and of the task completion time [45]. Since the technology is still in the maturing phase, some studies exist in this field of research, but the results are often contradictory. The following chapter introduces the related work of studies focusing on Pick-by-Vision-systems. I will discuss the conditions and objectives of various studies and compare the study results. Afterwards I will mention the research gap and the motivation of this research project.

1.5 Related work of Pick-by-Vision-systems

Although some research institutes and companies already deal with the use of smart glasses, the research area focusing on Pick-by-Vision-systems is very manageable. In my literature research, I found a small number of user studies, which are presented in the following.

In a laboratory study, Tümler compared Pick-by-Vision with Pick-by-Paper. 20 inexperienced test persons with an average age of 25.9 years had to pick several orders, each containing 15 parts. The Microvision Nomad HMD mainly displayed textual information in monochrome red color. A forearm keyboard served as interaction device. As a result Tümler found significantly higher headaches using Pick-by-Vision. The subjective strain shows a similar tendency. Analyzing the error rates, he proved an almost four times higher type error rate for Pick-by-Paper. The difference of the omission errors, on the other hand, was not significant. Regarding the task completion time Pick-by-Vision was significantly slower than Pick-by-Paper. 30% fewer components were picked per hour in comparison to paper-based picking. In general, the participants were positive about the use of an AR-system, but not about the one used. They criticized above all the headgear, the occurring headaches and the constant readjustment, which Tümler considers decisive for acceptance [16].

Kampmeier et al. also conducted a laboratory study comparing paper-based working with a HMD as visualization device. In addition, they subjoined a third scenario, in which the participants wore a switched-off HMD and used paper-based work instructions. Thus they could identify wearing comfort-related issues. 45 young participants, mostly students with an age between 19 and 33, had to perform three tasks: order picking, assembly and a manual placement of a fuse box. As hardware they used a Microvision Nomad HMD showing monochrome red colored information in combination with a portable PC attached to a belt as interaction tool. In their study they focused on ophthalmological consequences of a HMD-usage. Based on the study findings Kampmeier et al. conclude that HMD usage does not impair the eyes. In addition the switched-on HMD causes an increased feeling of pressure in the eyes and headache. Using the switched-off HMD two third of the users complain about backache, neck and shoulder pain. Nevertheless they estimate the wearing comfort as acceptable, even though they criticize the headgear, the size of the control device and the fixed length of the cable, which connects HMD and interaction tool. A d2-test of attention [59] did not achieve any significant differences between the scenarios. Regarding the working performance the results were divergent depending on the working task. Assembly tasks with AR-instructions were finished with more errors and with a higher task completion time than using paper-based instructions. The differences in the order picking scenario were not significant. Kampmeier et al.'s final assessment conclude, 'that from a medical and work psychological point of view nothing precludes the full shift usage of an Augmented Reality-system' [42, p.595].

In their user study Büttner et al. tested a combination of picking and assembly tasks with the same visualization in a HMD, on a paper and projected on or rather near the workstation. 13 test persons, aged between 21 and 46 years, mostly unexperienced in assembly tasks had to construct three LEGO animals. They used Vuzix star 1200 glasses as hardware. The results of the study show significant differences regarding task completion time and error rate between the smart glasses and both other methods, whereby the HMD-usage led to the worst results. The task completion time as well as the error frequency were more than 2.5 times higher than the paper- and the projection-based instructions [60].

Guo et al. conducted a user study with 8 participants in which they compared Pick-by-Paper, Pick-by-Light, Pick-by-Vision and a cart-mounted display (terminal). The 22 to 27 year-old, inexperienced participants had to pick a total of 2040 parts. As hardware they used a Microoptical SV3 opaque HMD controlled by a laptop in a backpack. The visualization was a colored context-independent map showing different rack positions. The findings indicate that using the HMD was significantly faster than the light- and paper-based instruction, but similar to the terminal. The error frequency was also significantly lower than using Pick-by-Light and Pick-by-Paper. It was also (not significantly) lower than using the terminal. The subjective strain on the participants resulted in the lowest value for the HMD. In another study, Guo et al. compared the opaque display variant described above with a transparent variant. However, they used a different pair of glasses, namely Google Glass. The results of opaque and transparent visualization were almost identical [45].

Contradictory results are presented by Funk et al. In their user study they compare, similar to [45], Pick-by-Paper, Pick-by-Voice, Pick-by-Vision and a projection based solution. The visualization of the HMD solution is based on [62]. As Pick-by-Vision hardware they used Epson Moverio BT-200 smart glasses.16 unskilled participants with a mean age of 24.81 years (mainly

students) had to pick four tasks in each case with ten steps and 30 items, which took approximately 60 minutes per test candidate. Analyzing the results, Pick-by-Vision turned out to be significantly the slowest alternative, whereas the cart-mounted display was significantly faster than the other alternatives. Regarding the error rates, using Pick-by-Vision led to significantly more errors than Pick-by-Paper, Pick-by-Voice and projection. The absolute value of the HMD was more than nine times higher than the projection- and the paper-based method. The NASA-TLX, which measures subjective workload, resulted in a similar negative finding for the HMD-based solution. The projection-based picking instructions were perceived as significantly less stressing by the participants. An interesting qualitative feedback is that participants liked working hands-free, while handling the paper list limited their freedom of movement [61].
Similar tendencies to Guo et al.'s findings present Reif and Günthner. In a user study with 16 skilled and unskilled participants with an average age of 27.6 years they investigated the difference of Pick-by-Paper and Pick-by-Vision in combination with speech interaction. The results demonstrate a not significantly faster picking using the Microvision Nomad HMD. Analyzing the error frequency the participants made seven times more errors using the paper list than using the AR-system. With reference to the perceived subjective strain, Pick-by-Vison offers a more stressless order picking. Due to the positive results of the HMD-based instructions the participants named the speech recognition as negative aspect in their qualitative feedback. Discussing the findings of the study, Reif and Günthner conclude that their results are not a reliable basis to forecast the effects of an eight-hour usage of smart glasses [26].
Schwerdtfeger and Klinker, who created the term 'Pick-by-Vision', focused on different visualization symbols. In a laboratory study they investigated the differences of an arrow-, a frame- and a tunnel-based context-sensitive guidance for order picking processes. Biocca et al.'s findings served as inspiration for creating the attention tunnel [62]. 34 participants with an age between 15 and 49 participated in the study. Each person picked 27 parts (nine per visualization alternative). Both in terms of the results of the error rate and the task completion time, the frame-based guidance is significantly the best. For this reason Schwerdtfeger and Klinker recommend this display for error-free and fast order picking. Concluding they mention that all findings depend on the quality of the hardware [27].

A related field of research deals with the usage of Augmented Reality in assembly. For more information, see [41] [47] [64] [65]. Comparing both research topics, the difference concerns mainly two essential points. In man-to-goods order picking processes, the employee moves between different positions in the warehouse. The path to be covered can vary between an arm length and a whole factory or storage building. In contrast, an assembly worker in flow production is mostly allocated to a specific assembly process. Therefore he does not cover distances as long as an order picker. Another difference is the importance of information to perform the task. Orders in picking processes are customer-specific and change in most use-cases from order to order, which means that pickers always need information about the required goods including the amount of goods. Performing the process without any information can consequently not be taught. For a visualization context-independent as well as context-sensitive information is suitable. At an assembly workstation the employee assembles supplied components. Every type of product can be built following the same process steps. For this reason an assembly process is largely learnable. A 3D-context-sensitive visualization supports especially beginners through visual guidance. Summing up, visualizations in an order picking context focus on 'what has to be done' whereas visualizations in an assembly context focus on 'how the task has to be done'. Use-cases in logistics concern predominantly the serial usage and use-cases in assembly mainly training scenarios.

1.6 Motivation of this thesis

Comparing the existing studies in literature, explained above, it is noticeable that the findings differ gravely in terms of task completion time, error rate and subjective strain. Based on literature research, no statement can therefore be made whether smart glasses-based instructions make economically sense and whether it is harmless to the user. The contradictory results suggest that the effects on error rate, task completion time and especially the subjective perception of the system depend on the selected hardware and the given task. Due to the rapid hardware development in the last few years, it is necessary to conduct new user studies for recently launched smart glasses on the market. It is also noticeable that most studies were conducted at a reference workstation in the laboratory, which was built specifically for the study [16] [27] [42] [45] [60] [61]. I identify here a lack of experience using smart glasses in order picking processes in a real industrial environment. Pick-by-Vision at a workstation coupled to the rhythm of the assembly line to be supplied therefore still needs to be investigated. All the above studies used predetermined orders. Until now no real-time interaction with a warehouse management system was performed or simulated. Comparing the duration of the studies it ranges between several minutes [27] and two hours [16]. Only Kampmeier et al. tested their HMD during 7.5 hours, but the given tasks like picking LEGO bricks out of a book shelf are not comparable with real industrial order picking tasks [42]. Based on Tümler's proposal of further 8 hours studies, I focus on a full shift usage of smart glasses [16]. Summing up, I formulate the central research question of this research project:

> What is the impact of a full shift usage of smart glasses in industrial order picking processes - with real-time interaction with the warehouse management system - on workers and process?

The term 'worker' means that all participants of the field study to be conducted should be experienced order pickers, in contrast to the test candidates of [16] [26] [27] [42] [45] [60] [61]. As the field study is to be conducted in a real production plant, several workstations can serve as test environment, which leads to a further research question not investigated in laboratory studies:

> How to evaluate the suitability of workstations for an Augmented Reality-usage and how to select the best workstation?

While [16] [26] [27] [42] [45] [60] [61] tested the AR-based system mainly with younger participants with a maximum age of 49 [27], I try in my main study to convince order pickers from early career workers to almost pensioners to be a test candidate. All presented studies used monocular HMDs as visualization device and excluded wearers of corrective glasses, which was also overserved by [60]. For better augmentation, I use in this research binocular glasses. When selecting the hardware, I make sure that spectacle wearers can also participate. There is only one product on the market that meets these two requirements. The ODG R7 of the Osterhout Design Group are binocular smart glasses, which offer the possibility for spectacle wearers to attach extra clips with the individual lens thickness behind the projection glasses. In addition, it has a comparatively large field of view of 30 degrees, which is advantageous for a better immersion. For this reason, these glasses are used as hardware in this research project. Existing publications did not focus on investigating different interaction mechanisms. Most studies used a Wizard-of-Oz-approach [27] [45] [61] or an interaction on the participants' request [42]. Reif and Günther tested a speech recognition, which was seen as negative point by the participants [26]. Tümler decided to use a forearm keyboard [16], which is not a common interaction method in an industrial environment. Since scanning is widely used in logistics areas, I will compare different scanning methods as interaction mechanism.

Analyzing all above-mentioned studies in the Pick-by-Vision-context, a late involvement of the future users is noticeable. Systems, user interfaces and preferred interaction device depends on the user needs. But none of the publications describes a defining process of this user requirements. A collection of the participants' ideas of the future user interface could increase system acceptance. However, such a user-centered design process is not described for Pick-by-Vision. Change loops of system and interfaces according to the users' feedback are also lacking. A similarly late involvement of employees can often be observed in industrial innovation projects, when workers on the shop floor first get in touch with a new technology during a so-called proof of concept. Valuable expert knowledge about order picking processes is subsequently lost. This gap in research and the insufficient involvement of shop floor workers in industry leads me to the following further research questions:

How can an innovation introduction process be defined, in which shop floor employees are involved at an early stage?

How can future users participate in the user interface design without having expert knowledge about the Augmented Reality-technology?

The following chapter describes the single steps to investigate this research questions. In addition, it gives an explication which scientific papers deal with which research question.

1.7 Structure of this thesis

Chapter 1 gives a brief introduction into the theoretical background of the topic. First I describe the dynamic change from flow production towards smart factories (chapter 1.1). Afterwards that chapter 1.2 explains the term Augmented Reality and its fields of application (chapter 1.3). As this thesis focuses on AR in order picking processes, the theoretical background of order picking (chapter 1.4) and Pick-by-Vision-Systems (chapter 1.5) are explained in detail. Based on related work, Chapter 1.6 describes the research gap, the motivation and the aim of this thesis. The current chapter 1.7 gives an overview of the structure of the thesis. The main section consisting of individual publications, which are introduced by short transitions, starts in Chapter 2. A list of all publications can be found on page 7. In the second chapter, a process model for the early involvement of shop floor employees in the introduction of innovations is developed, which was presented at the 20th Congress of the International Ergonomics Association. Another publication, presented at the 9th international conference on Applied Human Factors and Ergonomics Conference 2018, deals with the development of a methodology for assessing the suitability of workplaces for an Augmented Reality-usage in Chapter 3. Chapter 4 contains a methodology for user-centered user interface design for AR interfaces based on design thinking. The publication was presented on the 10th PErvasive Technologies Related to Assistive Environments Conference 2018. Chapter 5 focuses in particular on the selection of suitable interaction methods for communication with the warehouse management system comparing different scanning mechanisms. The publication was part of the Sixth Workshop on Interacting with Smart Objects of the ACM Conference on Human Factors in Computing Systems 2018. After selecting the form of interaction in the preliminary study, the main study in Chapter 6 forms the core of this thesis. A full shift study in our production plant investigates the impact of using smart glasses on worker and process. The presented paper is accepted by the International Journal on Interaction Design & Architecture(s). Chapter 7 contains a discussion of the findings. In addition, further potentials of the technology are pointed out. One of these potentials, language-independent working by AR-support, is analyzed in detail in a further publication. This paper was presented on the10th PErvasive Technologies Related to Assistive Environments (PETRA) conference 2018 in the 2nd International Workshop on Designing Assistive Environments for Manufacturing. In the annex is another publication, published in German at the Spring Congress of the Gesellschaft für Arbeitswissenschaft, dealing with another possible application: motivation through gamification. Chapter 7 discusses the research results, answers the research questions and points out the potentials for future research. Figure 7 shows an overview of the chapters and the containing publications, marked by a document symbol.

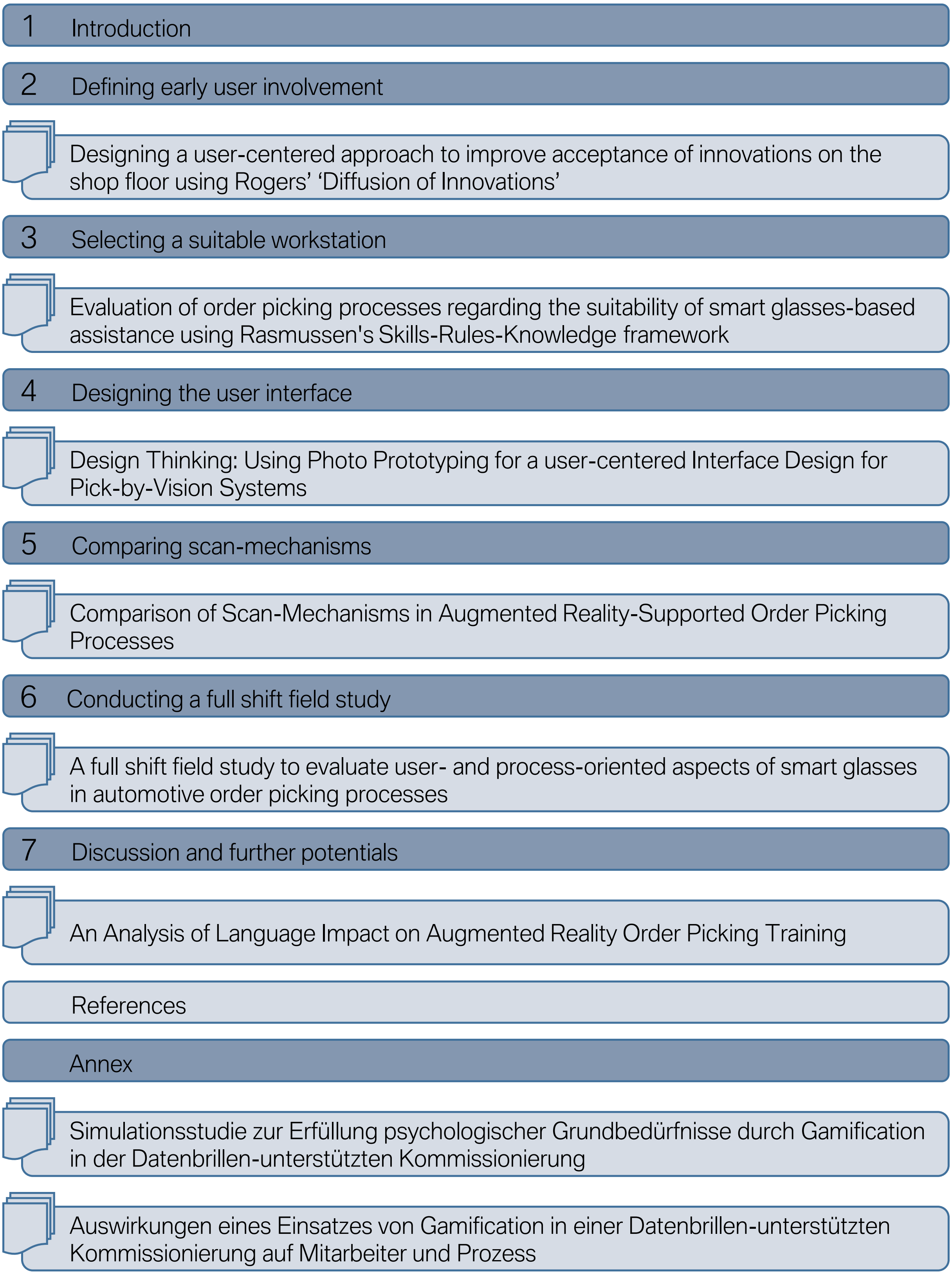

Figure 7: Structure of this thesis

2 Defining early user involvement

The user's acceptance of new technologies strongly depends on the involvement and subjective attitude towards the technology. Dealing with newly emerging technology, with which users have not yet encountered, reservations can occur. Thus barriers must be considered and overcome when introducing innovations [66]. This also applies to smart glasses. Koelle et al. investigated which factors support an adoption of smart glasses. They named 'Usefulness', […] 'Functionality' and […] 'Usability' as most crucial to long-term adoption' [67, p.298]. While functionality mostly refers to hardware-related issues, usefulness and usability aim at finding a suitable use case and designing visualizations and interaction in a user-centered way.

Planning the introduction of smart glasses in a shop floor environment, the functionality of the hardware can hardly be influenced. Not being not a hardware producer, it is helpful to constantly analyze the market and compare the functionalities of emerging new devices. On the contrary usefulness and usability can positively be influenced by selecting the right use case and by designing visualization and interaction methods customized exactly to the user's needs. This user-centered approach is widely spread in product development for commercial issues. At the shop floor, where workers are the customers of the innovation development process, the involvement of future users and user-centered development focusing on the workers' needs is an unusual way planners choose. Often testing or implementing innovations is planned by office employees, who do not have sufficient insight into the daily working life on the shop floor. Despite of the workers' expert knowledge regarding the improvement of the process, I observe user involvement mostly at a late point of time when performing a so-called proof-of-concept. Following Koelle et al.'s suggestion of more research 'involving in-depth requirement analysis' [67], I focus in the following publication on defining an innovation introduction process, which allows an early involvement of shop floor workers. This chapter answers subsequently the following research question:

> How can an innovation introduction process be defined, in which shop floor employees are involved at an early stage?

The following publication 'Designing a User-Centered Approach to Improve Acceptance of Innovations on the Shop Floor Using Rogers' 'Diffusion of Innovations'' was presented at the 20th Congress of the International Ergonomics Association (IEA) 2018.

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Designing a user-centered approach to improve acceptance of innovations on the shop floor using Rogers' 'Diffusion of Innovations'

Nela Murauer

BMW Group, Max-Diamand-Str. 5, 80788 Munich, Germany
nela.murauer@bmw.de

Abstract. Analyzing innovation implementation processes in theory and in the industry different approaches are observable. Whilst in Rogers' 'Diffusion of Innovations' the future user is the initiator of the implementation process, the situation is different for shop floor innovations. Mostly, it is a planner or an innovation scouting department, who decide to implement a new technology. The workers as future users will be involved later for the purpose of a proof-of-concept. This late time of user involvement often leads to a low acceptance rate. In order to enhance user acceptance in a shop floor context this paper proposes a user-centered approach of innovation implementation based on Roger's model. As a first step of the industrial application, I conduct guided interviews to involve workers into the process of my innovation use-case on smart glasses in order picking processes.

Keywords: acceptance of innovations, shop floor, logistics, user-centered development, Augmented Reality, smart glasses, order picking processes

1 Introduction

Today's challenge for manufacturing companies lies in shaping the fourth wave of the industrial revolution. In the automotive industry the use of smart wearables, robotics, and autonomous transports or for example predictive maintenance advance with the aim to create smart factories. While robotics change the assembly process, autonomous transports impact greatly on intra-logistics. An important process in intra-logistics are order picking processes. Specific to order picking processes is the degree to which automatization differs depending on the tools in use (pick-by-paper, pick-to-light, pick-by-voice, pick-by-vision, etc.). All these systems are based on human work. Especially order picking processes can benefit significantly from the picker's flexibility in task management, reaching and grasping objects with high accuracy [1]. Thus full automatization is not suitable for order picking workplaces, but the usage of assistive devices can be advantageous. For this reason, I focus in my research project on testing the use of assistive devices, in particular Augmented Reality (AR)-devices, called smart glasses.

Most research projects do not sufficiently involve the shop floor-employees from the beginning of the innovation process. Comparing the frequently cited process model in Rogers' 'Diffusion of Innovations' [2] to the usual innovation process management in the automotive industry, I found the same tendency in being output- or process-focused instead of being user-centered. Innovations are thus mostly introduced in a top-down approach. For this reason, I saw the opportunity to modify Rogers' model for the context of shop floor innovations. There are two principal initiators for innovations, first the planner and second the shop floor-employee. These two roles pursue different aims, which can be ergonomic (improve working conditions and work tools) or economic (such as improvement of time, quality and costs). Regularly shop floor-initiated innovations are based on the outcome of CIP (continual improvement process). In contrast to these incremental innovations, many planners find it also necessary to pursue disruptive innovation and to shape the dynamic change towards a smart factory. In innovation projects the involvement of the workers can just be as difficult as it is important. Rogers' model includes five phases: *knowledge*, *persuasion*, *decision*, *implementation* and *confirmation* [2]. Even though planners and management pass through all phases, the workers may influence the innovation development only from the decision phase onwards – provided that they exert any influence. Tackling this lack of early involvement in future users, this paper proposes to attach a separate consultation cycle consisting of a (continual) knowledge, persuasion and decision phase for the shop floor-employees. By consulting the workers concerning their needs at the operational level, workers take the role of experts, and can subsequently influence the final product for implementation. I aim to gain higher acceptance for innovations by creating consensus in the shop floor environment.

Applying the described user-centered cycle approach to a practical example, the innovation process of my research project started with an interview series to create a knowledge basis and start the workers' persuasion phase. The interview series - including 14 employees working in the logistics department - focused on previous experiences with smart glasses, knowledge about the technology, ideas about possible changes to the process, the suspected advantages and disadvantages as well as the beneficiaries of smart glasses-assisted order picking processes.

2 Related Work

The theory of the Diffusion of Innovation was originally developed in the context of agriculture to explain the ways, reasons and speed of innovations. Rogers' theory swept as translational knowledge into many other sectors such as communication, economics or public health. Rogers analyzed in his research for example a failed diffusion, where only few people in the Peruvian village Las Molinas took up the practice of boiling water to decrease germ load [2]. If, as described in the example above, the rate of adoption is too low, few potential future users are reached. Generally, Rogers defines diffusion as a 'process by which an *innovation* is *communicated* through certain channels *over time* among the members of a *social system*' [2]. The social system, where implementation takes place, depends on the work environment. For this reason innovation should best be introduced at a workstation, which enables smooth diffusion. The acceptance of an innovation can be maximized when future users understand its usefulness and efficiency. Hence, the perception of innovation within a social system can be a limiting factor and can slow the rate of adoption.

As mentioned before, the innovation-development process after Rogers consists of five main steps: *knowledge*, *persuasion*, *decision*, *implementation* and *confirmation* (see Fig. 1).

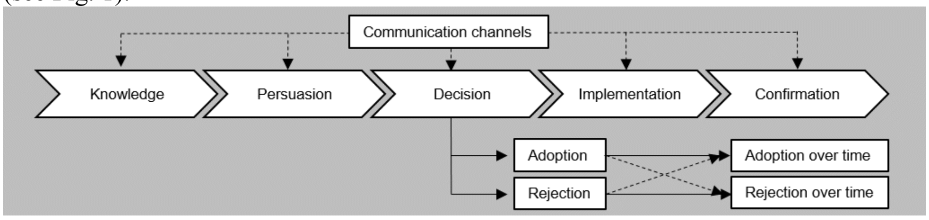

Fig. 1. Five phases of innovation development based on [2]

The knowledge phase serves to understand the functionality or purpose of an innovation. The persuasion phase gives a foundation for taking a favorable or unfavorable attitude. Building on the persuasion phase, the decision phase, which includes first tests, guides to a decision pro-adoption or pro-rejection. Once a decision is taken in favor of adopting the innovation, it can be implemented for regular use. The confirmation stage includes the review of the previous decision concerning further activities of dissemination.

3 Methodology

Comparing Rogers' innovation decision process with common innovation implementation processes in the automotive industry, I detected several differences. During my research, I observed different innovation processes in the context of bringing innovative technologies such as robotics, wearables, tablets or scanners to workstations on the shop floor. According to Rogers' innovation decision process future users hear about innovations, then obtain information about these, are subsequently convinced by the new knowledge and decide whether or not to use the innovation. In contrast, the phases at the production plant are different. Rogers concludes that early adopters are often individuals who do not have a great need for the innovation; while individuals with a higher need (based on factors such as education, socio-economic status and other determining factors) are later beneficiaries [2]. At the plant, those who are closest to the innovation - the workers – are usually not encouraged to join the group of early adopters either. At our production plant I observed two ways of improving processes. First, the continuous improvement process (CIP) collects all ideas of the shop floor workers to improve their processes. Improvements can consist of proposals to implement another technology, avoid unnecessary time spent on longer walking routes, energy or materials, or support for ergonomic work. Together with lean management planners, the employees plan, test and implement their ideas. Especially in the context of digitalization special knowledge is needed to get an overview on potential innovations, their readiness for implementation and possibilities for process improvement. Second, in production contexts innovation scouting departments analyze upcoming innovations, which are interesting in terms of implementation at the production plant and decide to test potential improvements in a so-called 'proof-of-concept'. If this test is successful, a roll-out of the innovation begins (see Fig.2). Summing up, the planner passes through the knowledge and persuasion phase and decides - alone or in an expert team - whether an innovation will be tested on the shop floor. In contrast the worker often learns through the planner-initiated proof-of-concept about the innovation. In my research project my role is similar to an innovation planner. Yet, my research project on the usage of smart glasses in order picking processes takes a different approach and is conceptualized in such a way that workers are encouraged to become early adopters. In the following, I describe my approach to design a more user centered innovation process.

At the beginning of my research project, I decided to work one week during the morning shift at a number of order picking workstations, which could be possible workstation for the main study. I viewed the workers as experts in order picking from the start. According to workers at the operational level, it is common that employees 'from the offices' implement a decision for a process improvement or an innovation without talking (enough) to the workers - the future users. Due to this manner of implementation, the operational employees often have a negative attitude towards innovations and must be convinced of the usefulness of an innovation after the decision for implementation has already been made. In order to avoid such negative experiences which shop floor workers connected to innovations, I tried to involve workers as much as possible during the innovation process.

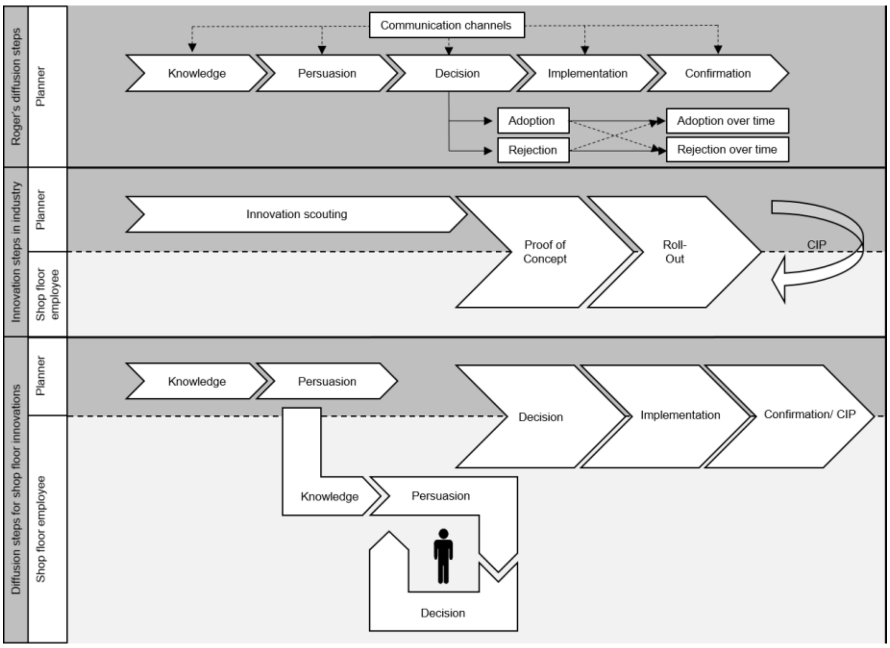

Fig. 2. Comparison of innovation processes according to [2], in the industry and our proposed process for the shop floor context.

Fig. 2 shows the role-specific approach to an innovative project. The planner starts the process by scouting innovations (knowledge phase). He evaluates the upcoming technologies according to - for example - their potential of process improvement or economic efficiency and other characteristics, which support business strategies. During the persuasion phase he provides information to workers about the innovation, how it works, and what the differences, major risks and chances in comparison to the actual process are. The planner's job includes the creation of a common understanding of the technology. During the persuasion phase of the workers, their expert knowledge about the process can be a great input and of high value for the planner. Based on this input the planner develops a first prototype, which can be evaluated and improved and asserted several times until the worker's decision phase is ultimately completed. Shop floor employees and planer decide subsequently together which developed solution would be the best fit for the test (as part of the proof-of-concept). Of particular significance is a test for a company when it is conducted under real production conditions with the workers, the future users, as participants. Collecting the users' feedback and their preliminary assessment - whether the innovation can be permanently implemented - helps the planner and the management to decide in a user-centered way. It must be noted here, that some advantages like economic reasons can be rated more important than the workers assessment due to prioritizations in business strategies. One example where the interests of the worker and the company will not align are use cases where an innovation can replaces an employee. Shop floor employees will rarely agree with such an innovation. Nevertheless it is important to involve affected employees working at the workstation, where a technology may be introduced during the decision phase. This gives workers a chance to get acquainted with the new technology and know what changes are likely to occur to their work environment. The final decision will be made by the planner or the manager based on the worker's assessment and the business strategies. Once an innovation is implemented, the planner relies on the worker's feedback to navigate through the confirmation phase.

4 First steps of the industrial application

The environment of my research project are manual man-to-goods order picking processes. Following the instructions of an order list printed on paper or visualized on a digital device, the worker collects products or components and puts them into target bins or shelves. This process is very similar to a shopping process in a supermarket with a prepared shopping list. I, in my role as innovation planner, focused on smart glasses as visualization device. I compared different hardware, advantages and disadvantages, possible use cases and related work. I was persuaded to test smart glasses at our production plant due to the benefits, which the implementation of AR promises. The stages I passed through correspond to the knowledge and the persuasion phase of the planner (see Fig. 2).

4.1 Interview methodology

In order to involve workers into the innovation process, I first conducted guided interviews consisting of seven questions. In the beginning, I aimed to explore the respondents' knowledge and ideas on AR-technology. I asked the participants whether they had contact with Augmented or Virtual Reality (question Q_1). Then I inquired the respondents' understanding of the term 'smart glasses' in question Q_2. In question Q_3 I asked the pickers to describe how order picking workstations with AR-support look like in their imagination and how workstations will change due to the introduction of AR-technology (question Q_4). All questions served as a means to initiate the knowledge phase. Hereafter, I showed a short video prototype, which visualized an AR-design sample for the pickers. I produced this video by filming the order picking process at a workstation with a head-mounted camera GoPro® Hero 5 and overlaying this base film with a possible user interface design with the Adobe After Effects ® program. This form of prototyping helped respondents, who were unfamiliar with AR, to get an idea of the future process. For further information about prototyping methods in the AR-context see [3]. Showing the movie explained the technology to future users. This explanation is an important step to inform shop floor employees about the innovation. Thus the interviews and presentation of the movie are the starting point of the workers' knowledge phase. In this way the future user is guided to the knowledge phase by the planner. In my experience, most shop floor employees will not engage in additional technological research, hence their persuasion phase starts immediately after the planner's explanation. I supported the transition to the persuasion phase by asking the participants, what they liked and what they did not like thinking about AR-supported order picking processes (questions Q_5 and Q_6). The final question Q_7 inquired after the respondents' opinions on the potential beneficiaries of an AR-usage.

A total of 14 employees with varying roles in the logistics department participated voluntarily in the interview series. By involving mainly pickers (who are the future users of the technology), foremen, but also logistics planners, innovation experts for order picking processes and department leaders I aimed to gain a wide range of ideas and comments. The analysis of the interviews followed the step-by-step clustering process published by Meuser and Nagel [4].

4.2 Results

Only few of the interviewees already had contact with Augmented or Virtual Reality (Q_1). As examples they named a Samsung Gear, Head-up Displays in cars, Nintendo's AR-game Pokémon Go, 3D cinema and video games. One participant of an innovation department already tested some smart glasses, like for example a Google Glass. Most participants heard about the technology, but never tested it by themselves.

Summarizing the basic notions of smart glasses from the pickers' point of view, most of the descriptions were use-case rather than hardware specific. Smart glasses from their perspective are 'computerized glasses', 'like a head-up display for humans', which 'support workers' through the visualization of 'the most important information' like 'images, forms, colors, data and facts' 'in the field of view'. Processes will be 'facilitated'. 'I see [in the smart glasses], what I have to do', summarized one picker. This process transformation caused nevertheless few negative associations. 'The individual fades into the background', 'is there still a human or only half human half robot?' and 'This is a dehumanization.' Workers evaluated their employment only for their physical power and not for their cognitive abilities negatively. An interesting fact was that some participants already criticized the smart glasses in the first definition question.

They expected that an AR-supported workstation will be faster and more flexible through the avoidance of head- and eye-movements, through the visual highlighting for minimizing the risk of confusion and especially through a lean visualization of required information. Some of the interviewees thought that the project will produce individualized user interfaces. One participant could envision to integrate actual soccer results during the evening shift as additional information or brain teasers to enhance concentration and attention during the day. Most participants assumed that the AR-support at an order picking workstation avoids errors. All answers were very goal-oriented and few process-describing. The next question addressed the changes caused by an implementation of smart glasses. The answers were quite similar to the previous question. With AR, in their opinion, the visualization will be clearer and the pickers will know faster, what they have to do. They thought that particularly the error frequency, the task completion time and the training time will decrease, which they viewed as positive aspects.

In addition to the above issues, the participants liked the expected support of the smart glasses, which could lead to 'more skilled and more confident' employees. Due to the decrease of error rates and a higher efficiency, the production plant will become 'more future-proof and competitive'. This is an important base for the employees to 'identify [themselves] with the company'. Negative comments were related to hardware limitations like battery life and wearing comfort and to the dependency on the IT-department or the supplier in case of software changings. In addition, they had doubts that refocusing the eyes will be too demanding.

With reference to the beneficiaries, the interviewees' answers were similar. The expected benefits are on the one hand more flexibility for the employees, a calmer process and a decrease of the error frequency. In their opinion the company and the management on the other hand profits from time-, cost- and error decrease, a reduction of rework, faster training times and a guided, language independent training possibility.

5 Discussion & Conclusion

The time and grade of involvement into an innovation process in a shop floor environment depends on the role of the employees. In contrast to Rogers' 'Diffusion of Innovation' the planner or an innovation scouting department rather than the worker initiate the innovation process. To support the earlier involvement of shop floor workers, a new process model based on Rogers' 'Diffusion of Innovation' for a production context was created. The active consideration of the workers' expert knowledge serves to design an optimal user-centered solution.

In the interviews workers wanted an easy, clear and comprehensible visualization of a future Augmented Reality user interface design. To develop the software according to the employees' comments and ideas, I plan to conduct a creative workshop directly on the shop floor. Due to the lack of a suitable method for creating AR-content, I will develop a tool for motivating the participants to uninhibitedly design their ideas of a possible user interface of smart glasses. The objective is to find a common ground for discussions with workers, who do not have any know how regarding Augmented Reality or smart glasses.

The idea which will be seen as most suitable, will be programmed and evaluated, continuously redesigned and evaluated until the workers decide, that it is perfect from their point of view. This describes the whole human-centered development circle shown in Figure 2. The next step will be a test phase, which is classified under the process step 'decision phase' directly after the circle. The results of the field study, which contains user-related as well as process-related variables, supports the later decision process toward a roll-out into the production environment.

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3 Selecting a suitable workstation

In Chapter 2, I developed a procedure for the early involvement of users in the innovation process. As a first step, I conducted guided interviews. These interviews served on the one hand to achieve a common understanding of the technology (knowledge phase of the worker) and on the other hand to collect first arguments for and against the technology based on the expert knowledge of the employees initiating the persuasion phase of the employees.

Chapter 3 contains the next step in which I search for a suitable test environment. Not every workplace is equally suitable for the usage of smart glasses. In literature research, I found few methods evaluating the suitability for AR-usage. Wiedenmaier presents an approach using Rasmussen's skills-rules-knowledge framework to evaluate the suitability of different activities for AR-support [41]. Based on this approach, I compare all potential workstations in our factory with the support of planners and employees having the aim of finding an ideal test environment for the Pick-by-Vision-system. This chapter answers subsequently the following research question:

> How to evaluate the suitability of workstations for an Augmented Reality-usage and how to select the best workstation?

Since this step is done in preparation of the later user-study in the decision phase, it represents the persuasion and decision phase, which is a continuous circle around the employee, in the process model designed in Chapter 2 (see Figure 8).

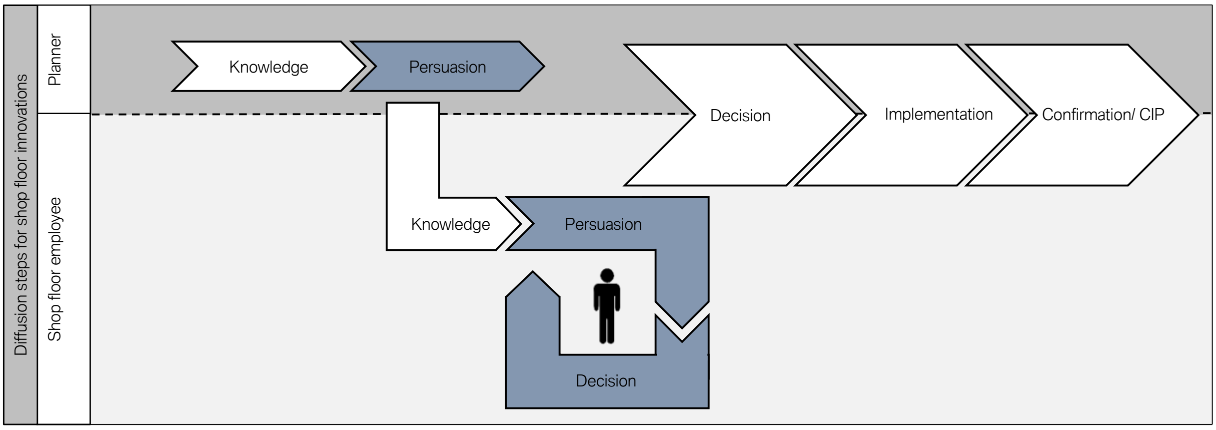

Fig. 8: Involving the user during the selection of a suitable workstation

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Evaluation of order picking processes regarding the suitability of smart glasses-based assistance using Rasmussen's Skills-Rules-Knowledge framework

Nela Murauer[1], Steffi Gehrlicher[2]
[1, 2] BMW Group, Max-Diamand-Str.5, 80788 Munich
[1] nela.murauer@bmw.de, [2]steffi.gehrlicher@gmx.de

Abstract. Augmented Reality (AR)-technologies are an important part in the change towards digital manufacturing. Fields of application are assembly, order picking and maintenance. For a full-shift study evaluating smart glasses in order picking processes, we selected the most suitable workplace in logistics area using Rasmussen's Skills-Rules-Knowledge framework. Since the classification into Rasmussen's three levels of human behavior has been quite subjective so far, we propose a more objective approach based on a pairwise comparison and a cost-utility analysis. Developing this method, we define numeric boundaries between the three levels of Rasmussen's framework. After the evaluation by ten experts, we selected the best workstation for our future full-shift study at BMW Plant Munich.

Keywords: Rasmussen's Skills-Rules-Knowledge framework · smart glasses · Augmented Reality · logistics · order picking processes

1 Introduction

The increasingly dynamic transformation process changes from a traditional flow production to a smart factory. The usage of wearable devices supports the change towards digital manufacturing. Especially Augmented Reality (AR)-technologies such as smart glasses provide a benefit in facilitating hands-free work while simultaneously displaying additional information. Our research project tests smart glasses for order picking-processes in full-shift usage.

Before testing begins, it is necessary to select the best picking workplace at our automotive plant for the employees. Relying on the Skills-Rules-Knowledge framework of cognitive control levels [1], activities can be classified into three levels: *skill-based, rule-based* and *knowledge-based*. [2] assumed that AR is only helpful in all rule-based activities. Skill-based activities have no need for displaying information and knowledge-based activities are too complex and unexpected to prepare enough information in the AR-glasses. Each picking process consists of several steps of varying complexity. In our new evaluation methodology, we add previously unlisted cognitive process steps to analyze the possibility of AR-assistance. Our evaluation procedure is similar to a *utility analysis*. Every work task is rated according to the criteria of activity itself, the required information for the task, the experience and the error susceptibility. The activity-criterion is subdivided into *perceptual, motor* and *cognitive workload*, based on the Model Human Processor [3]. Logistics experts weight these categories using a pairwise comparison. Afterwards they evaluate the activities by category. Multiplying the weighting factor by the absolute score and adding up the individual categories yields a classification score. A higher classification score indicates knowledge-based and a lower one implies skill-based behavior. Previously assessed examples of a literature review serve a basis for dividing the three Rasmussen-levels. Calculating the proportion of rule-based activities at each workstation supports the comparison of each workstation regarding AR-technologies.

2 Related Work

2.1 Augmented Reality in assembly and order picking

Augmented-Reality (AR) refers to augmentation of the reality by displaying virtual information. The combination of reality and virtuality creates a new environment between real world and virtual world [4]. The use of AR-visualizations is possible in different fields of applications. Various studies in the military context [5], in architecture [6, 7], in health sciences [8, 9] in order picking [10, 11, 12, 13, 14, 15] and in assembly [16, 17] show the wide range of future possibilities of this technology.

In the production context literature research reveals many studies using head mounted displays (for the purpose of this paper we refer to 'smart glasses') for assembly or order picking processes. Most publications do not describe the selection of the test environment. [15] compare order picking and assembly processes with the assistance of projection and smart glasses. For their laboratory study, they build an order picking workstation and ask the test participants to assembly LEGO® animals. [14] evaluate smart glasses in order picking processes as well. Similar to [11, 12, 13 and 15], [14] build their study environment by themselves and do not select a special workstation in a real production plant, which benefits especially from the AR-usage compared to other workstations. [18] focus their laboratory study on ophthalmological impacts on workers analyzing assembly and order picking tasks supported by smart glasses. [18] create three different tasks to shed light on the usefulness for AR-support. Where additional context-sensitive visualization of information is helpful, AR-support can be considered. [2] presents an interesting approach analyzing different tasks using Rasmussen's Skills-Rules-Knowledge framework. [2] classifies assembly tasks into the three levels of human behavior (*skill-based, rule-based* and *knowledge-based)*. We explain Rasmussen's framework in detail in capture 2.2. According to [2], especially the medium level of rule-based human behavior is suitable for AR-support. [10] relies his workstation selection on research from [2]. [10] defines rule-based order picking tasks as complex activities of high training effort, where support by additional information is needed. After comparing test conditions of assembly, order picking and quality assurance, he selects an order picking workstation as test environment. Hence, [10] focuses on the best test environment and not on choosing the best AR-supportable activity during the selection process.

Our research project is a field study in an automotive production plant. Thus, we decided to select our test environment according to [2] based on Rasmussen's Skills-Rules-Knowledge framework [1], which we explain in detail in the following.

2.2 Skills-Rules-Knowledge Framework

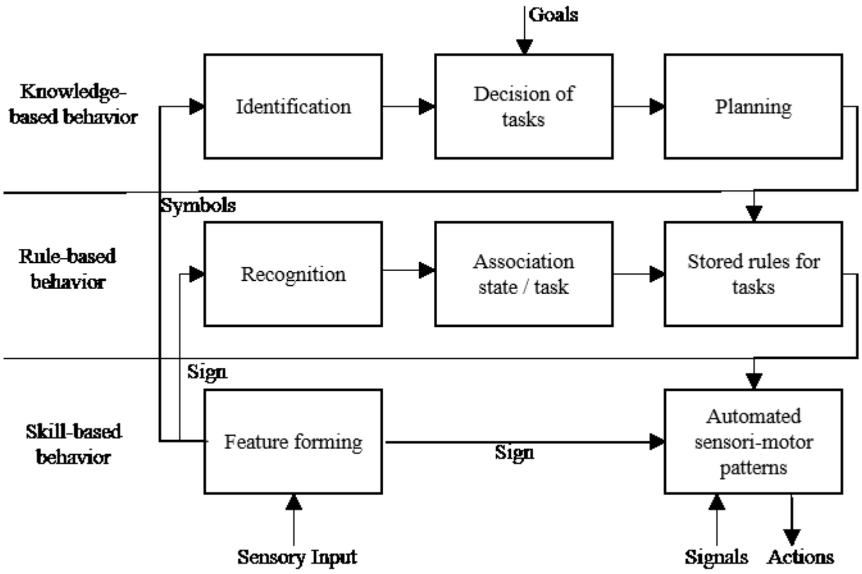

Fig. 1. Skill-Rule-Knowledge Framework based on [1]

Rasmussen's framework describes three regulation levels of human behavior: skill-based, rule-based and knowledge-based behavior. 'The skill-based behavior represents sensory-motor performance during acts or activities which, following a statement of an intention, takeplace without conscious control as smooth, automated, and highly integrated patterns of behavior' [1]. He names drawing or simple assembly tasks. 'At the next level of rule-based behavior, the composition of such a sequence of subroutines in a familiar work situation is typically controlled by a stored rule or procedure which may have been derived empirically during previous occasions, communicated from other persons' know-how as introduction or a cookbook recipe, or it may be prepared on occasion by conscious problem solving and planning' [1]. At this level of behavior humans profit from stored and usual behavioral patterns, which they learned in similar situations in the past. Actions base on if-then-rules [19]. The knowledge-based level describes goal-controlled considerations, which action alternative would be the best to achieve the goal. [1] defines this level as follows: 'During unfamiliar situations, faced with an environment for which no know-how or rules for control are available from previous encounters, the control of performance must move to a higher conceptual level, in which performance is goal-controlled and knowledge-based'. Table 1 shows examples of already classified tasks to a level of human behavior according to Rasmussen's framework.

Table 1. Examples of skill-, rule- and knowledge-based tasks in literature

Activity	Skill-based	Rule-based	Knowledge-based	Reference
Steering behavior	Experienced driver	Novice driver	Swerving	[20]
Driving	Stabilization	Driving maneuvers	Guided by navigation-system	[21]
Navigation planning	Daily way to work	Selection between known ways	Foreign Metropolis	[20]
Water tap	turning	Sensor below tap	Foot pedal	[20]
Pressure flow sensory	signal	Sign (if valve is open, then…)	Symbol (functional thinking)	[1, 22]
Height control of an airplane	Keep height	Adjust angle of climb	Motor speed too low	[1]
Assembly	Clip assembly	Harness assembly	Assembly of window regulators	[2]
Orientation in a city	No auxiliary means (known city)	Following landmarks	Supported by map	[23]

Classifying a task into one of the three levels depends on the person's experience level. Training and repetition should cause a level-down grade, but this level 'jump' is not taken into account. Thus, different training states lead to smooth transitions instead of clear boundaries between the performance levels [1, 2]. According to [2], task classification can change from rule-based to skill-based with repetition.

2.3 Utility analysis and pairwise comparison

The methodological context of this paper is based on a *utility analysis*, which prepares a 'systematic decision-making' between competing alternatives in order to identify the alternative with the highest utility score [24]. Such a utility analysis structures the evaluation of all possible alternatives in six steps. The first step identifies each possible alternative, the second step designs a matrix with all alternatives and criteria for a comparison of these alternatives, while the third step standardizes the evaluation scale, for example '1-2-3'. The fourth step attributes a specific weight to the evaluation criteria using *pairwise comparison*. Pairwise comparison supplements the inter-relational weighting between the evaluation criteria in the 'n x n – matrix' comparing each processual criterion with all other processual criteria. In each cell, the choice is between two processual criteria [24, 25]. In pairwise comparison, ratings may be 2 points for 'criterion A is more important than criterion B', or 1 point for 'criterion A is just as important as criterion B', or 0 points for 'criterion A is less important than criterion B'. The principle diagonal stays unassessed and grey in the matrix. The fifth step sets a partial utility value and the last step computes a final utility score by multiplication of partial utility scores with the weighting factors [24, 26, 27]. Afterwards, each partial result of one alternative is then summed up to an outcome score. The ranking orders the alternatives from the highest to the lowest score.

3 Methodology

In order to select the most suitable workplace for the usage of smart glasses, the process steps of the workstations are correlated with the levels of the Rasmussen model. The workstations are more suitable for AR-use when they contain process steps, which belong to rule-based behavior. For such an approach, the process is divided into small tasks until each task contains only one activity type. In doing so, process descriptions of the MTM (methods of time measurement) indicate times for the individual process blocks. These are typically reach, grasp, bring, position, release.
To assess the process steps objectively, the principle of utility analysis is applied. The process steps are assessed under a set of criteria. Each criterion is evaluated separately. This procedure requires a uniform rating scale. The pairwise comparison of the individual criteria leads to the weighting of the criteria. A multiplication of the individual partial scores by the weighting scores and the subsequent addition of these outcomes give a classification value, which allows a comparison of the different process steps. This resulting value is referred to as 'Rasmussen index' 'r'.

$$r_n = 1/3\,(p_a\, a_{m,n} + p_a\, a_{s,n} + p_a\, a_{c,n}) + p_i\, i_n + p_e\, e_n + p_s\, s_n \qquad \textbf{(1)}$$

Rating categories are the complexity of the activity (a_n), amount of required information (i_n), experience (e_n) and error susceptibility (s_n). The *activity* category involves evaluating the complexity and difficulty of the process step. For a more detailed assessment of the category *activity*, we introduce the three subcategories *motor, sensory* and *cognitive* based on the model Human Processor [3]. *Sensory* describes the seeing, hearing and feeling, *motor* symbolizes effort and *cognitive* represents the processes in the human brain. These four overall criteria are weighted by using pairwise comparison in expert interviews. The *activity* score in the pairwise comparison results from dividing the sum of motor-driven, sensory and cognitive scores by three.

2: more important
1: just as important
0: less important

	Activity	Required infor-mation	Experience	Error suscepti-bility
Activity				
Required information				
Experience				
Error susceptibility				
Weight	p_a	p_i	p_e	p_s

Fig. 2. Pairwise comparison for classifying tasks into Rasmussen's framework

The rating scale is a 1-2-3 scale. In the *activity* category, a 0 score for "no activity" is also a valid rating. Evaluating a 'remember' process step, for example, does not require motor activity. All other activities are classified from low to high. The number of required information can be evaluated as 1 (dispensable), 2 (supportive) and 3 (essential). Experience scores are considered in reverse order, whereas lower experience leads to a higher classification in Rasmussen model. Under the condition, that someone has a lot of experience and a certain routine in fulfilling a task, the activity can fall by one level in the Rasmussen. The higher the error susceptibility of a process step, the more complex and less automated it is. Therefore rating scores can be 1 (barely), 2 (moderate) or 3 (high).

Table 2. Rating scale

Category	Rating			
Activity	0 (none)	1 (low)	2 (moderate)	3 (high)
Information		1 (dispensable)	2 (supportive)	3 (essential)
Experience		3 (barely)	2 (moderate)	1 (substantial)
Error susceptibility		1 (barely)	2 (moderate)	3 (high)

In order to assign different values of the Rasmussen index ‘r’ (see formula 1) to the three levels of the model, we conducted a literature analysis on example descriptions, which already classified these according to the Rasmussen levels. The research project verifies these classifications through the procedure described above. The assumption is that the associated level was already established. Using the results of our industrial use case (generated by expert interviews) determine the prioritization values p_a, p_i, p_e and p_s. By calculating the Rasmussen index ‘r’ and considering existing classification for the literature examples into the three levels of the model, three ranges of values are found. Having identified these ranges, each value now references a level.

Table 3. Rasmussen framework – Boundaries between levels

Level	Rasmussen index ‘r’	Smart glasses support
Knowledge-based	2.60-3.00	complicated
Rules-based	1.50-2.59	reasonable
Skill-based	0.79-1.49	not reasonable

Using the described approach, human behavior can be classified to the skill-based, rules-based, or knowledge-based level. The evaluation shall be based on expert interviews. The obtained values of the surveys are averaged. It shall be emphasized that the item *experience* can be assessed with a specific person in a specific situation. For example, a driving task is rated differently for a beginner than for a substantially experienced motorist. Changing the *experience* variable from 3 to 1 may lead to classification of the task at a lower level. This is a solution to one of the main criticisms of the Rasmussen framework.

4 Industrial application

At the BMW Plant Munich we will test the usage of smart glasses in order picking processes. Until now, a screen displayed required information for order picking processes. Smart glasses shall show this information from now on. It is essential to choose the most suitable out of nine possible so-called supermarkets (order picking workstations in the logistics area) for a full-shift study.

We prepared the expert interviews analyzing so-called “standard work sheets”, which explain the order picking process step-by-step. During this comparison, we noted that the process descriptions differed in detail. This suggests that different logistics planners described the standard worksheets. For this reason, we standardized the nine process descriptions to the same level of detail. Process descriptions in the production environment describe physical and visible activities. Cognitive processes are missing. Thus, we added the process steps memorize, read and compare visual information. After comparing the workstations, we noticed that the process of each workstation contains the same basic process steps. These are *grasping, reading, memorizing, comparing visual information, spatial orientation, walking, positioning without prior selection, positioning with selection, final control, switching monitor* and *cleaning workstation.* Ten production experts from various divisions of the company, for example logistic planning, assembly planning, operative factory logistics, quality and process improvement in the plant and the innovation areas in logistics and engine construction, were evaluating.

4.1 Pairwise comparison

Every expert conducted the pairwise comparison by him- or her-self. It was noticeable that, quality experts classify the experience as less important than error susceptibility. Planning experts, on the other hand, classify the experience as more important than the error susceptibility and rely on the experience-based recognition and correction of errors. After averaging the values, the relative weighting of the activity itself was about 21%, the number of required information about 26%, the experience about 29% and the error rate about 24%. The one-third of the criterion activity gives a weighting of about 7% for the sensory, motor and cognitive load. Figure 3 shows all determined values.

2: more important
1: just as important
0: less important

	Activity	Amount of infor-mation	Experience	Error suscepti-bility
Activity		14	10	12
Amount of information	6		11	9
Experience	10	5		7
Error susceptibility	8	11	13	
Sum	24	30	34	28
Weight	0.206897	0.258621	0.293103	0.241379

Fig. 3. Pairwise comparison in industrial application

4.2 Evaluation of the process steps

After pairwise comparison, the experts individually assessed the basic process steps using the rating scale defined in the section above. At an order picking workstation the ‘final control’ is the most complex activity. Due to different skill- and education-levels in different contexts or jobs, we advise a context-specific evaluation.

Table 3. Evaluation of exemplary order picking process

Process step	Sensory activity	Motor activity	Cognitive activity	Required information	Error susceptibility	Experience	**r**	Experience	**r**
grasping	1.9	2.8	1.0	1.2	1.2	1.0	**1.29**	3.0	**1.87**
reading	1.9	0.3	2.1	2.8	1.9	1.0	**1.77**	1.0	**1.77**
memorizing	0	0	2.9	1.5	2.8	1.0	**1.56**	1.0	**1.56**
Comparing visual information	0.5	0.3	2.7	2.9	2.8	1.0	**1.96**	3.0	**2.55**
Spatial orientation	1.7	0.2	2.8	2.7	2.1	1.0	**2.10**	3.0	**2.41**
Walking	1.1	2.5	0.8	1.0	1.0	1.0	**1.10**	1.0	**1.10**
Assembly	2.2	2.8	1.1	2.0	2.2	1.0	**1.70**	3.0	**2.35**
Positioning without selection	1.0	2.1	0.9	1.7	1.0	1.0	**1.25**	3.0	**1.83**
Positioning with selection	2.0	1.9	2.2	2.2	2.9	1.0	**2.13**	3.0	**2.57**
Final control	2.0	0.9	3.0	2.9	2.8	1.0	**2.13**	3.0	**2.71**
Switching monitor	1.0	1.0	1.1	1.0	2.0	1.0	**1.25**	3.0	**1.83**
Cleaning workstation	1.2	2.1	1.0	1.0	1.0	1.0	**1.09**	3.0	**1.68**

Amongst the most important process steps in so-called supermarkets are picking, orientation in space and positioning with selection. The participating experts rated the grasping as predominantly sensory and motor demanding but considered the cognitive load low. To execute grasping activities the worker needs additional information. In our evaluation, error susceptibility of the grasping movement was also low rated. Spatial orientation is cognitively demanding and due to strain on the eyes, it also stresses the sensory activity according to expert opinion. In these situations, motor activity may be neglected. Experts evaluate the required information to guarantee spatial orientation indispensable, such as for example the worker’s own position in the room and the arrangement of the warehousing positions. For this task the amount of required information is high. Since disorientation can occur, the results of the evaluation regarding error susceptibility is also comparatively high. Positioning with the option of selection, for example the placement of the component in the correct target bin is sensory, motoric and cognitively demanding. In this process step, information about the correct target bin is necessary. The error susceptibility reaches with a value of 2.9 almost the maximum value on the rating scale. Confusion errors with the positioning of components are frequent errors in the order picking. These occur in our experience more frequently than omission errors. Particularly noteworthy are the evaluations of the process steps of the final inspection and the workstation cleaning: The final check is considered to be sensory and cognitively demanding, while it is not challenging in motor activity. In addition, the number of required information and the error rate are classified as particularly high. The process step of keeping the workplace clean is in part sensory demanding through visual perception, but in part relatively simple activity with a lower susceptibility to errors. The process step can be made without additional information. Further evaluations can be found in table 4.

The experience is classified according to common employee characteristics as the 'typical worker' at a workstation. Serial production, for example, mainly uses experienced employees. Therefore, the experience in this case is commonly rated to a standard of 1. However, if the Rasmussen model is used to view a learning case, the experience of the unskilled worker should be adjusted to 3. The process steps memorize, read and leave retain the experience value 1 in both scenarios, since these activities are independent of the workplace and are often carried out in everyday life. Thus, every adult human is classified as an experienced worker.

After calculating the Rasmussen index, all process steps are assigned to the levels of skill-based, rule-based, and knowledge-based behaviors. In a standard case, all process steps are skill-based or rule-based. Whereas grasping, walking, positioning without selection, switching the monitor and cleaning the workstation are skill-based tasks. Reading, memorizing, comparing visual information, spatial orientation, assembly, positioning with selection and final control are rule-based tasks and are therefore suitable for the use of AR-technologies, according to [2].

When we consider training scenarios, level 'jumps' may occur. The final control assessment changes from a rule-based to a knowledge-based level. Scores for the grasping, the switching of the monitor (frequent accidental skipping of slides), the positioning without selection and keeping the workplace clean change from the skill-based behavior to the rule-based level. Walking is the only process step belonging to skill-based behavior. This evaluation shows that AR-technologies can significantly support more process steps during training. A reduction of the visualizations with increasing experience in the process steps is an option.

4.3 Workstation selection

Analyzing the evaluation of the nine possible workstations, we conclude that all nine workstations include rule-based process steps and are at first glance suitable for AR-support. Under this precondition, the choice between the workplaces changes into a new challenge of ranking the workplaces according to their 'suitability'. For the purpose of our research project, gaining experience and representative data for as many different process steps as possible is beneficial. The benefit is the transferability of the observations from the reference workstation to other workplaces in the BMW logistical world. Specifically, suitability of the workstation denotes not only choosing a workplace for testing. Furthermore, it requires that the workplace is adequate for subsequent roll-out and that the observations of AR-testing are indicative of the general benefits of AR-use for logistics.

Exploring the differences in workstation reveals that the processes differ in variability and in the amount of rule-based process steps at each workstation. Detailed analysis of the different workplaces is theoretically possible using the MTM-descriptions of the process, but the sub-processes in the MTM-evaluation cannot represent the added cognitive activity. Thus, the obtained percentages in rule-based time slices compared to the entire process time is underestimated. Our study describes individual cognitive elements and thus contains more task elements, which impairs comparison with the MTM basic processes.

Therefore, our approach still gives priority to the variability facing rule-based process steps. Thus, we decided that selection based on the percentage of rule-based tasks is preferable irrespective of the loss in precision of the method. The selected workstation for the test, where footwell claddings are picked, contains 75% rule-based process steps in the case of series production and is particularly suitable for the test due to its versatility (picking with pre-assembly). In comparison, other processes include 56.67% to 44.44% rule-based process steps.

To complete the selection we analyzed the environmental conditions such as light conditions, workplace dimensions, the ability to display indoor navigation, as well as the shelving construction. Examining the lighting condition, we focus on avoiding glare, darkness and reflections. A spatial delimitation of the workstation ensures occupational safety. Whereas unobstructed field of view increases the usability of visual guidance. Generally, due to the current hardware limitations, shelf dimensions have to correspond with actual limitations of tracking technologies.

5 Discussion and Conclusion

In consideration of our future full-shift study, we compared nine possible workstations at the BMW Plant Munich in terms of their suitability for AR-usage. Following the approach from [2], we used Rasmussen's Skills-Rules-Knowledge framework for evaluating every process step.

The literature research shows a lack of objective approaches to classify tasks into Rasmussen's framework. Consequently, we proposed a new method for an objective classification. The first step is a pairwise comparison of the categories activity, required information, error susceptibility and experience. The second step is an evaluation of the individual process step according to the four categories. A so-called Rasmussen index 'r' results from summing up the category's weighting multiplied by the individual evaluation value. With our new method, we evaluated established examples in literature, which already classified tasks according Rasmussen's framework. In this way, we were able to define numeric boundaries between Rasmussen's levels of human behavior. These are the first concrete numeric boundaries for Rasmussen's Skill-Rules-Knowledge framework. Our evaluation is based on specific evaluation in expert interviews and is therefore comparatively more objective than previous classifications. Although the average value of expert opinions still contains subjective evaluations, involving a large number of persons into the evaluation ensures the validity [28]. Future research is invited to review and refine our defined boundaries by evaluation of more experts of different areas of expertise pertinent to the specific workplace.

Starting with the assumption that smart glasses support rule-based tasks especially well, we compared the percentage of rule-based tasks at our nine possible workstations. Finally, we selected the workstation with most rule-based process steps as a test environment for our study. The other supermarkets are also supportable by smart glasses, but the worker needs the AR-support in comparatively less process steps. The ranking of the relative amount of rule-based process steps could be used in chronological order for a further roll-out plan of smart glasses in logistics area.

After identifying supportable process steps using AR-technologies and considering additional research projects, we focus on designing the user interface of smart glasses involving the employees, which work at our selected workstation. According to [29], the completeness of the information, the arrangement and the legibility of the information are relevant for the picker and for his error rate and performance. We use our workers' expertise in a design-thinking workshop for realizing a user interface, which fulfills all demands and satisfies the pickers' needs during the order picking process. Hereby we hope to increase the acceptance of the AR-technology and prepare for the best possible conditions for our full-shift study at BMW Plant Munich.

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4 Designing the user interface

After selecting a test workstation in Chapter 3, Chapter 4 focuses on the next step in the preparation phase. Together with the future users of the system, I design the user interface of the smart glasses. The lack of expert knowledge regarding the possibilities of programming is a barrier in involving the employees in this step. Nevertheless, the wealth of experience of the employees is a valuable source for the development of an ideal visualization. Only the order pickers themselves know exactly which information they need in which step and, above all, which they do not need. Often planners tend to overload displays. But essentially it is only important for the planner that orders are displayed, but not how. With regard to colors, symbols, font sizes and positioning in the field of view, the possible solutions do not have to follow any specifications. This enables employees to implement their ideas. Consequently the final decision regarding the content lies with the picker. A suitable methodology for collecting ideas must be found. Design Thinking is an approach used for creative and user-centered solution finding. 'Quick and dirty' prototyping using handicraft materials, paper and pens serves as a brainstorming method. It allows to discuss ideas with participants of different backgrounds and to develop them further without having expert knowledge about the later technical implementation. This approach is a basis for the development of a methodology for generating AR-user interfaces, which will be presented and applied in the following paper. Chapter 4 answers subsequently the following research question:

How can future users participate in the user interface design without having expert knowledge about the Augmented Reality-technology?

Since this step is a preparation for the later user-study as well as Chapter 3, it represents the persuasion and decision phase, which is a continuous circle around the employee, in the process model designed in Chapter 2 (see Figure 9).

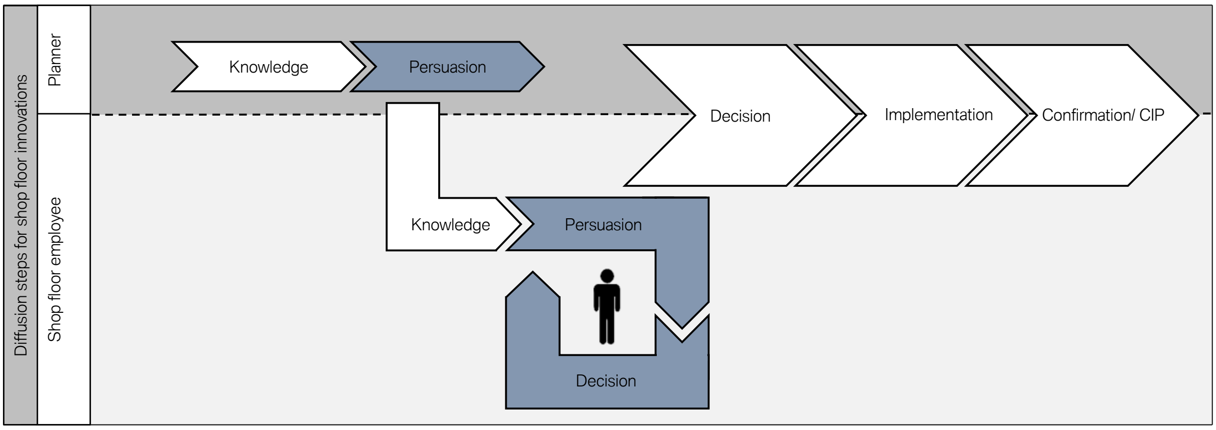

Fig. 9: Involvement of the users designing the user interface

The following publication 'Design Thinking: Using Photo Prototyping for a user-centered Interface Design for Pick-by-Vision Systems' was presented at the 11th PErvasive Technologies Related to Assistive Environments Conference 2018.

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Design Thinking: Using Photo Prototyping for a user-centered Interface Design for Pick-by-Vision Systems

Nela Murauer
BMW Group
Max-Diamand-Straße 5
80788 Munich, Germany
nela.murauer@bmw.de

ABSTRACT

With Industry 4.0 manufacturing facilities experience a dynamic change towards smart factories. Digitalization of processes accompanied by extensive data acquisition enables process planners to utilize innovative technologies like Augmented Reality (AR) to support employees in their tasks on the shop floor. Among others a visualization in the user's field of view allows hands-free work and avoids unnecessary head movements. To make use of the employee's expertise, we try to involve workers with the aid of Design Thinking at an early stage in the AR-interface design process. A pervasive method in app design is Paper Prototyping. Early sketches of user interfaces serve as common language in interdisciplinary teams. In this paper we develop a method based on Paper Prototyping especially for AR content needs, which is called Photo Prototyping. This method overlays the user's field of view with sketches of the future AR-content. Furthermore we elucidate our experience, we've gained during a workshop with 40 workers out of logistics in the automotive industry.

CCS CONCEPTS

• Human-centered computing → Interaction paradigms → Mixed / augmented reality • Human-centered computing → HCI theory, concepts and models • Human-centered computing → User centered design • Human-centered computing → Interface design prototyping

KEYWORDS

Augmented Reality; Photo Prototyping; Design Thinking; Storyboard; user-centered; picking; logistics.

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1 INTRODUCTION

Augmented Reality (AR)-technologies are used in different fields of application such as architecture, tourism, service, production, etc. Especially in production-related use cases there are multiple conceivable possibilities for an AR-implementation. Büttner et al. present a comprehensive overview of AR-related publications in logistics, maintenance and training [1]. The context of this paper are manual man-to-goods order picking processes, in which the employee moves between fixed pallets or shelf positions [2]. Through AR the industry hopes to achieve error reduction, as well as time and cost decrease, improved employee training and an increased level of job rotation. While logisticians are researching innovative process improvements such as autonomous forklifts, tugger trains or robots, in order picking processes human work still plays an important role due to flexibility concerning task management and the ability to handle various objects [3]. By utilization of AR-systems workers can nevertheless be supported in their work. Especially Head-mounted displays (HMD) or smart glasses, which we regard as synonymous in this paper, offer the advantage of working hands-free. In addition, the visualization of work task instructions can help the worker b avoiding unnecessary head or body movements.

Wang et al. [4] show that user-centered projects are neglected. They reviewed 304 publications about the implementation of AR in assembly processes and concluded that only 3.62% of all publications touched on usability evaluations. Evaluating industrial software products Mayer and Ondrusch [5] also determined that there are few solutions with a simple, intuitive user guidance and attractive interface design. Thus, they underline the use of Design Thinking to focus on users during software development. In the process of an application development Paper Prototyping, a fast sketching of ideas, is often used. Within the context of AR, where the reality is enriched with the aid of computer-based overlays, the method is unusable.

For this reason, we present in this paper a new method called 'Photo prototyping', with which users and interface designers are able to create a user-interface in a creative way. This method is based on Paper Prototyping, Storyboarding and the so-called 'Zwicky-Box', which are explained in the following. After a description of the method development and the use procedure, we depict a first test run of the method for the user-interface design of an AR-application for order picking processes at our production plant. Through the usage of creative methods and the involvement of the order pickers, we hope to create a user-interface design, which fulfils the employees' needs and expectations. Giving the workers an instrument to formulate, to share and to discuss their ideas and process improvements, we hope to find a common ground in interdisciplinary teams. After all, we will present some workers' quotes to highlight their feedback regarding the method usage.

2 RELATED WORK & THEORY

2.1 Visualizations of Pick-by-Vision Systems

Early attempts to redefine user-interface design were already made in the ARVIKA-research project (1999 – 2003). This described project produced a Style Guide, which only adheres to the state-of-the-art at that time. As a consequence of hardware limitations, no recommendation in regard to different colour display and colour coding was issued. Equally context-sensitive visualizations [6], which means attached to the object itself, were not taken into account [7]. Figure 1 shows the difference between context-sensitive and context-independent visualizations through the example of an order picking target shelf. On the left side, the context-independent letters are hovering in the field-of-view of the user, while on the right side the green frame is attached at the target box.

Figure 1: Difference between context-independent and context-sensitive AR-applications

In the context of order picking processes HMDs or smart glasses have also previously been tested. Reif [8] realized a context-independent display in red colour (caused by the hardware Microvision Nomad ND 2000), which highlights the box, the component number and the number of items to pick. The user interface design process did not include pickers. In addition, a round, tunnel-like direction to the box in combination with the displayed order number as well as the number of items is given in red colour. Schwerdtfeger [9] designed a similar display, which directs the user to the box by a squared context-sensitive tunnel. Tümler [10] visualized component numbers, shelf numbers and order numbers as well as an arrow red coloured in a context-sensitive way. Baumann's [11] interface is similar to a map of the shelfing in which every row is specifically coloured (red, yellow, green, blue, and white). The background was black. Büttner et al. worked also on a coloured visualization. Prior to and during the assembly, the ultimate picture of the finished product is already hovering in the user's field of view in its original colours [12]. All presented solutions were initially developed and subsequently tested. An involvement of the user during the interface design is not described.

2.2 Design Thinking & creative methods

The Design Thinking process is subdivided in six iterative steps: understanding, observing, synthesis, ideas, prototyping and testing [6]. The first two steps focus on in-depth understanding of the user and his surroundings. Direct communication with the user helps to identify his goals and needs [5]. The following brainstorming contains an unstructured collection of ideas [6]. During a prototype- and test phase the solutions are evaluated. Depending on the evaluation results of the ideas the phases are repeated until the solution fulfils the requirement [5].

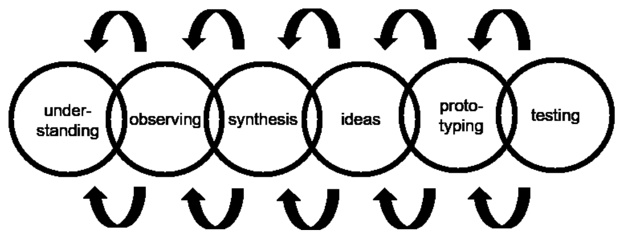

Figure 2: Design Thinking process based on Grots and Praschke [14]

Concerning the development it is important to differentiate between product development and process design. Ideas for usage situations and new products can be collected in an unstructured way with the aid of brainstorming technique. An example for product development is a design of a new ergonomic office chair. In process design, for example an application for flight booking, where the user is guided through the buying process, and an unstructured collection of ideas must be made for every process step. The order of the solution (for example flight search, offer, choice, booking, payment) is already inherently structured.

One well-known method to describe the course of user's actions is the use of storyboards which are also suggested for prototyping in Design Thinking [13]. The method provides a visualization of single sequences similar to a comic book [15]. Stories can be used in all development phases and describe the contextualisation of the research [16]. The user is given the role of a main character or as persona and remains in focus. This way to describe and to form processes allows 'to start […] designs from a story describing an ideal experience from the persona's perspective, focusing on people, and how they think and behave, rather than on technology or business goals' [15]. The visualization of the story follows in the shape of sketches, which are collected on a whiteboard. This easy and fast sketches of ideas is particularly helpful for interdisciplinary teams [17] since it creates a common language for complex problems [18]. Especially in app development sketches or paper prototypes are used to visualize the later interface design. As an example of applying creative methods in interface design is [19], who designed 3D interfaced with the aid of a so-called Mirrorbox and a Framebox. A further method to structure alternative solutions is the morphological method [20], known as 'Zwicky-Box'. All possible solutions and their combinations are structured in an easily comprehensible matrix. This method simplifies the process of finding the best solution.

2.3 Method development

To produce an idea generation process realistically in the AR-context, Paper Prototyping has to be extended, as the background of the display is changeable. For this reason printed screenshots of the single story-sequences are used as background for brainstorming. These photos represent reality and become AR-graphics by means of sketching and sticking. This 'Photo Prototyping' is an easy and fast method to obtain individual solutions with users, who have never been in contact with AR-technologies.

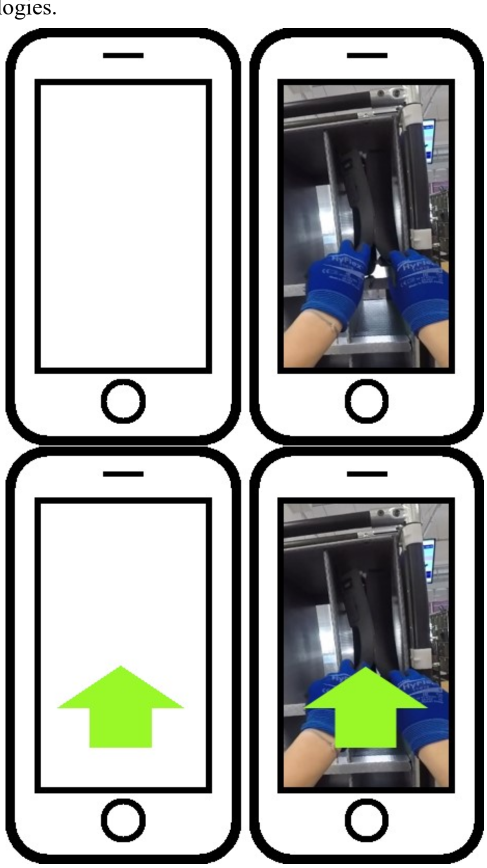

Figure 3: Difference between interface without (left) and with (right) AR content

Figure 3 shows the difference between an interface without (left) and with (right) AR content. The graphics below show the difference between Paper Prototyping and the new method, called Photo Prototyping. Photo Prototyping can be used for unstructured brainstorming in the context of AR for a user interface design, which does not follow a fixed storyline. The choice of the device does not matter. Photo Prototyping can equally be used for smart glasses, smartphones and tablets.

For a process design the methods Paper Prototyping, Storyboarding and the Morphological Method are combined. By means of a head-mounted camera the process can be filmed from the user's point of view. To get the best impression of the process, we recommend that a skilled worker wears the head-mounted camera. After that, the workshop supervisor prepares screenshots of the individual process steps, which will be fixed on a whiteboard as storyboard serving as a base in the later workshop. A verbal process description can be attached above. For each individual story sequence solution alternatives are collected, which are fixed one below the other. Every solution alternative is designed with photo background (Figure 3) and follows the Photo Prototyping method. The structure of the process-oriented approach is a combination of Storyboarding and Morphological Method, hereafter referred to as Morphological Storyboard (Figure 4). This method can also be used for process developments without AR context. Affixing green points (positive) and red points (negative) helps to evaluate alternatives and to select the best solution. We propose that ideas should exclusively be rated by future users.

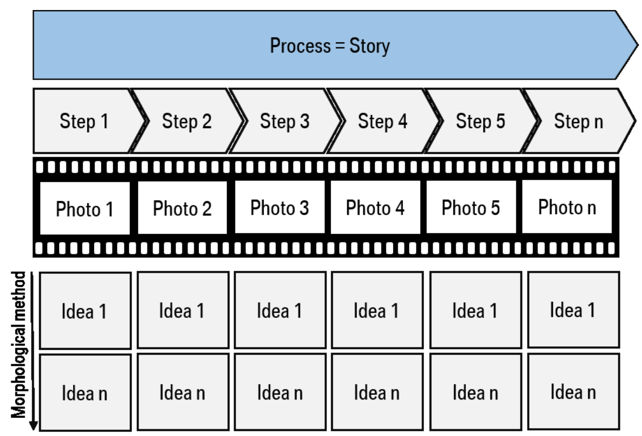

Figure 4: Morphological Storyboard

The video clip taken for the screenshots serves as first prototype. For this propose the desired overlays can be integrated into the video clip. Thereby users are able to watch potential AR contents before programming. It is easy to take into account proposed amendments at that point of time. This corresponds to the iterations of Design Thinking described by Meyer and Ondrusch [5].

3 INDUSTRIAL APPLICATION

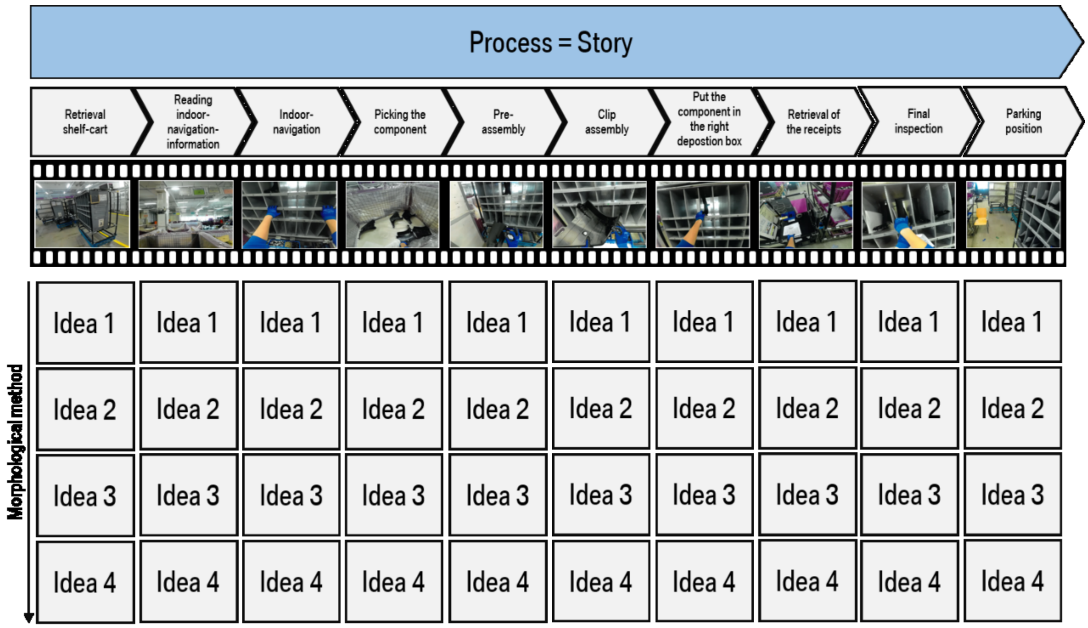

Figure 5: Industrial application of the morphological Storyboard

In our research project we test smart glasses in an automotive manual man-to-goods picking processes during a full-shift operation. For this purpose we developed a user interface design using Design Thinking. Based on the six steps of Design Thinking, we first observed and understood the context of usage. For this reason, we worked one week during the morning shift to experience the tasks, the challenges and the problems. We observed other pickers and interviewed 15 employees afterwards.

For the screenshots we filmed the picking process using a Google Glass. As the quality of the resolution and the colour representation were not satisfactory, we used a head-mounted camera GoPro ® Hero 5. The video clip serves as the basis for subsequent prototypes.

Figure 5 illustrates how the structure of the Morphological Storyboard was transferred on a whiteboard to execute a Photo Prototyping Workshop. The whiteboard was then set up at the shop floor in our logistics are. Figure 6 presents our provided workshop material. We provided photos of every process step (in part taken from different angles and perspectives), paper, glue, post-its and pens. We also applied the option of using transparent paper in order to achieve a layered visual product. Moreover templates were dispersed, which help to construe the Field of View (FoV) in the smart glasses ODG R7 as experienced in the trial situation. These templates could be placed on top of the photos. The FoV was measured at the average distance of an arm's length between the picker and the shelf. Furthermore the smart glasses ODG R7 could be test-worn to give users a feeling for the measures of display.

Aiming to reach the greatest number of employees the creative photo prototyping workspace was open for use in both shifts of the day and for the duration of the entire working shift. Its location was chosen in a central spot and reachable for everyone directly next to the tugger train station. The employees were encouraged to participate voluntarily. To incentivise voluntary participation coffee and sandwiches were offered (inspired by [21]). The date of the workshop was communicated several weeks in advance at the pre-shift meetings and also advertised with posters to motivate participation early on. Apart from the pickers, foremen, foremen in leading positions, managers and employees from different departments tasked with innovation were invited to enrich the brainstorming with their individual perspectives.

Figure 6: Provided workshop material.

Figure 7 shows the results of 40 participants from both shifts of the day. The workers found solutions for every single step in the process. They created both, context-sensitive as well as context-independent visualizations. For the first step of the process, namely the retrieval from the shelf-cart, a context-sensitive and hovering note of the cart number was proposed. To increase the level of work safety the employees had a further idea to mark routes in red on which tugger trains and forklifts were driving at that moment.

Figure 7: Photo Prototyping results in the production plant.

For the following phase concerning the navigation to the retrieval box, numerous suggestions were made. One solution is a context–sensitive arrow aimed to the component names and a note of the required number of items. Alternatively a hovering notice emphasized by white background could both show the number and name of the required component. Indoor navigation by the use of arrows in neon yellow on the floor (similar to a route manager in the Head-up Display) were also drawn. Displaying the component name which hovers over the grid box, 'same as FIFA operationalizes in computer game for players in soccer games' is an additional option.

Error feedback given by a green tick for 'right' and a red 'X' for 'wrong' above the grid boxes is another solution. Also the table-like display with a list of component numbers on the left side and a list of the disposition shelves on the right side was drawn in neon green. A drop-like marker (similar to Google Maps) above the target in combination with the arrows which lead the way, were a further proposal. It is noticeable that all hovering notices and displays in this story sequence were either glued at the side of a photo or drawn, whilst their presentation was exclusively made with neon colouring or black writing on transparent white background. All context-sensitive overlays were drawn with neon green, neon yellow, neon orange, or 'right' in green and 'wrong' in red. In the second step of picking the component, only two solutions were proposed as the number of items was mostly already dealt with in the previous step. On the one hand a sketch of the component in the upper right corner attached to a note with the required number of items was proposed. On the other hand an innovative add-on was suggested to check components for damages. For the story sequence of the pre-assembly phase only one solution was developed which shows the context-independent yellow framing of the pre-assembly location in combination with a graphic of the component determined for assembly. At the point of clip assembly, the location shall be framed in the same manner as described for pre-assembly. Additionally already conducted tasks shall be marked as green and outstanding tasks shall be visualized in red (see Figure 8).

Figure 8: Evaluation of the idea for the clip-assembly.

The most important task in order picking is the deposition of the right component in the right shelf box. Most of the collected ideas were made regarding this task. The proposals span from a hair cross, over context-sensitive green framing of the target deposition box, over a green area attached to the target deposition box (target-sensitive) to directions given based on the visualization of Schwerdtfeger [8]. For this step error feedback was demanded visualized by red and green framing of the target deposition box. A simple way of visualization was the display of the component name in the left upper corner followed by the corresponding number series which entails the numbers of all target deposition boxes where components have to be placed. Context-independent displays were once again neon coloured and error feedback green and red. Context-sensitive displays were either marked with neon writing or with black writing on transparent white background. The following phase of the process, namely navigation to the printer from which receipts are to be taken shall be implemented by means of yellow arrows. The retrieval of the papers shall either be visualized by a paper stack graphic or in text with the tag 'retrieve papers'. The story sequence second to last includes the final inspection process. In this step the participants would like to see all error feedbacks meaning the display of green framing on all target deposition boxes in a positive scenario. The process ends with the parking of the cart. A context-sensitive overlay of the right parking spot on the floor was designed. Furthermore, some participants request a tick to symbolize the end of the finalized process.

The Photo Prototyping session was welcomed on both implementation days. Employees from different departments participated and gathered different solutions based on their varying perspectives and backgrounds. Despite conducting the workshop during normal shift work, enthusiasm and participation among employees was high.

4 EVALUATION

After successful a Photo Prototyping of directly affected employees evaluated the collected ideas. For this purpose the possibility to stick green or red points on the augmented photos was given. As a result context-sensitive as well as context-independent displays were evaluated positively.

In the first process step, the cart retrieval, both display solutions showing the cart number were evaluated positively. While navigating indoors to the right grid box the participants preferred the visualization of a drop symbol similar to Google Maps in combination with arrows for guidance, as well as a context-sensitive arrow, which points at the component name including the display of the number of items required. The instant error feedback implemented by means of a green tick and a red 'X' is welcomed. For the finding of the target deposition box the pickers prefer a combination of red and green context-sensitive frames (Figure 9). For the pre-assembly and clips the display of the point of assembly – including error feedback – is requested (Figure). An easy idea to display a series of numbers, which is most similar to the actual process, has been evaluated positively.

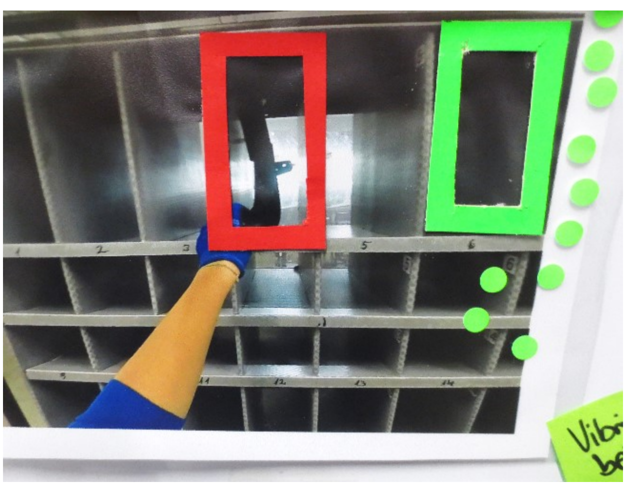

Figure 9: Evaluation of the idea for finding the target deposition box.

The overlay of a stock of paper graphic referring to picking-up the retrieval receipt is considered most appropriate. The visualization of all the green and red frames during the final inspection is desired. Only in the last step, all those ideas which show the parking position are deemed unnecessary (Figure 10). This can be explained by the fact that in the observed process there is only one possible parking position.

Figure 10: Evaluation of the idea for the parking position.

Subsequently the results, which were collected and evaluated during the brainstorming sessions, are implemented in the GoPro®-filmed picking process as a first coherent prototype. This video clip can also be watched on the smart glasses.

5 CONCLUSIONS

Design Thinking is used to place pickers as users in the centre of the user interface design for smart glasses. Withal the picking process is documented as a Storyboard and the collection of ideas as a Morphological Method. Photos, which show the pickers views, serve as the basis of the brainstorming. By means of the photos, which were painted and stuck over, the Paper Prototyping method was transferred into the AR-context. Owing to this 'Photo Prototyping' a lot of different solutions were generated in a short period of time. These surpass the known solutions in current literature. The 'Photo Prototyping'-method is recommended for all AR use cases to visualize ideas in a fast way and to find a common language in interdisciplinary teams. If the AR use-case can be described as a process, the usage of the 'Morphological Storyboard' scheme supports 'Photo Prototyping'. This provides the possibility to focus on the general process at any point in time and simultaneously present opportunities to discuss all combinations of alternative solutions. The concluding documentation in form of a video clip, which is the first coherent prototype, creates a basis for discussion and at the same time is an ideal medium of communication. Though the early involvement of the workers as future users, they can be part of the design process in an innovation implementation. Hence, they do not feel overwhelmed by innovations, which is often the case during in a centralized planning approach. 'It is great to be asked, what we want, as we are the experts in the picking process', 'less is more. planner are prone to implement more than the process really needs', 'we have to work with the system, so it's cool, to contribute all ideas, I ever had for optimizing the process', are some quotes of participants. Few workers said, that they were not creative enough to produce completely new ideas. Summarizing the feedback of the employees, who attended the Design Thinking workshop, the new method 'Photo Prototyping' is suitable for the development of AR-applications on the shop floor.

As a next step the required user interfaces will be programmed for the ODG R7 and evaluated on a test workstation. The final version going to be tested under full-shift operation conditions and real production circumstances.

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5 Comparing Scan-Mechanisms

After designing the user interface for the ODG R7 smart glasses, which has already been selected for its advantages in terms of binocular display and suitability for spectacle wearers, the interaction mechanism should be selected as the last step before testing the Pick-by-Vision-system in a field study. The employee has to interact with the smart glasses as well as trigger bookings in the warehouse management system via pick confirmations. Scanning is a common interaction method in the logistics context using stationary scanners as well as mobile scanners, which are hand-held or worn as glove with the scanner attached on the back of the hand. When using smart glasses, the scan function can also be integrated into the glasses. So far no studies combining Pick-by-Vision with scan-confirmations can be found in literature research. Therefore, the options of a combination solution of smart glasses and an external scanner and an integrated scan function must be examined with regard to their effects on the employee and the process. The aim of this preliminary study is on the one hand to avoid choosing a form of interaction slowing down the process and on the other hand to find a method, which is positive from the employees' perspective. This should promote subsequent acceptance. Since this step is a preparation for the later user-study as well as Chapters 2 and 3, it represents the persuasion and decision phase, which is a continuous circle around the employee, in the process model designed in Chapter 2 (see Figure 10).

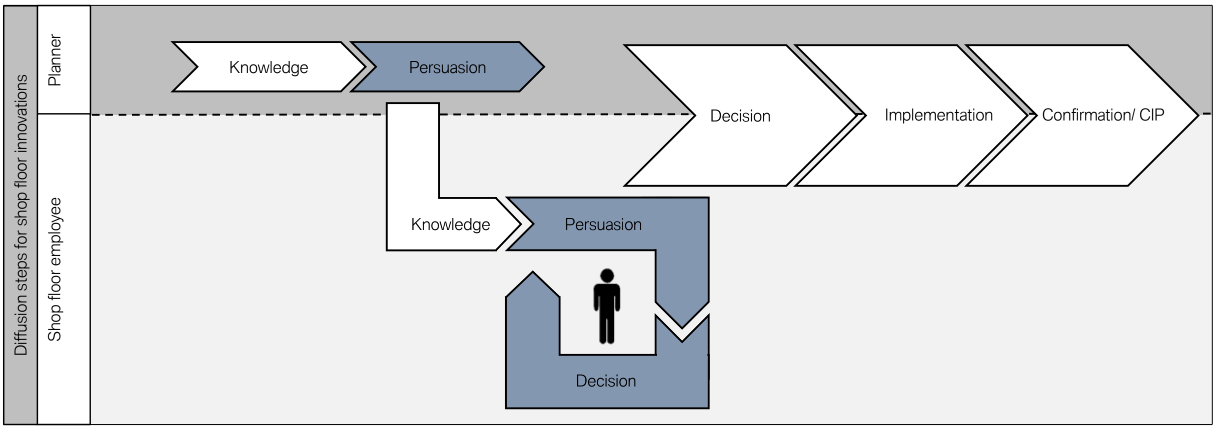

Fig. 10: Involvement of the users selecting the interaction mechanism

The following publication 'Comparison of Scan-Mechanisms in Augmented Reality-Supported Order Picking Processes' was presented at the Sixth Workshop on Interacting with Smart Objects of the ACM Conference on Human Factors in Computing Systems 2018.

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Comparison of Scan-Mechanisms in Augmented Reality-Supported Order Picking Processes

Nela Murauer
BMW Group
Max-Diamand-Straße 5
80788 Munich, Germany
nela.murauer@bmw.de

Nerina Pflanz
BMW Group
Max-Diamand-Straße 5
80788 Munich, Germany
nerina.pflanz@web.de

Cecilia von Hassel
Technische Universität München
Arcisstr. 21
80333 Munich, Germany
c-v-h@gmx.net

Abstract

Designing the change towards a digitalized production plant, we analyze in our research project whether the usage of Augmented Reality (AR)-technologies offers advantages for the worker and the process. In this paper we focus on the comparison of confirmation methods for order picking with smart glasses in the automotive industry. As logistic processes require manual or automatic confirmation to interact with the warehouse management system, we compare different scan-mechanisms for smart glasses. In our pilot-study, we analyze the picker's task completion time, error frequency, attention before and after the usage and subjective assessments regarding the usability and health-related information during an 8-hour work shift. In this pilot-study, we aim to evaluate scan-mechanisms with the best fit for a smart glasses usage. With the best visualization and confirmation combination, we will conduct a consecutive field study at our production plant. Based on our results, we recommend a scan-glove in combination with smart glasses as visualization device.

Author Keywords

Augmented Reality, order picking, logistics, pick confirmation, interaction mechanisms, smart glasses

Figure 1: Scan Glove during Scan process

Figure 2: Scan Glove

ACM Classification Keywords

• Human-centered computing → Mixed / augmented reality • Human-centered computing → Empirical studies in HCI

Introduction

The further advancement in digitalization of the production environment provides ample opportunities to support workers with well-fitted Augmented Reality (AR-) technologies. According to Tümler [1], mobile AR is defined as a situation-friendly visualization of computer-based information, which is positioned on portable display devices in the user's field of view. It is important that the AR content does not bother the user during his work [1]. On the shop floor, AR-technologies, such as head-mounted displays (HMDs), can support workers through visual guidance and hands-free work. In this paper we regard HMDs as synonymous with smart glasses. Smart glasses have the potential to replace monitors or paper-based picking lists, which show orders in a tabular structure. The advantages of smart glasses in an order picking context range from avoiding unnecessary head-movements through visualizations in the user's field of view to a step-by-step visual guidance for the training of unskilled workers. The majority of publications in this research field discuss for example see-through calibration [1], different guidance methods [2], the comparison of projection or head mounted displays with a picking list and with auditory instructions [3]. Most studies were placed in a laboratory setting [1-7]. The pilot study, which we present in this paper, is also a laboratory study and serves as a base for a further study, which will be conducted in a real production environment, where the process time depends on the predetermined manufacturing rhythm at the assembly line.

To implement smart glasses in standard production on the shop-floor, the visualization device delivering order information needs to be connected with the warehouse management system. Additionally, the picker has to interact with the warehouse management system by confirming process steps. With this feedback of completed orders, the worker receives information about the next order sequence from the system. Various confirmation methods are conceivable solutions. Common confirmation methods in logistics contexts are buttons or scans. Work guidance through the process requires confirmation for the warehouse management system at each retrieval and placement box. When buttons are used for confirmation purposes, high investment is needed. An alternative are barcodes, attached to pallet cages and target bins, which are less cost-intensive. One advantage of using barcodes is the flexibility in case of processes changes. This is why scanning barcodes is a popular interaction method in logistics. Scanning devices can be hand-held scanners, scan gloves (see fig. 1 and 2) and the smart glasses themselves. As hand-held devices can disrupt the work flow during order picking processes and pre-assembly, these devices have been excluded.

The paper's objective is to determine the best fit between three confirmation scenarios using wearables in order picking. While one scenario uses a ring confirmation clicker with auditory feedback with visualized order information on a monitor, two more scanning scenarios including AR-technologies are investigated. In AR-scanning option number one, the smart glasses scan the barcodes, which means that the worker visually focuses on the barcode for a set amount of time but simultaneously receives ordering information in his field of view. In AR-scanning option number two, smart glasses are combined with a scan glove. During pointing the scanner at the barcode, the worker is able to look in a different direction.

With the presentation of our pilot study, we aim to find a custom-made solution for easing the work process by combining mobile devices. Current rapid development of wearables on the market has broadened the variety of available devices and scanning options. Analyzing individual process steps in a workstation-specific context will give information which device can support the worker. Retrieval and placement of items is one action, while confirmation is another action. It may be possible that one wearable, namely the smart glasses, is capable of conducting both actions. We aim to inquire, whether a combination of wearables or one wearable is better suited for the order picking workstation regarding task completion time, error frequency and ergonomic support.

Related Work

A great number of studies addresses AR-technologies in the production area. Head-mounted displays or smart glasses and beamer-based projection are favored visualization tools [8]. Hereafter, we present a sample of previous publications.

Kampmeier et al. [6] conducted a laboratory study with 60 participants analyzing the impact of AR-usage on the worker and the process. A HMD Lite-Eye LE 750 A was used for visualization. For interaction with the glasses the study conductors switched the display on participants' request to the next order. Wiedenmeier [9] presents another use-case with AR-supported assembly tasks. A sample of 36 participants wore a Microoptical Clip-On HMD during three assembly tasks. They interacted with the HMD by a mouse click. Speech recognition as an interaction method was applied by Reif et al. [7] in a laboratory study with 19 participants. They assumed that speech recognition is partially difficult to process by the device. In Theis' et al. [5] study, during which 45 participants performed assembly and order picking tasks, they used a portable PC carried on the belt to switch the slides in the Microvision Nomad HMD. Another interaction method is presented by Tümler [1]. During his laboratory study, 20 participants had to confirm tasks using a forearm keyboard. Funk et al. [3], Schwerdtfeger et al. [10] and Guo et al. [4] used the wizard-of-oz technique during their studies in an order picking context, which means that the study supervisor switched the visualization in the HMD.

To resume the described publications, many studies did not primarily investigate confirmation mechanisms. The applied mechanisms such as a portable PC carried on the belt or a forearm keyboard are not a step forward in contrast to buttons or scans. The suggested use of speech recognition cannot be implemented feasibly at our production plant due to the surrounding noise from tugger trains and forklifts. Wiedenmeier's [9] confirmation method, a mouse click, resembles a button attached to a box, and can therefore feasibly applied in production areas. In logistics, scanning is a common confirmation method, which is not tested by any of the presented studies. We assume that scanners in combination with HMDs/smart glasses have not been investigated due to a recent innovation leap in scanning devices. Compared to previous hand-held scanners, the

Workflow description at the production plant

The picker starts the process between pallet cages A (left) and A (right). He first picks all A-left components in consecutive sequence of the order information from his left and then all complementary A-right components from his right. Afterwards, the picker moves to the next set of pallet cages, which supply alternative components opposite from each other. The current workflow which we aim to ease on the part of the worker, provides visualization via a monitor fixed to the right side of the movable shelf.

new scan glove supports hands-free work and does not impair the worker through high weight.

Test environment and hardware

In our pilot study, we emulate the work environment and conditions of the real order picking workstation of our production plant, where we will conduct further studies. We selected this workstation using Rasmussen's Skills-Rules-Knowledge framework [11]. The workstation of our choice, a so-called 'supermarket', is an order picking workstation, where the employee composes 16 pairs of nine possible types of footwell claddings into a movable shelf in the correct sequence. Order information can differ in color, model series, variant driver's side and components for emergency vehicles. In addition, the process contains a pre-assembly work step of either fitting a boot switch or a shutter on the driver's side, depending on the ordered special equipment. After picking a sequence consisting of 16 pairs of components, the picker parks the shelf at the parking position, from where a tugger train takes the shelf to the assembly line. For our pilot study, we built a reference workplace (Fig. 3), which is similar to the real workstation. We used the same pallet cages and the same target shelf, but we reduced the variability of component alternatives from nine to three. As the target shelf is identical, the number of footwell claddings to pick remain the same for one sequence. A detailed workflow description is explained on the left.

As test hardware we used a ring confirmation clicker, binocular ODG R-7 smart glasses and a scan glove from 'ProGlove'.

Figure 3: Test environment

Methodology of the user study

In our pilot study we compared the described status quo (using a monitor for order information and confirmation by a ring clicker) with AR-supported order picking combined with two different interaction mechanisms: scanning by the smart glasses and scanning using a ProGlove scanner. To measure the picker's performance, we analyzed the total task completion time and the error frequency. Each participant was given the opportunity to familiarize him- or herself with the workflow and hardware for a full round of order picking (full-shelf trail) before measurements began. For a better differentiation between error characteristics, a subdivision of the error frequency into error types according to Lolling [12] into quantity errors, type errors, omission errors and quality errors is possible, which Schwerdtfeger et al. [13] describe as 'wrong amount, […] wrong item […], missing article […] [and] damaged article'. In our pilot study, we provided only undamaged components and therefore excluded quality errors from the evaluation scope. Due to the narrowness of the target boxes, Order of the methods used in the study:

- d2 Test of Attention
- Total completion time and error frequency during the order picking process
- Visual fatigue questionnaire
- System Usability Scale
- Raw NASA-TLX
- d2 Test of Attention

Participants:

- Production employees
- Mean age: 25
- Voluntary participation

Orders:

- Randomized orders
- 384 footwell claddings per participant per day
- 192 pre-assemblies per participant per day

All participants performed all three scenarios.

quantity errors could only be omission errors because putting more than the required quantity into the box is impossible. Therefore quantity and omission errors were both treated as omission errors. Summarizing, the evaluation focuses on the erroneous picks in wrong or missing items. If the picker pre-assembles the wrong boot switch or shutter, we view this as an error due to wrong item. In both cases, whether it concerns wrong item or wrong pre-assembly, the component has to be re-assembled.

For the evaluation of the usability-friendliness of the three different visualization-interaction scenarios we used the system usability scale (SUS) [14], consisting of ten questions alternating between positive and negative statements. The evaluation scale is a 5-point Likert scale starting from "I do not agree at all" and ending to "I fully agree". In addition, the d2-Test of Attention [15], the Raw NASA-TLX [16] and Visual Fatigue Questionnaire (VFQ) [17] measure several aspects of psychological and physical strain.

The d2-Test of Attention can be used to assign a numeric value to an individual's concentration capacity. The test contains 14 lines with 47 'd's and 'p's in each line, while each 'd' or 'p' can be supplemented by one to four marks above or below the letter. During the test procedure, the respondent is was given 20 seconds processing time for one line. The participant has to find as many 'd's with two marks as possible during the predefined time period. The concentration capacity 'CP' can be calculated based on the scores for the amount of the processed quantity of letters, the omission errors and the confusion errors.

Relying on the Raw NASA-TLX questionnaire, we evaluate mental demand, physical demand, temporal demand, performance, effort and frustration. Each dimension of the questionnaire delivers a numeric value between 0 and 100. The total R-TLX is the sum of the six dimensions divided by 6 [16].

To estimate visual impairment, Bangor's VFQ [17] contains the assessment of 17 categories of visual strain, which are evaluated on a scale from 'not noticeable at all' to 'extremely noticeable'.

Results of the user study

The test procedure emulated the conditions, temporal restraints and tasks of the workstation at the production plant. We tested a sample of five participants at the reference workplace in our pilot study to determine user-friendliness and feasibility of implementing scan mechanism for the confirmation in AR-supported order picking in a larger sample. More details regarding the study design are described on the left.

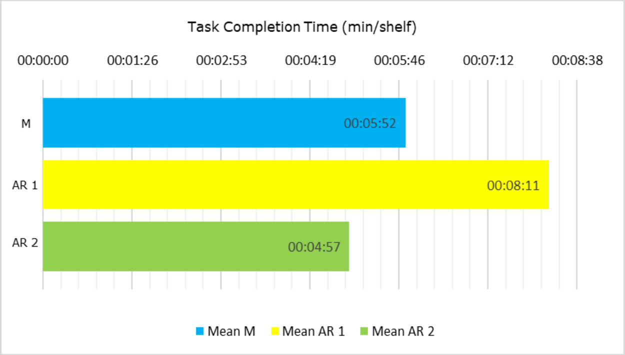

Figure 4: Mean Task Completion Time

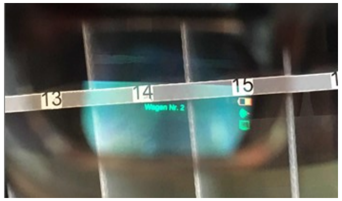

Figure 5: First visualization with shelf number

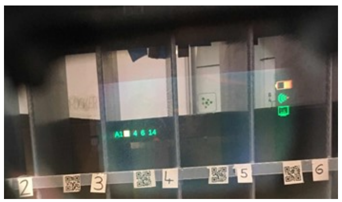

Figure 6: Order picking sequence for component A

Regarding the mean task completion time (TCT) per shelf (Fig. 4), we observed, that baseline measurements with the monitor scenario (M) were at 5:52min (SD ±00:31min) per shelf. Scanning with the glasses (AR 1) was more time-consuming with mean TCT at 8:11min (SD ±01:08min). Figure 5 and 6 show examples of AR1-visualizations. Yet, receiving order picking information by the glasses and using a scan glove as confirmation mechanism (AR2) reduced the mean TCT per shelf by almost a minute to 4:57min (SD ±00:29min). Consequently, worker were the fastest in the AR 2 scenario even though hand and arm movement towards the target boxes to trigger the confirmation mechanism were comparable to scenario M. Since the maximum TCT is dependent on the real-time manufacturing rhythm of the production plant, a confirmation mechanism may not exceed the current TCT time limit, as this would put the entire production on hold. Thus, based on this findings, implementing the AR 1 scenario at the production plant is unfeasible at the current level of technical development. TCT results suggest that for the introduction of smart glasses to order picking merely AR 2 scenario has the potential to be tested at the plant.

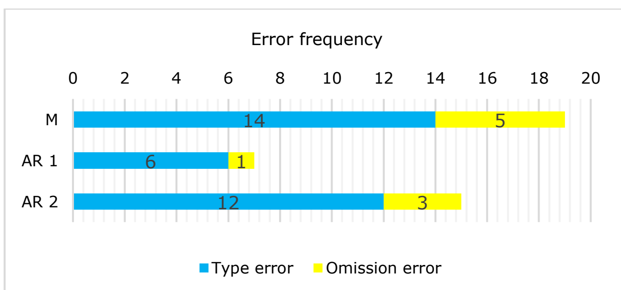

Figure 7: Error frequency

Analyzing the occurrence of errors (fig. 7), the majority of errors were type errors (wrong part or wrong pre-assembly). The fewest errors were observed in AR 1, followed then by AR 2 and the most errors were made in the baseline scenario M. AR 1 decreases error frequency the most, but at the expense of increasing TCT. The observations from the pilot study imply thus that introduction of AR-technologies supports error reduction at the current TCT using a scan glove.

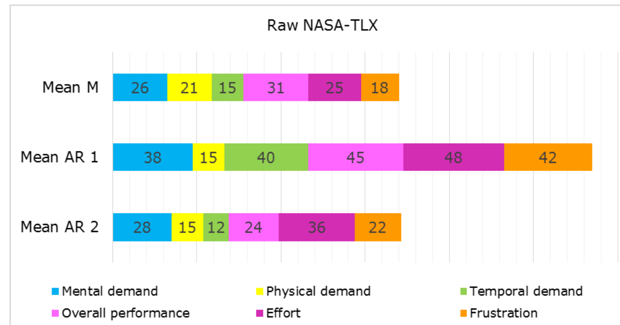

Figure 8: Results Raw-TLX

Averaged Raw NASA-TLX scoring (fig. 8) provided detailed information on work strain in terms of mental, physical and temporal demand as well as effort and frustration connected to the employees' workload. These scores were almost identical for scenario M and AR 2 (m=22.7 vs. 22.8) but considerably higher for AR 1 (m=38.0). Hence, AR 2 did not alter work strain compared to the baseline whereas AR 1 implementation affected the workers physically and mentally for the worse. Raw NASA-TLX results complimented information gathered with a SUS questionnaire in which all participants preferred AR 2 to AR 1. The mean SUS-value for scenario M is 77 (SD ±1:80), for AR1 59 (SD

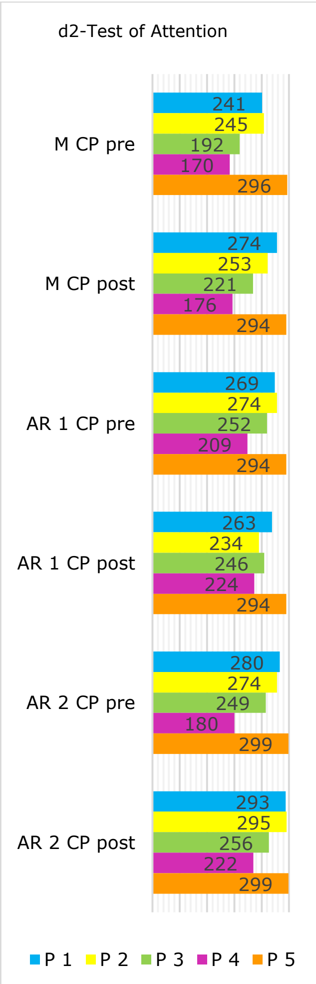

Figure 9: Results D2-Test of Attention

±14:84) and for AR2 76 (SD ±13:42). This outcome means that acceptance for AR 2 is higher and will make implementation at the plant easier. SUS outcomes gave no definitive answer whether scenario M or scenario AR 2 is the better fit in terms of workstation design as 3 participants rated M higher than AR 2 while 2 participants gave the higher scores for AR 2. Between the two AR scenarios, all participants preferred the AR 2 scenario. Analyzing the feedback on self-rated visual function with the Visual Fatigue Questionnaire, small deviations were observed, with a positive tendency regarding AR 2 in comparison to AR 1. Impact of AR-use on concentration performance individually varied. There is a tendency to reach higher concentration performance scores with the d2-Test of Attention at the post-shift assessment (in contrast to the pre-shift measurements), although one participant's concentration performance was not (or hardly) affected by any of the scenarios, because the participants consequently reached almost the maximum of the value. For three participants, working for the duration of an entire shift under exposure to AR 1 technology lowered their d2 scoring and affected their attention span and concentration negatively. Detailed results are presented in figure 9.

Discussion and conclusion

In conclusion, we expect scenario AR 1 no to be the right solution for introduction at the plant on a trial-basis due to the high TCT and low workers' acceptance. Based on the results from our pilot study, we recommend two of the three tested confirmation mechanisms for trial in the production area. The scenarios recommended to test in a larger sample are scenarios M and AR 2. Both M and AR 2 fulfill the prerequisites for production implementation in terms of TCT adherence and potential to reduce errors. To determine the ultimate reach of the two confirmation methods on TCT and error frequency, more studies are needed. Lastly, such studies will contribute to estimating the exact impact on visual fatigue and concentration performance levels. Through a field study with a larger sample of test persons during a full-shift usage, we hope to deliver results, based on which we can decide whether a serial production with AR-technologies at order picking workstations is useful.

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6 Conducting the full shift user study

Two different interaction variants were tested in Chapter 5. I compared on the one hand the integrated scanning in the smart glasses and on the other hand a display of the orders in the smart glasses and an external scanner, called ProGlove, as interaction device. The preliminary study showed that the combination of two devices delivered the best results regarding task completion time. The integrated scanning exceeded the maximum available process time specified by the assembly line, and is therefore not usable for the field study. Within the meaning of Rogers' diffusion theory the ProGlove scanner is subsequently adopted and the integrated scanning is rejected.

The visualization for the smart glasses was developed in Chapter 4 together with the employees. They rated the idea of a series of numbers in which the processed numbers disappear to the left positively. In further employee surveys I analyzed this idea with regard to the positioning of the font, font size, font color and font deposit using pairwise comparisons until the final version was found. I also compared this visualization created by an empirical procedure with standards and guidelines from the literature.

Chapter 6 forms the core of this research project. Conducting a user study, I test the Pick-by-Vision system over a full shift in the real process. The system consists of ODG R7 smart glasses and a ProGlove scanner, which are controlled via a local server. The server accesses the production data of the SAP warehouse management system via LAN connection and reports the pick confirmation, which is made by the scan, back to SAP. Figure 11 gives an overview about the test system:

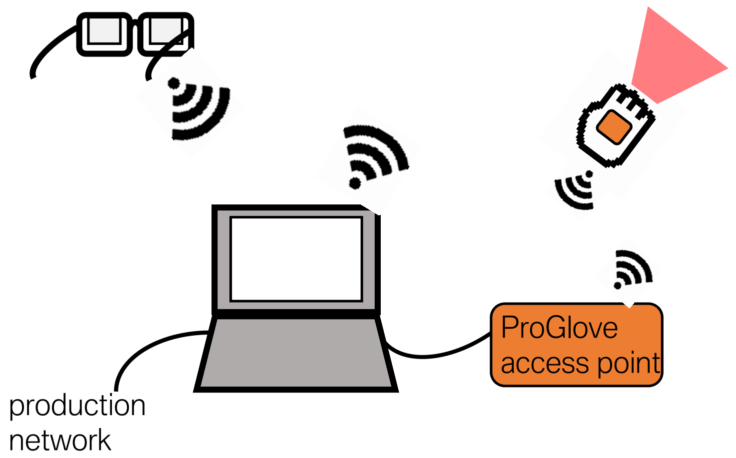

Fig. 11: Functionality of the test system

Conducting a field study represents the design phase in the user involvement process developed in Chapter 2. The study experiences and results are groundbreaking for deciding whether the system can be used permanently in the serial production process (see Figure 12).

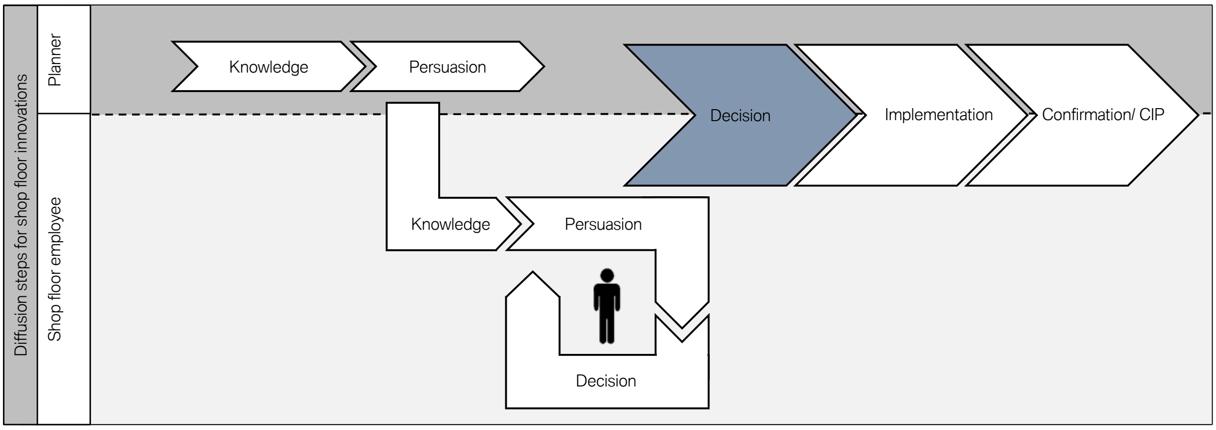

Fig. 12: Involvement of the users during the proof-of-concept

The BMW plant Munich served as test location for the study, described in the following paper. 23 experienced order pickers of all ages participated. The integration of spectacle wearers into the test was also ensured when selecting the hardware. Each employee worked a full shift with the system previously used, consisting of monitor and ProGlove scanner, and a full shift with the Pick-by-Vision system. Since the maximum working time per picking order is determined by the rhythm of the assembly line, it also had to be ensured that no error caused by the test was passed on to the assembly line. For this reason, a member of the test team had to check the quality after the process. Analyzing process- and user-related variables during the full shift operation served as input for answering the following research question:

What is the impact of a full shift usage of smart glasses in industrial order picking processes - with real-time interaction with the warehouse management system - on workers and process?

Figure 13, which can be played as video clip using the QR-code, shows an extract of the order picking process using the Pick-by-Vision-system:

Figure 13: Frame of a video clip showing an extract of the AR-supported picking process

The following publication 'A full shift field study to evaluate user- and process-oriented aspects of smart glasses in automotive order picking processes' was accepted by the International Journal on Interaction Design & Architecture(s).

A full shift field study to evaluate user- and process-oriented aspects of smart glasses in automotive order picking processes

Nela Murauer[1], Nerina Pflanz[2]
[1,2]BMW Group, Max-Diamand-Straße 5, 80788 Munich, Germany
[1]nela.murauer@bmw.de, [2]nerina.pa.pflanz@bmw.de

Abstract. Traditional flow production is experiencing a dynamic change towards smart factories. In the context of Industry 4.0 new technologies for worker assistance can be implemented in assembly, logistics or maintenance. Using Augmented Reality (AR) in order picking processes can provide advantages like time and error reduction and subsequently cost decrease. But what is the impact on employees wearing smart glasses during a full shift? Conducting a field study on the shop floor of an automotive production plant with expert order pickers, we analyze health-oriented aspects as well as the task completion time and the error frequency for a full shift usage of smart glasses in order picking processes. We face challenges such as an interaction with the warehouse management system and a predetermined production rhythm to ensure reliable results for the 8-hour usage of smart glasses, which may point the way towards future digital manufacturing.

Keywords: Augmented Reality, smart glasses, order picking processes, logistics, full shift usage

1 Introduction

The forth industrial revolution, known as 'Industry 4.0', forces manufacturing companies to shape the dynamic change from traditional flow production based on Taylorism towards smart factories. An increased amount of automatization is especially interesting for production plants with high personnel costs. But also other motives, such as the decrease of error rates and an increased level of quality, supporting workers with assistive technologies or surveillance of real time data show the entire range of opportunities of digital manufacturing. Changing logistic processes we focus on autonomous transportation systems like forklifts and tugger trains, robotics for efficient handling of empties, for automatic sorting and for truck unloading. Additionally, we conduct research on virtual reality for logistic planners and worker support with the aid of Augmented Reality (AR) and mobile devices such as smart watches. There is potential to automate many processes alongside the entire value stream, but especially in order picking processes we profit from the employees' flexibility regarding handling different objects and materials [1]. Therefore we engage in the context of Industry 4.0 in an order picking environment with assistive

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technologies for workers instead of their replacement by robotic solutions. Manual man-to-goods-order picking processes, where the positions of pallet cages to pick from are fixed and the worker collects all required components by moving from one pallet cage to the other [2], are the main focus of our research project. One highly promising technology is the usage of AR visualizations in head-mounted displays (HMD) or smart glasses, which we regard as synonymous in this paper. By displaying order picking information in the worker's field of view, we hope to decrease task completion times due to the elimination of unnecessary head- and body-movements. Integrating conspicuous error feedback may provide a reduction of error frequency. Additionally, visual guidance of workers can be a tool for an increased amount of job rotation, which contributes to the flexibility of the shop floor management and motivates employees by learning new processes.

Many studies in the context of AR for manufacturing use cases, which are explained in detail in Chapter 2, are laboratory studies with young participants without prior order picking experience. Thus there are no reliable reference points for a full shift usage of smart glasses in an industrial context. A further point, which received no attention, is the interaction of AR-devices with a warehouse management system. Few studies consider interaction methods, for example a button attached to a belt (but none corresponding to common interaction methods in logistics departments) and most use a Wizard-of-Oz-technique. In addition, most of the studies excluded workers wearing corrective glasses from participating. As all of the points mentioned above are highly relevant for a trailblazing decision for or against the implementation of smart glasses in a full shift operation, we conduct a field study concerning the following research question: *What is the impact of a full shift usage of smart glasses in order picking processes on workers and the process?* Hereby, we choose a real workstation in an automotive production plant as test environment, we use experienced order pickers of all ages as participants, we do not exclude corrective glasses wearers and we interact in real time with the warehouse management system.

2 Related Work

2.1 Order picking processes

Especially in times of increased individualization and variant diversity, order picking is one of the most important departments of intra logistics [3]. In automotive industry order picking workstations serve as suppliers for the assembly line. At so-called 'supermarkets' the pickers put the components precisely in the same order of the further assembly into the movable target shelf [2]. The order picking method at theses supermarkets is a manual man-to-goods order picking, which means the position of the provided components are fixed and the picker moves between the pallet cages during the component collection. So the picker has to run through the whole warehouse in the worst case scenario [4]. The pallet cages to pick from are refilled by internal or external suppliers [5]. Once a target shelf is filled, a transportation system such as a tugger train brings the shelf to the assembly line.

There are different methods for the visualization of order information and for the interaction with the warehouse management system. Pick-by-Paper means the listing of orders on a printed paper, which does not allow any automated interaction with the warehouse management system. The picker ticks all the picked components on the paper list [6]. Disadvantages are a lack of error feedback, no possibility to work hands-free and a lack of real time interaction with the warehouse management system. Using Pick-by-Light requires a confirmation with the aid of a confirmation button [4] attached to the withdrawal or target box. This method requires high investment costs, but allows hands-free work [2], real time interaction with the warehouse management system and error feedback. Pick-by-Voice is based on speech recognition and auditory orders. Hands-free work is possible, but this method can be demotivating for the picker due to auditory isolation of the environment [3] [2] [4]. Pick-by-Vision refers to worker support by AR-technology [7]. Required order picking information is visualized in the employee's field of view. Monocular or binocular head mounted displays can be used as hardware. The visualization of information can be context-sensitive, which means location-dependent signs like arrows or frames, or context-independent without tracking [8]. Advantages are the avoidance of unnecessary head- or body-movements, the enabling of hands-free work and a flexibility regarding provided information.

2.2 Augmented Reality in production

In our literature research we found several studies regarding AR-technologies in a productive environment. Büttner et al. [9] give an overview about AR- and virtual reality-related publications in a manufacturing context. Tümler [8] investigated AR-supported order picking processes with 20 participants with a highest age of 35 years in his laboratory study. He used a Microvision Nomad HMD and compared it with a paper-based order list. A forearm keyboard served as interaction device. In his study Tümler focused on process- and user-oriented variables. Among others, he analyzed eye dominance, task completion time (TCT), error frequency, heart rate variability and subjective strain. As a result an increase of headache and subjective workload was noticeable for the AR-system in comparison to Pick-by-Paper. Additionally, he observed four times more type errors and 30% less picked components using AR, witch means a higher task completion time for this visualization method. Summarizing his results, he expects other results for experienced pickers. Furthermore he postulates studies for an 8-hour usage. Based on the amount of omission errors, which increased during the test period, he recommends further research regarding concentration performance. Wiedenmaier [10] tested three different AR-assembly use cases with 36 participants with a highest age of 31. He also used a Microvison Nomad HMD and compared the usage with a paper-based scenario. The participants interacted with a mouse click with the HMD and did not get any error feedback. Whereas the error frequency is seen as task dependent, the subjective strain value showed no changes. Regarding the TCT, he determined time savings of 23% with the AR-system. Kampmeier et al. [11] focused in their laboratory study on ophthalmological variables. They tested paper-based instructions, paper-based instructions wearing a switched off HMD and a switched on HMD during 7.5

hours. 45 participants, mostly students with a highest age of 33, had to pick and to assemble technical toys. A portable PC worn at the belt served for the interaction with the HMD. Among others, they analyzed the d2-test of attention [12], the working quality and quantity and the heart rate variability. In their results, they observed a 13 percent increase in headaches wearing the HMD. Due to the fact that this increase was also detectable with a switched off HMD, they summarize that hardware-related reasons cause headaches. Nevertheless the participants classified the HMD wearing comfort as acceptable. Analyzing the different tasks, they regard AR-support as more suitable for picking than for assembly tasks. With reference to the ophthalmological results, they assume 'that from a medical and work psychological point of view there is nothing against a full shift usage of an AR-system'. Finally they recommend an improvement of the wearing comfort and a continuous monitoring of the users in case of a roll-out [11]. Büttner et al. [13] conducted a similar laboratory study. 13 unexperienced participants had to pick and to assemble LEGO ® animals. Focus of the study was the comparison of HMD-based, projection-based and paper-based instructions. As hardware served Vuzix Star 1200 glasses and a projector Optoma GT760. An interaction method is not explicitly mentioned. Referring to their results, the TCT during the HMD scenario was significantly higher than in both others. The error frequency behaves in a similar way. It is for the HMD scenario higher than in the projection- and the paper-based scenario. For the evaluation of the acceptance they asked the participants for a classification of the ease of use, the helpfulness and the joyfulness. Regarding the helpfulness and the joyfulness, they rated the projection- and paper-based scenarios significantly higher than the HMD-scenario. Thus they remarked that the 'combination of corrective glasses with HMD is not considered in most studies and settings' [13], and included spectacle wearers in their study. Guo et al.'s [14] study lead to conflicting conclusions. They investigated in a laboratory study the differences between Pick-by-Paper, Pick-by-Light, a cart-mounted display and a HMD (Microoptical SV3 opaque with laptop carried on the back). Eight unexperienced participants with an age of 22 till 27 years picked orders. Instead of the participant, the supervisor interacted with the system. Using the HMD the TCT was significantly lower than Pick-by-Light and Pick-by-Paper. In contrast to Büttner et al.'s observations the error frequency was lower in the HMD-scenario. Additionally, the subjective strain value was the lowest of all scenarios even though the hardware was uncomfortable. Reif and Günthner tested in their study the difference between Pick-by-Paper and Pick-by-Vision together with an industrial partner. Their 16 test candidates – students, researchers as well as skilled workers with an average age of 27.6 years – wore a HMD for a time period from 30 to 45 minutes. Speech input served as interaction method. As a result they observed a reduced task completion time by 4% using the AR-system in comparison with the paper list, which is not a significant difference. The error frequency was seven times higher using the paper list, but even this result does not lead to a significant result. Analyzing the subjective workload, the observations reinforce the effects with a lower subjective workload perceived after an AR-usage. Speech recognition as interaction method is viewed skeptically by the participants. In addition, they miss having an overview of all components to be picked. Consecutively, Reif and Günthner note that their results are not sufficient for a prediction of consequences of a full shift usage of an AR-system [15].

3 Methodology

In our field study, we compare two different visualization devices for displaying order picking tasks. The first device, which was implemented shortly before our study, is a cart-mounted monitor. The second device are binocular smart glasses. Conducting our study we analyze the differences of the impact on workers and the process using each device during a full shift.

3.1 Experimental environment

To find the best workstation as test environment, we analyzed all order picking workstations, so-called 'supermarkets', of the direct assembly delivery department at our production plant using Rasmussen's skill-rules-knowledge framework [16]. With Rasmussen's framework [17] human activities can be subdivided into skill-based, rule-based and knowledge-based tasks. According to [10] especially rule-based activities are suitable for an AR-usage. So we analyzed every single process step of all workstations and selected the workstation with the most rule-based process steps as test environment. The chosen workstation is for two workers. In a predetermined rhythm, analogous to the assembly line, they pick footwell claddings and put them into the target shelf in the same order as processed at the assembly line. There are different variants of footwell claddings (different colors, model series, driver's sides and components for emergency vehicles), which are located in a u-shaped layout at the workstation. Variant A and B were abolished a few month ago, so variant C is the first and variant L the last. Every variant position consists of two pallet cages, placed on the left and on the right of the way, providing components for the left side of the car and for the right side of the car. Figure 1 shows a picture of the chosen supermarket with the component designations and their color coding.

Fig. 1. Test workstation 'supermarket footwell claddings' with components C, D, E, F, G, H, J, K and L

The picker moves from C to L, picks all components of one variant and puts them into the target bins in the movable shelf. Six movable shelves are circulating. Three are at the workstation and three others on the way to the assembly line, at the assembly line or on the way back to the workstation. A tugger train brings the full shelves to the assembly line and brings back the empty ones. The target shelf consists of 16 consecutively numbered target bins. If the order contains components of the variants C, G and J, he puts C-components for example in bin 1, 3, 5, 7, 9, 10, 15, G-components in bin 2, 4, 6, 11 and J-components in bin 12, 13, 14 and 16. In doing so, he scans the pallet cage, from where he picked, and the target bin, which he filled, to interact with the warehouse management system. Additionally to the picking process, one pre-assembly has to be made for every pair of footwell claddings. Depending on the bought special equipment a boot switch or a shutter has to be assembled on the driver's side of the car. Furthermore, five white clips per pair must be fixed. While one worker picks the components, the other assembles the white clips. The pickers change role every other shelf, so that one picks and one clips during one round.

3.2 Hardware

The actual monitor is an innovation at this workstation and was implemented shortly before our study. The monitor is fixed on the right side of the movable shelf and can be repositioned easily from one rack to the next by the picker. Before this implementation pickers read the orders on a monitor, which hang from the ceiling.

The implementation of the new monitor was accompanied by the connection to the SAP warehouse management system. Scanning barcodes serve as interaction mechanism with the system. As scan device we use a scan glove, called 'ProGlove' of a Munich-based startup. Compared to classical hand-held barcode scanners, workers can work hands-free and the weight of the scanner is much lower. The scanner itself is changeable just like the cuff. A button in the palm of the hand triggers the scanner. Figure 2 shows the ProGlove cuff and the scanner.

Fig. 2. Scan-device 'ProGlove' [18]

As visualization device we use ODG R7 binocular smart glasses. They have a 30-degree Field-of-View, weigh 180g (compared to the 579g heavy Microsoft Hololens) and they are usable for persons wearing corrective glasses by fixing optical lenses behind the front glases on the nose clip.

In a pre-study we compared different scan-mechanisms using smart glasses as vizualization device [18]. First the participants used the glasses also as scan-device, then we tested the combination of smart glasses as visualization tool and a ProGlove as scanner. We used the same target shelf and processes as at the real workstation, where we test now, but with the difference that we provided three instead of nine variants. Even tough the error frequency was the lowest in case of scannning with the glasses, the mean task complection time was higher than in the actual process (8:11min; SD ±01:08min, monitor: 5:52min; SD ±00:31min). Using the ODG-ProGlove-combination was faster than both other scenarios (4:57min, SD ± 00:29min). Both, subjective workload and the usability assessments, led to worse results for using the glasses as scanner than for the combination or the actual monitor. Based on this results we decided to use an external ProGlove scanner in combination with ODG R7 smart glasses as visualization device for our main study. For detailed information about our pre-study see [18].

3.3 Visualization

For a user-centered interface design, we conducted a design-thinking workshop with future users directly on the shop floor. 40 participants had the opportunity to design and evaluate their desired solution. Based on paper prototyping, which is a common method in app design, we adapted this method for an AR-context. For further information about the new methodology called 'Photo Prototyping' and a new process oriented idea collection tool, called 'Morphological Storyboard', see [19].

The preferred solution is context-independent and contains the display of the boot switch (pre-assembly) on the left side, then the component name, followed by a color-coded square and a series of target bin numbers. Once the placement of a component is confirmed by a scan, the first target bin number disappears and the remaining numbers move to the left. Additionally, the pickers asked for error feedback, thus we added a brief illumination of a green check mark or a red 'x'. An example of a visualization shows figure 3:

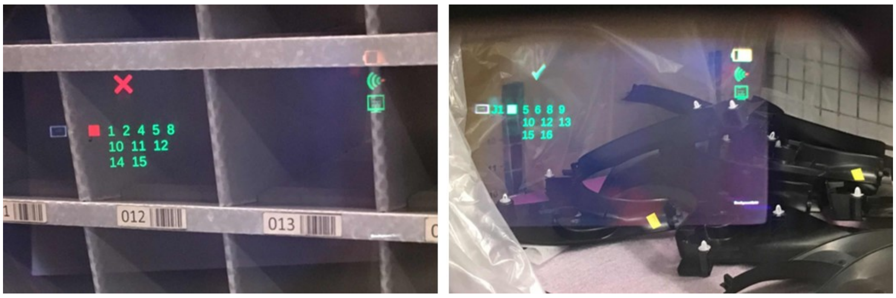

Fig. 3. Error feedback in the ODG R7 smart glasses

3.4 Study design

In our main study, presented in this paper, we focus on the impact of a full shift usage of smart glasses on the workers and the process. As explained above, an order picking workstation for footwell claddings at our automotive production plant in Munich serves as test environment. Inspired by [20] we tried to motivate the employees to participate in the study by providing sandwiches, sweets and coffee during one full shift. At our coffee-station the workers were open to talk and participate in the design thinking-workshop. At the same time they could volunteer for the main study. As a reward for the participation we announced a team event for all participants. All 23 participants are real logistics employees (20 male, 3 female). For the three spectacle wearers, we ordered individual manufactured corrective lenses for the smart glasses. Before the start, we had to discuss every variable to evaluate with the general works council and the data protection department. To avoid that they exercise their right of a veto, we accommodated their wishes. For this reason, we do not survey the age of participants and do not analyze personal differences between the scenarios but the overall average for each scenario. However, participants range from young workers with merely 2 years of working experience to long-employed workers who will retire in only 2 years.

We conduct our study during the morning shift, which starts at 5:50 a.m. and is finished at 14:55 p.m. During the shift, there are two breaks of 15min and one break of 30min. Consequently, the net working time is eight hours and five minutes. The process of the study is in both scenarios identical. We decided against a randomized design for two scenarios, which means we first test the monitor and then the glasses. Both scenarios are new for the pickers. One reason for our decision is that only the impact of the real scenario (old system first and then the innovation) counts for manufacturing companies, including all learn effects. Another point is that we have to change the SAP - warehouse management system to test the smart glasses. For a randomized design, we would have been forced to make this very change every day, which poses a risk. As we test at a real workstation, which delivers to the assembly line in a predetermined rhythm, we decided to avoid the risk of an assembly line stop caused by software changes for our workstation.

At the beginning of the first test scenario we ask the participants to rate their order picking experience. Additionally, we tested their ocular dominance. Before we start the first order picking task, we conduct the d2-Test of Attention [12], the Simulator Sickness Questionnaire (SSQ) [21] and the Visual Fatigue Questionnaire (VFQ) [22]. During the shift, we stop the task completion time (TCT) per shelf, we count the error frequency and we ask the participants to evaluate their mood six times per shift using a smiley scale, inspired by [23]. After the shift we repeat the d2-Test of Attention, we add the Raw NASA-TLX [24], we repeat the SSQ and the VFQ. To get further comments from the participants, we do a brief guided interview at the end of the shift. Table 1 gives an overview about the timeline and the methodology. Method details are briefly explained in our pre-study [18] and will be explained below.

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Table 1. Methodology of the full shift study

Pre-test	Test	Post-test
Ocular dominance test	Error frequency	d2-Test
d2-Test		
SSQ	(type error, omission error,	Raw NASA-TLX
VFQ	scan-error)	SSQ
	Task completion time	VFQ
	Smiley scale	Guided interview

3.5 User-oriented variables

The d2-test of attention is a common tool for the evaluation of concentration performance. It consists of 14 lines with ‘d’s and ‘p’s. Below and above the letters one to four marks are added. During 20 seconds per line the participant has to mark as much ‘d’s with two marks (two below, two above or one below and one above) as possible. With the aid of a stencil omission errors and confusion errors can be detected. The concentration capacity ‘CP’ can be calculated by subtraction the confusion errors from the amount of right detected ‘d’s with two marks per line. Conducting this test we adhere to the guidelines of the test-manual [12].

The Simulator Sickness Questionnaire is a qualitative questionnaire, which contains 16 variables of subjective discomfort: *general discomfort, fatigue, headache, eyestrain, difficulty focusing, increased salivation, sweating, nausea, difficulty concentrating, fullness of head, blurred vision, dizzy (eyes open), dizzy (eyes closed), vertigo, stomach awareness* and *burping* [21]. The evaluation scale is word-based and contains four steps: none, slight, moderate, severe, scored with 0, 1, 2 and 3. Based on a factor analysis [21] found three symptom groups ‘nausea’, ‘oculomotor’ and ‘disorientation’. Value N is influenced by the individual scores of *general discomfort, increased salivation, sweating, nausea, difficulty concentrating, stomach awareness* and *burping.* The sum of the individual scores must be multiplied by 9.54. Value O is based on the individual scores of *general discomfort, fatigue, headache, eyestrain, difficulty focusing, difficulty concentrating and blurred vision.* The multiplying factor is 7.58. Value D contains the individual scores of *difficulty focusing, nausea, fullness of head blurred vision, dizzy (eyes open), dizzy (eyes closed)* and *vertigo.* Value D is multiplied by 13.92. The total score (TS) is calculated as sum of N, O and D, multiplied by 3.74 [21]. For our study we use the German translation of [25].

To evaluate the perceived change of eye-related variables we use the Visual Fatigue Questionnaire. 17 items (*dry eyes; watery eyes; eyes are irritated, gritty, or burning; pain in or around the eyeball; heaviness of the eyes; problems with line-tracking; difficulty in focusing; ‘shivering/jumping’ text; ‘foggy’ letters; glare from lights; blurry vision; double vision; headache; neck pain; dizziness; nausea; mental fatigue)* have to be evaluated on a Likert-scale from ‘not noticeable at all’ to ‘extremely noticeable’ [22]. In contrast to [26], we maintained the scale from 0-8 instead of expanding it from 0-10. Due to the absence of a total value, all items have to be analyzed individually [26]. For our future analysis we name the items a-q. A German translation is provided by [26].

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For the analysis of user-oriented variables during the picking process, we created a smiley scale, inspired by [23]. The six step Likert scale contains smiley faces from very bad mood (6) to very good mood (1). The scores 6 to 1 are based on the German school marks. We ask the participants to evaluate their general mood six times per shift to get a course of the inter-daily mood development.

For the measurement of the subjective workload we use the Raw Nasa-TLX. The questionnaire measures six items *mental demand, physical demand, temporal demand, performance, effort* and *frustration* using a Likert scale from 0 till 100 [24]. The mean value of the six items equate to the final score. [27] and [28] provide German translations.

3.6 Process-oriented variables

During the shift we stop the task completion time (TCT) and count the error frequency. To get more detailed information we subdivide errors into error types. In literature we found a subdivision into quantity errors, type errors, omission errors and quality errors [29] or a subdivision into 'wrong amount, […] wrong item […], missing article […] [and] damaged article' [30], which are usable as synonymous. Due to a lack of influence of the visualization device on the quality of components, we do not survey this error type. Additionally we do not count quantity errors. The target boxes of the shelf at our test workstation are too narrow to put more components into the bin, so that quantity errors can only be omission errors [18]. Summarizing we focus on omission and type errors. Furthermore we add scan-errors to our evaluation, which means that the picker has correctly picked and put, but scanned a wrong barcode. To measure corrections of the worker during the process, we subdivided every error type into 'corrected' and 'uncorrected' errors, which means self-discovered and corrected errors and errors, which will be detected at assembly line. Especially the uncorrected errors are extremely relevant in the industrial context. In case of an error detection the foreman has to drive as fast as possible to the assembly line for changing the component. If that is not possible within the assembly rhythm, this error will cause reworking, which contains at worst a step-by-step disassembly and reassembly. For stopping the TCT, we defined the process start at the moment, when the picker touches the shelf to start picking and we defined the placement of the shelf on the parking position as process finish. To avoid interfering influences, we make sure that enough components are in the pallet cages. If a pallet cage has to be changed, we ask the forklift driver to do this between two picking processes.

3.7 Hypotheses

Based on literature research and the results our pre-study, we formulated hypotheses for the main study comparing the two visualization devices monitor (M) and smart glasses (AR). The formulation of hypotheses regarding the positive or negative impact of study performance on workers and the process is based on the indicators extracted from preliminary results in a pre-study or suggested impacts in scientific literature.

H1: The mean task completion time changes significantly regarding scenario M in comparison to scenario AR.
H2a: The mean amount of corrected type errors per shelf changes significantly regarding scenario M in comparison to scenario AR.
H2b: The mean amount of uncorrected type errors per shelf changes significantly regarding scenario M in comparison to scenario AR.
H3a: The mean amount of corrected omission errors per shelf changes significantly regarding scenario M in comparison to scenario AR.
H3b: The mean amount of uncorrected omission errors per shelf changes significantly regarding scenario M in comparison to scenario AR.
H4: The mean amount of scan-errors per shelf does not significantly change regarding scenario M in comparison to scenario AR.
H5: The inter-daily difference of the mean smiley rating does not significantly change regarding scenario M in comparison to scenario AR.
H6: The amount of the mean raw NASA-TLX does not significantly change regarding scenario M in comparison to scenario AR.
H7: The inter-daily difference of the mean concentration performance does not significantly change regarding scenario M in comparison to scenario AR.
H8: The inter-daily difference of the mean Total SSQ-Score changes significantly regarding scenario M in comparison to scenario AR.
H9a-9q: The inter-daily difference of the value of each item of the VFQ changes significantly regarding scenario M in comparison to scenario AR.

4 Results

We conducted our study with 23 participants. Figure 4 shows their picking experience. Two participants have less than 6 month experience, three 6 month - 2 years, three 2-3 years, six 3-5 years, seven 5-10 years and two more than 10 years.

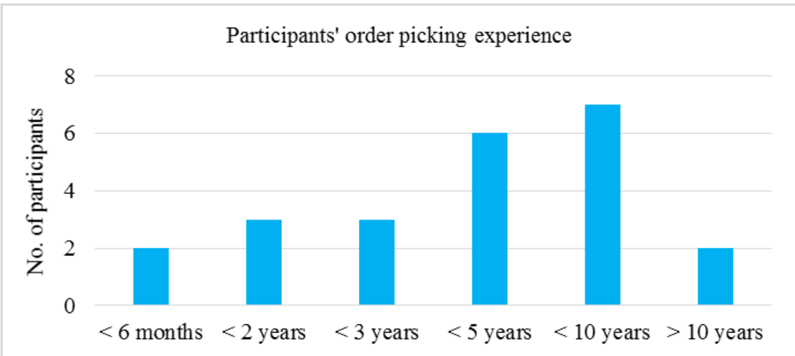

Fig. 4: Participants' order picking experience

4.1 Process-oriented variables

For the statistical evaluation of the TCT and the error frequencies, we conducted a two sided t-test in a paired sample (α=0.05).

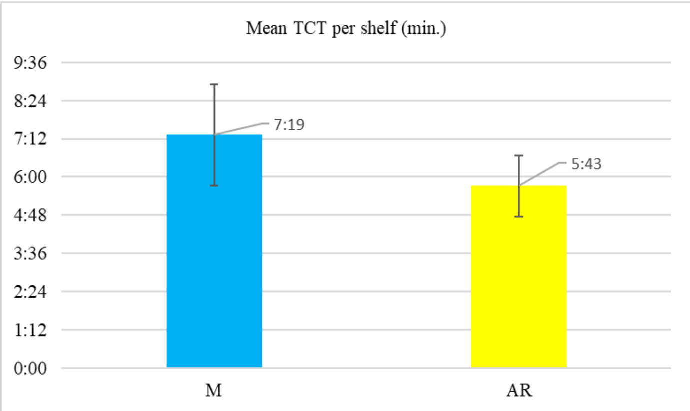

Fig. 5. Mean TCT per shelf for scenarios M and AR

Comparing the mean TCT per shelf, we observed a highly significant difference (p= 0.00) between the two scenarios, see Figure 5. While the mean TCT in scenario M was 7:19min/shelf (SD ±1:35min), we measured 5:43min/shelf for scenario AR (SD ±0:58min/shelf). The difference amounts to an average time reduction of 1:36min/shelf and 22%. Subsequently we maintain hypothesis H1.

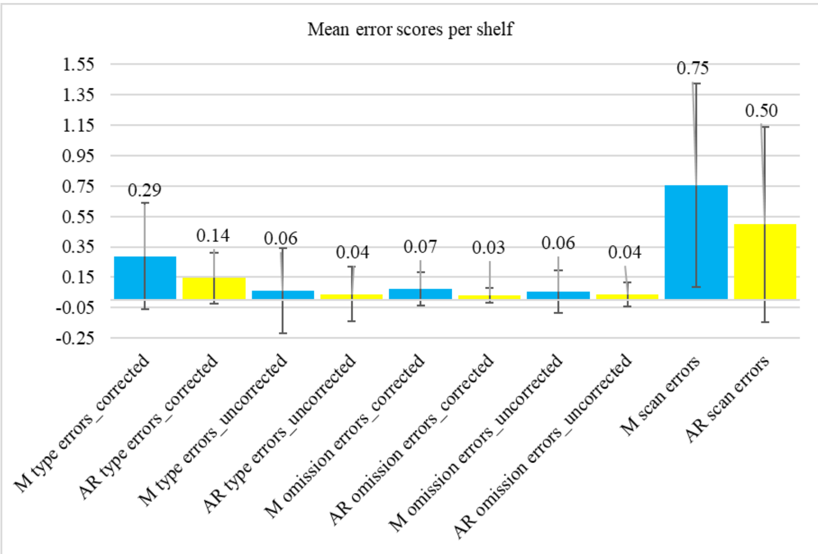

Fig. 6. Average error frequency per shelf for scenarios M and AR

Analyzing the error frequency in the predetermined error categories, we observed a decrease of the average amount of corrected type errors from 0.29 errors/shelf (SD ±0.35) to 0.14 errors/shelf (SD ±0.17) (p=0.05), of uncorrected type errors from 0.06 errors/shelf (SD ±0.28) to 0.04 errors/shelf (SD ±0.18) (p=0.25), of corrected omission errors from 0.07 errors/shelf (SD ±0.11) to 0.03 errors/shelf (SD ±0.05) (p=0.09), of uncorrected omission errors/shelf from 0.06 (SD ±0,14) to 0.04 (SD ±0.08) (p=0.56) and of scan errors from 0.75 errors/shelf (SD ±0.67) to 0.50 errors/shelf (SD ±0.64) (p=0.06) regarding scenario M in comparison with scenario AR. Subsequently the difference between the average amount of corrected type errors in scenario M and AR is significant. Therefore we maintain H2a. All other differences are not significant, thus we reject hypothesis H2b, H3a, H3b and maintain H4. Figure 6 shows an overview of the results.

4.2 User-oriented variables

A six step smiley rating scale serves for the detection of mood changes during the full-shift order picking operation. Figure 7 shows the two mean courses of the rating for scenario M and AR.

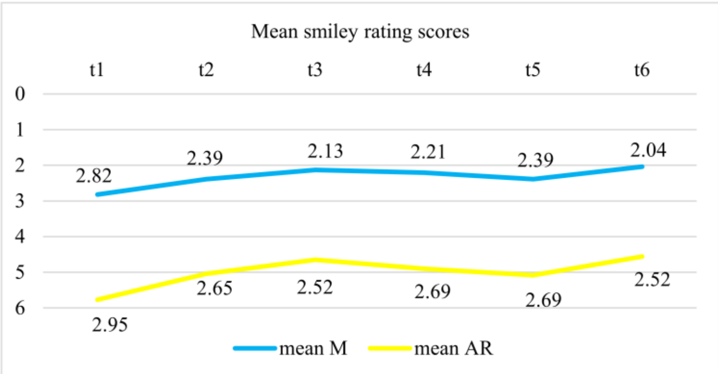

Fig. 7. Mean course of the smiley rating curve for scenario M and AR

For both scenarios the participants' mood got better during the morning shift. It is conspicuous that the course of scenario AR already starts worse than the one of scenario M. Both behave nearly parallel. From the beginning of the shift to the first break (t3) the curve develops positively, then until the 30min-lunch break (t5) it decreases and increases until the end of the shift. The curve during the AR-usage does not show any abnormalities in comparison to curve M. In addition, we could not determine any influence of working with smart glasses on the mood. The highest (worst) value of both scenarios is the baseline measurement before the shift started. Due to the lack of a significant difference of the mean inter-daily smiley rating (α=0.05) (p= 0.57) regarding scenarios M and AR, we maintain hypothesis H5.

With the aid of the Raw NASA-TLX questionnaire we statistically analyzed the perceived workload after the full shift usage of the visualization devices. Figure 8 shows the results.

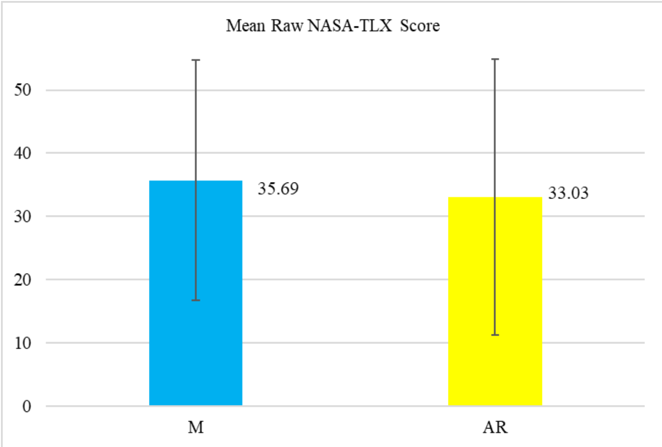

Fig. 8. Mean Raw Nasa-TLX score for M and AR

Regarding the mean raw NASA-TLX of the two scenarios, the difference is not significant (α=0.05) (p=0.53) with 35.69 (SD ±19.00) for M and 33.03 (SD ±21.80) for AR. Subsequently we maintain hypothesis H6. Interesting findings serves the analysis of the six subcategories. Whilst the mean score of both scenarios is relatively similar, the values of the subcategories are clearly different. After using the monitor (M) the participants evaluated their physical demand with 40.87, temporal demand with 36.30 and effort with 39.78 higher than after the usage of the smart glasses (AR) (31.52; 26.52; 32.39). The mean values for mental demand, performance and frustration behave inversely with (44.57; 25.86; 26.74) for M and (47.83; 28.48; 31.52) for AR.

Beside the NASA-TLX Brickenkamp's d2-Test of Attention provides interesting insights. Figure 9 presents the mean concentration performance values (CP) for both visualization devices M and AR and the inter-daily difference (pre-shift and post-shift) (α=0.05). Contrary to our initial expectations, the concentration performance increases during a full shift. The pre shift score of both scenarios is with 148.69 (M) and 148.6 (AR) similar. After using the monitor (M) the mean CP increases significantly by 18.6 to 167.3 (p=0.00). This enhances regarding scenario AR, in which the mean CP increases significantly by 26.48 to 175.08 (p=0.00). Comparing the mean inter-daily changes of both scenarios, we did not found any significance (p=0.26). Subsequently we maintain hypothesis H7. We assume that the early start of the morning shift influences lower scores in the morning and a gradual increase in concentration performance towards the end of the shift.

It is conspicuous that the standard deviation is quite high in both scenarios. This is probably based on a wide range of skill and educational levels in our sample.

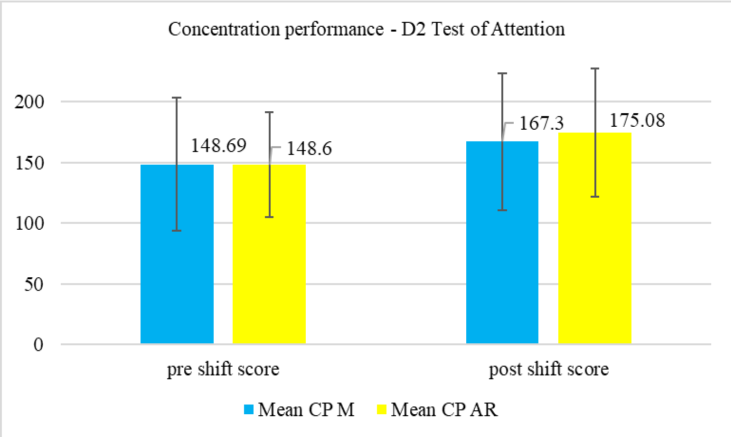

Fig. 9. Mean concentration performance (pre- and post-shift) for M and AR

Analyzing the mean pre- (t1) and post-shift (t2) scores of the Simulator Sickness Questionnaire brings interesting findings. The mean Nausea score starts with 15.35 (M) and 20.74 (AR) and increases to 25.72 (M) and 25.72 (AR). The inter-daily differences are significant ($\alpha=0.05$) ($p=0.04$) for M and not significant ($p=0.50$) for AR. The oculomotor pre-shift values are with 33.29 (M) and 32.20 (AR) nearly similar and behaves similarly regarding their increase to 45.81 (M) and 46.14 (AR). Both inter-daily changes are not significant ($p=0.11$) (M) and ($p=0.08$) (AR). Disorientation increases during the working shift as well. For M the mean score nearly doubles from 21.16 to 41.15, which describes a significant inter-daily change ($p=0.04$). For the AR-visualization the value behaves similarly and changes from 26.02 to 49.63, which is not significant ($p=0.07$). Figure 10 gives an overview of the results.

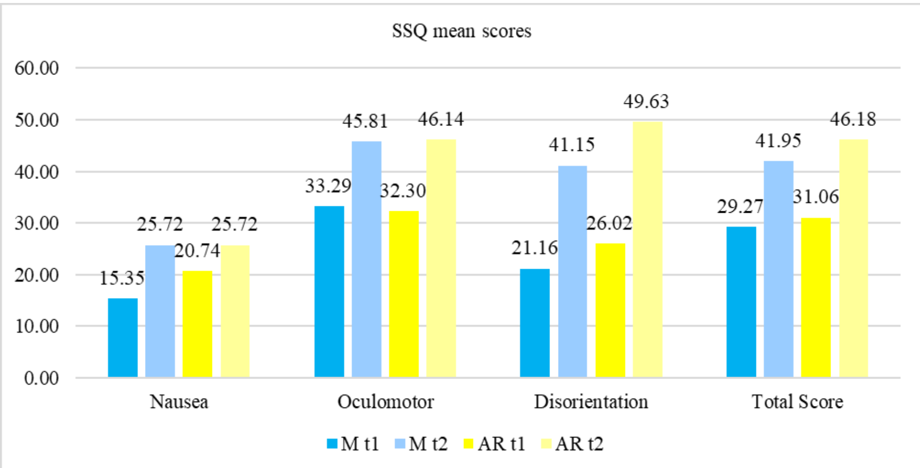

Fig. 10. Mean values of Nausea, Oculomotor, Disorientation and the Total Score for M and AR

The evaluation of the total score TS does not present any significant inter-daily changes (p=0.06) (M) and (p=0.12) (AR) with pre-shift scores of 29.27 (M) and 31.06 (AR) and post-shift scores of 41.95 (M) and 46.18 (AR). Regarding the mean inter-daily changes of the monitor-based picking in comparison with the smart glasses-based picking, there are no significances (Nausea p=0.49, the Oculomotor p=0.89, Disorientation p=0.75 and Total Score p=0.81). Subsequently we reject hypothesis H8.

The Visual Fatigue Questionnaire contains 17 items (*dry eyes (a); watery eyes (b); eyes are irritated, gritty, or burning (c); pain in or around the eyeball (d); heaviness of the eyes (e); problems with line-tracking (f); difficulty in focusing (g); 'shivering/jumping' text (h); 'foggy' letters (i); glare from lights (j); blurry vision (k); double vision (l); headache (m); neck pain (n); dizziness (o); nausea (p); mental fatigue (q))*. The individual categories of the used Visual Fatigue Questionnaire are reliable indicators on their own. The questionnaire is not designed to provide a single quantitative sum value as an indicator of visual fatigue.

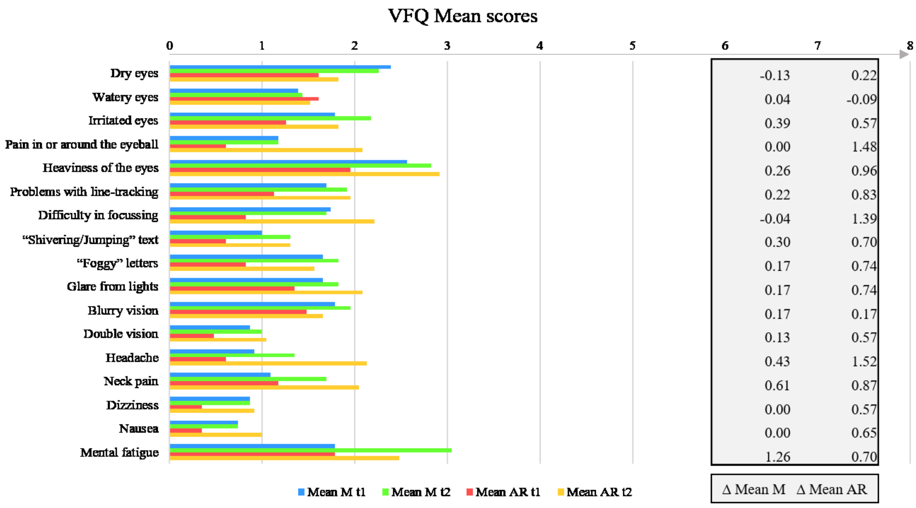

Fig. 11. Mean values of VFQ-items a-q for M and AR

Figure 11 presents the mean inter-daily deltas of the individual VFQ-scores of both scenarios M and AR. Analyzing the development of the scores caused by the monitor-based picking the scores range from an increase by 1.26 to a decrease of 0.13 for scenario M in comparison to an increase of 1.52 to a decrease of 0.09 for scenario AR. Only two items, watery eyes (b) and mental fatigue (q), worsen more working with the monitor than with the AR-system during the day. Item k, blurry vision, does not change depending on the visualization device. All other items increase more regarding the inter-daily difference of scenario AR. It is obvious that our participants experienced the most negative development during the shift for the items m 'headache', d 'pain in or around the eyeball' and g 'difficulty in focusing'. On a scale from zero to eight the mean value for item m increases by 1.52 (AR), item d by 1.48 and item g by 1.39. For said items we observed significant differences between the mean inter-daily changes of both scenarios ($\alpha=0.05$) (item m: $p=0.0217$; item d: $p=0.0068$; item g: $p=0.0214$). Further significances could not be established in our sample. Summarizing, we merely maintain hypotheses H9d, H9g and H9m and reject hypotheses H9a, H9b, H9c, H9e, H9f, H9h, H9i, H9j, H9k, H9l, H9n, H9o, H9p and H9q.

4.2 Guided interviews

For getting additional qualitative feedback, we asked the participants for their perceived positive and negative aspects of the full shift AR-usage. Additionally, we motivated participants to voice suggestions for improvement or for suitable use cases and workstations where they could imagine wearing smart glasses during a full shift operation. Summing up, the pickers' opinions about the full shift usage of smart glasses is combination with a ProGlove as interaction device are quite different. Some employees 'had fun' and think that working with the glasses is 'cool'. Most of them liked the user interface and the colors, especially the series of numbers, with which they had a better overview. Providing for error feedback is appreciated and leads to 'a nearly error-free picking'. The higher working speed is viewed as advantageous, caused by a visualization in their field-of-view and an avoidance of head- and body movements. Wireless working without any power bank prevents entanglement. Spectacle wearers liked the corrective clips and did not notice the weight difference between smart glasses and spectacles. One picker described the tasks as 'robot work, where we do not think, but only act', which he liked. Negative aspects were mostly hardware related comments. Most pickers perceived the weight of the glasses as uncomfortable and did not like the imprint on their nose caused by the nose clips, with which they did not want to go to the break room. Some participants found the temples inflexible and narrow. In fact, they saw a connection between the headache at the back of the head and the design of the temples. Another challenge was to refocus from objects to visualization in the glasses and the limited field of view. Few pickers perceived the display as blinding.

Suitable workstations from the participants' perspective are logistics, especially order picking workstations and pre-assembly, but not the assembly line. Some pickers firmed that the test workstation is a suitable working environment for an AR-support. Another aspect are training scenarios, in which AR-guidance leads unskilled workers through the process. For a future 8-hour usage, we gathered many proposals. Most suggestions concerned the wearing comfort of the smart glasses: lower weight, individually adjustable temples, padded nose clips and easy adjusting of contrast and brightness. Few ideas for improvement pertain to the design of the user interface, with which most pickers were satisfied. The symbols for battery status and wifi connection are not necessary in the field of view and can be replaced by attached lights on the side of the glasses. Some workers wished the numbers were bigger and located further down in the field of view.

5 Discussion & Conclusion

Due to the lack of studies of AR-usage during a full shift operation in real industrial working environment, connected with real-time interaction with a warehouse management system and real order pickers of all ages as test candidates we conducted a field study at our automotive production plant in Munich. In our research we focused on exploring the impact of a full shift usage of smart glasses on workers and the process. Under the conditions of our testing scenario the AR-support contributed a 22% decrease of the mean task completion time. Depending on the error type, we observed a reduction of the mean error frequency up to 58%. The statistical analysis of the subjective workload did not yield significant differences between the scenarios M (monitor) and AR. Whilst the sub-values ‘mental demand’, ‘performance’ and ‘frustration’ of the NASA-TLX are higher after using smart glasses as visualization device, the sub-values ‘physical demand’, ‘temporal demand’ and ‘effort’ were higher using the monitor. We hypothesize that a higher physical demand for M is caused by head- and body-movements, which can be avoided though smart glasses. Due to the decrease of the TCT the temporal demand is lower for AR, but nevertheless the participants evaluate their frustration scores higher. Even though the objective variables such as TCT and error frequency point to better performance using AR, workers underestimate their performance. This effect is probably caused by a perceived uncertainty during working with a novel technology, with which they have never been in contact. An inter-daily increase of the mean concentration performance can stem from two possible reasons: either the time of day or the continuous mental demand using AR, which could support the workers’ attention. Further research should investigate the effects of different work shifts such as a morning shift, an evening shift and a night shift. Regarding the results of the Simulator Sickness Questionnaire the values for scenario AR increase more than for scenario M, but the maxima are quite similar. Merely the end-of-shift AR score for disorientation is striking and indicates higher disorientation than after working a full shift with the monitor. Yet, no participant opted out of the study and or reported significant nausea. In fact, performance scores such as TCT improved during the day despite of prolonged use of the hardware. VFQ answers suggest that differences between afternoon and baseline measurements in the morning are higher for AR. These subjective assessments of the workload and effect of working a full shift with AR technology stand in contrast to Kampmeier et al.’s [11] findings. We cannot determine for certain whether the differences between our results and [11] were caused by a different testing environment, diverging test methods or another working task. Further insight into the topic would be welcomed.

Summarizing, the process-oriented variables are indicative of the suitability of AR technology for full shift usage in automotive order picking. Improving the wearing comfort of the smart glasses would support of a user-oriented approach to introducing such innovations to a productive working environment. Neither interacting with the warehouse management system nor the battery performance were an issue in conducting the field study. We did not observe that age or wearing corrective glasses hindered participants in working with smart glasses. We can imagine to introduce the tested technology at predetermined and well-suited workstations to gather further insights and requirements for long-term usage in the industrial environment.

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7 Discussion and further potentials

7.1 Summary of the methodology and the findings

Manufacturing companies aim to reduce error rates and task completion time through the use of assistance systems in manual man-to-goods order picking processes. Wearables such as smart watches, smart clothes and smart glasses shape the ongoing change towards a smart factory on processes, which cannot be fully automated yet. Smart glasses in particular, which display orders in the employee's field of view, can contribute to achieve this goal of error and time reduction. Existing studies testing Pick-by-Vision systems in user studies differ greatly in their results regarding task completion time, error rate and subjective strain. In addition, there is a lack of any studies investigating Pick-by-Vision-systems under real production conditions during a full shift. Reasons for this research gap could be hardware-related, environment-induced or social context-based. Hardware challenges are battery life, hardware weight, hygiene issues and a maturity at a prototype level. Further challenges are complex connectivity to the warehouse management system, to production Wi-Fi and a predetermined working rhythm, due to which it is difficult to conduct studies under real production conditions. To persuade the works council requires effort, depending on the company and on the labor union. In his conclusion, Tümler calls for further research investigating the usage of smart glasses during eight hours [16]. Most studies are laboratory studies with students without picking experience as test candidates. There are also still unexplored areas with regard to the age structure of participants. Test candidates older than 50 years are generally not included in user studies. Therefore, the currently available research results do not reflect the age structure in the workforces of most companies. Especially logistics employ workers in the later years of their career until the beginning of their retirement due to physical limitations caused by many decades working at the assembly line. Hence the older workforce is of particular interest for research in the industrial production context and should not be foregone. The involvement of older employees as well as separate studies on workers of advanced age can provide interesting results. Even the previous exclusion of persons wearing corrective glasses does not allow to make a statement about a possible standard-production use, since an assistance system should be usable by all employees. In my research project, I focused subsequently on testing a Pick-by-Vision system in real production with the duration of a full shift. Only experienced order pickers of all age groups, including spectacle wearers, participated as test candidates. In contrast to existing studies, binocular smart glasses were chosen as hardware, which offers to display the entire color spectrum on a comparably large field-of-view. Just one hardware met the requirements of the binocular display and the integration of spectacle wearers through extra clips attached to the nose clip. Since in other projects only Wizard-of-Oz technique, forearm keyboards, buttons or speech recognition served as interaction method, even though the usage of scanners is common in logistics, I paid special attention to the selection of the interaction method. In my main study, I investigated user- and process-related impacts of a full shift usage of smart glasses. Aside from economic variables such as error frequency, error type and task completion time, I focused especially on the perceived subjective evaluation of, among other, physical strain, usefulness, stress, performance, frustration, effort, pain experiences and mental demand. A positive subjective evaluation of all these variables automatically leads to higher acceptance, while the same cannot be said for objective measuring criteria. For this reason, qualitative and quantitative evaluation tools such as questionnaires using Likert-scales and interviews generate valuable subjective data. Following Rogers' Diffusion of Innovations theory, the feedback and findings of the proof-of-concept serves as basis for a decision for or against a standard-production use.

It is noticeable that in the publications presented in Chapter 1 the users were only involved at the time of the study. This phenomenon of late user involvement can also often be observed in industrial innovation projects. The production planner scouts emerging technologies with which he achieves process improvements. In most cases, the shop floor employee only learns about the technology in a proof of concept. Hence, I developed a process for early user involvement based on Rogers' Diffusion of Innovation as a first step in this research project (Chapter 2). The planner, who carries out the innovation scouting or triggers a process improvement based on the continuous improvement process (CIP), acquires knowledge and is persuaded of the technology. Then he starts the knowledge building and the persuasion phase of the shop floor employee, who will continuously be integrated during the development phase. At any point in time he is at the center of the innovation project. Finally, the jointly developed solution is tested in a proof-on-concept. The feedback of the employees and the results of the tests serve as input for the subsequent decision regarding a standard-production use. The CIP represents the continuous improvement of the system and the process. My developed approach, explained in Chapter 2, allows the employee to be involved well before the proof of concept. His expert knowledge of the process helps to design an optimal system for the employee. Another aspect is, that allowing employees to influence the system promotes the appreciation of their knowledge and skills and increases subsequent system acceptance. The new approach can be used for any innovation implementation projects on the shop floor and is therefore not limited to the context of Augmented Reality.

As a first step in the employee involvement process, I conducted guided interviews to introduce the technology, the wishes, misgivings, ideas and fears of the employees. These served as a basis for the project.

As a second step, a suitable workplace was selected in Chapter 3 inspired by Wiedenmaier's approach using Rasmussen' skill-rules-knowledge framework to evaluate the suitability of activities for AR-support [41]. According to Wiedenmaier, rule-based activities are particularly suitable for AR-support [41]. Due to the lack of objective methods to classify activities into Rasmussen's framework, I developed a new approach based on cost-utility analysis and pairwise comparison. For the first time, the new method allows numeric classification with clear boundaries between the three levels 'skill-based', 'rule-based' and 'knowledge-based'. Level jumps caused by higher experience are also possible using the new evaluation method. It thus solves Rasmussen's two greatest criticisms - the lack of numeric boundaries and the missing solution for level jumps - and can be used to evaluate all kinds of human behavior in the future. Further research needs to review and verify the defined numeric boundaries, as the involvement of a larger number of experts increases their validity. Using the new evaluation methodology I selected the best test workstation for an AR-usage containing the most rule-based process steps together with the shop floor workforce. One point of criticism on our approach is the fact that the relative number of rule-based steps was consulted. A time-based percentage would be more valid. However, this should be calculated by measuring true durations of process steps and not based on target times of the MTM analysis. But in manufacturing companies the approval of the works council is required for taking these real process times. Our selected workstation is an order picking workstation for footwell claddings. To perform the process, information about the pick orders and the pre-assemblies is required.

In a further step of employee involvement, I asked workers to design the display of this information themselves during a Design Thinking workshop. This is a further step in employee involvement. For the design of AR-content I adapted the method of paper prototyping. I used photos of a video of the order picking process filmed by a GoPro head mounted camera as background for drawing and gluing augmentations. This simple 'photo prototyping' methodology allows employees, who have no expert knowledge of AR technology or subsequent programming, to contribute their ideas. During the workshop many ideas could be collected in a very short period of time. Photo Prototyping creates a common language in interdisciplinary teams and a discussion basis for finding solutions. The feedback of the participants was very positive. ‘Less is more. Planners are prone to implement more than the process really needs’, ‘it’s cool, to contribute all ideas, I ever had for optimizing the process’ are some quotes of the workers [68]. In the future, photo prototyping can be used as a methodology for user-centered user interface design of any AR-content.

In a preliminary study, different interaction techniques, on the one hand the integrated scanning in the glasses and on the other hand the use of an external scanner in combination with an AR-display, were compared. The integrated scanning took considerably longer, since movements could not be parallelized due to the staring at the barcode. The combined solution saved 16% of task completion time, 14% of type errors and 40% of omission errors compared to the previously used monitor. It should be noted, however, that I made no distinction between corrected and uncorrected errors. Corrected errors affect the time, uncorrected errors reach the assembly line and can cause rework or even a production stop. Therefore, the main study once again distinguished between these two types of errors. In the study, I compared two interaction mechanisms. Further research should therefore investigate a comparison of different interaction mechanisms, such as other scanners, buttons, speech input, gesture control, RFID-based interaction, or similar. The interaction methods investigated in the preliminary study thus represent only a subset of interaction mechanisms due to their relevance in our study environment.

Conducting the full shift study under real production conductions, I selected experienced workers as participants to investigate the differences between monitor-based and smart glasses-based order picking. Most participants had between three and ten years of order picking experience. The results of the study can therefore not be generalized to a group of unskilled workers. Analyzing the process-oriented variables, I could prove a reduction of the task completion time by 22% and a decrease of the error frequency, depending on the error type, by between 33% and 58%. The time savings are due to the avoidance of body and head movements, the parallelization of information reception and the execution of tasks, as well as the more intuitive display of orders according to the wishes of the employees. In order to be able to transfer this time saving to MTM-based process time descriptions for a standard-production use, the MTM method, which is used to determine the target times, must be modified to allow the parallelization of perceiving information and moving the body. The error rate of all error types decreased, so a generally positive influence on the number of defects can be proven by the smart glasses and the aim of a zero-defect-picking [9] will be supported. During the study approximately 25000 parts were picked, wherefore I estimate the process-oriented findings as highly meaningful. It should be noted that the standard deviation of all process-oriented variables describing the impact on task completion time and error rate are reduced using the Pick-by-Vision system. I conclude from this observation that the manageability of the AR system is significantly higher for employees of all performance levels and that the system is therefore suitable for more employees. Those employees, who sometimes took more than twice as long as other employees using the monitor, were slower with smart glasses, but the time difference was much smaller. Integrating employees, who find processes challenging, is therefore easier with AR. The concentration performance increases during the shift in both scenarios, for AR more than for the monitor-based scenario. Due to conducting the study only in the morning shift, I recommend investigating the differences of morning-, evening- and night-shifts. The findings of my study are not automatically transferable to other times of the day. The increase of the concentration performance can be seen in connection with the decrease of the errors. Performing the process during all times of the day must nevertheless remain acceptable to the worker. Analyzing the standard deviation of concentration performance a wide spread is observable. I suspect that the reason for this is the different levels of education of the employees and the resulting different demands on concentration in their previous working lives. Nevertheless, the very large dispersion of concentration performance needs to be further investigated. In addition to the concentration performance, the subjective evaluation of the mood also shows a positive curve progression throughout the shift. With regard to this subjective variable, further research must clarify the influence of shift times. Both in the preliminary study and in the main study, the subjective workload hardly differed between the two visualization variants. Nevertheless, it was possible to measure a change regarding subjective workload in both studies. Mental demand, performance and frustration are higher after the usage of the Pick-by-Vision system compared to the monitor, while physical demand, temporal demand and effort were lower. However, the mean value of the strains is approximately the same. A question raised several times in discussions with the works council and the personnel department, is whether the change of workload types in the process will change the requirements for the employee and thus also the classification of the salary in the pay scale structure. The results of Raw NASA-TLX suggest that the demands on the employee will change, but the overall workload for the employee will remain the same. Therefore, I do not recommend changing the job difficulty assessment. However, this statement can only be made for the group participating in this study. In other groups with different educational backgrounds, different technical affinities or different cultural backgrounds, the results could be different. Significant differences in the inter-daily delta of the probability of occurrence of simulator sickness could not be detected. I noticed a slight tendency towards higher values for smart glasses. Pre-shift scores in the morning were already higher on the days evaluating AR-usage, leading to the assumption that users tend to rate the baseline higher using AR. Therefore I recommend an evaluation with more objective test methods. The visual fatigue questionnaire only provided significant differences between the two visualization devices comparing the inter-daily deltas of neck pain, difficulty in focusing and pain in or around the eye ball. In the analysis of the mean absolute values the highest value participants evaluated is 1.48 on a scale from zero to eight, which corresponds to the interval between 'not noticeable at all' and 'rarely noticeable'. The findings show consequently the same tendency as Kampmeier et al.'s results, based on which they concluded that full-shift use of smart glasses is unproblematic [42]. It remains to be noted, that I collected the eye-related parameters in the field study using a questionnaire, while Kampmeier et al. investigated objective ophthalmological parameters in a laboratory study. Further research on ophthalmological parameters in the real production environment is welcomed. Further long-term examinations should investigate long-term effects on the workers' vision [42]. Giving qualitative feedback participants said that they 'had fun', 'working with the glasses is 'cool' and that they liked the interface and the colors, especially the series of numbers visualized in their field-of-view. The integration of error feedback supports achieving the aim of error free picking. Employees generally consider all logistics workstations, in particular manual man-to-goods order picking workstations, to be very suitable for a usage of smart glasses. In addition, they can also imagine training scenarios with smart glasses. In Chapter 7.3 I present a further study dealing with smart glasses-based order picking training. Referring to Koelle et al.'s three key factors supporting an adoption of the technology by the users, presented in Chapter 2 [67], these findings and qualitative feedback indicate high usefulness and usability in the pickers' opinion. As explained in Chapter 2, mainly usefulness and usability can be influenced through a consequent involvement of the future users in an innovation implementation project at the shop floor. This approach retrospectively turned out to be absolutely right and is therefore recommended for further innovation projects on the shop floor. After a longer period of standard-production usage the users' acceptance can be reviewed. Referring to Koelle et al.'s third key factor, the functionality [67], is primary influenced by the hardware producers. The negative feedback from users was largely related to hardware-related topics. Especially the high weight, the inflexible and narrow temples and the impression that the glasses produced on the nose, disturbed them. They suspected that headaches and neck pain are due to weight and temples. Another point of criticism is the limited field of view, which allows displaying all required information, but which produces a feeling of being restricted. In the pickers' point of view, hardware functionality and design should change for the better to achieve a long-term acceptance. This statement refers only to the ODG R7 used. Nevertheless, it is currently valid for the entire hardware market, as explained in Chapter 1.2. Referring to the ODG R7 the order pickers wish a lower weight, individually adjustable temples, padded nose clips, an easy adjusting of contrast and brightness and a LED-based status display of current battery status and Wi-Fi connection attached on the temples.

7.2 Next steps towards a standard-production use

The results of the field study show extremely positive effects on task completion time and error rate. User-related variables mainly show no significant differences between monitor and smart glasses. The perceived visual fatigue increased more than using the monitor, but in a range which does not exceed the evaluation 'rarely noticeable'. Additional positive user feedback leads me to recommend initiating the next steps towards a standard-production use. I am aware that the hardware ODG R7 is not yet as mature as other devices used as assistive technologies in production. It should be noted, however, that I observed that the AR-software was much more stable than the one on the SAP-based monitor. In spite of the disadvantages of the smart glasses hardware, it can be used to trigger a change towards smart order picking workstation. Only making more experiences in a serial production supports learning about the technology and its problems to solve. To start this learning process, I suggest not working on a global roll-out, but a smooth change first at one work station (in our use case the footwell cladding-supermarket) supervised by the innovation team. To achieve standard-production use quite a few obstacles need to be overcome. Shaping the next steps towards standard-production use represents the implementation phase of the user involvement-process described in Chapter 2 (see Figure 14).

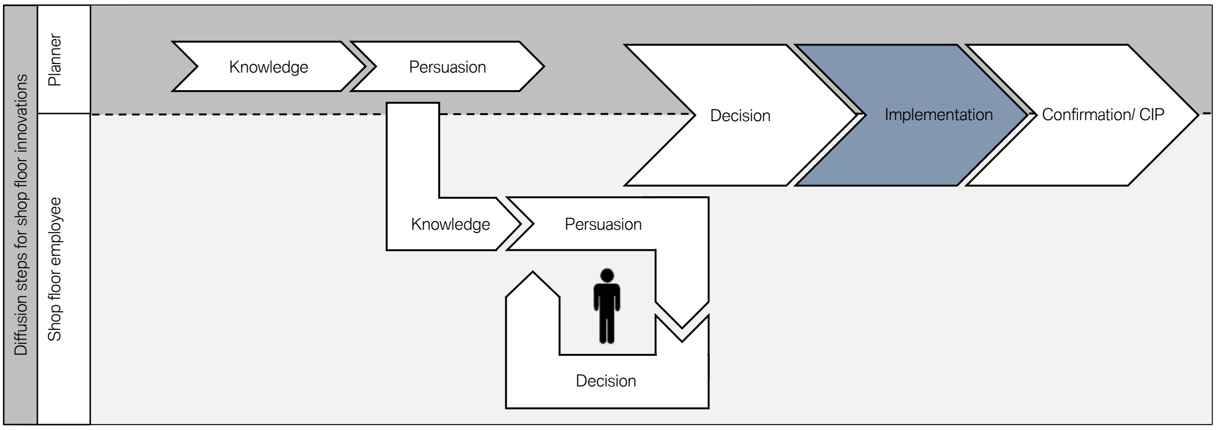

Fig. 14: Involvement of the workers during the steps towards a standard-production use

First, the future serial usage must be discussed with the works council. In implementing new assistive technologies, they must be convinced due to their right of veto. Second, the ODG R7 hardware must be approved for working with it at the production plant. This internal approval contains adhering to standards regarding cyber security and avoiding worker surveillance possibilities. For this purpose hardware changes, such as sensor removal, can be requested. A further important challenge is the connection to the warehouse management system. For my field study, I used a special SAP interface. For a standard-production use in Munich, it is sufficient to use this interface again. But for the long term a solution connected to an Internet of Things-cloud, as described by [7], will be more flexible. Thus all types of mobile devices could become visualization tools for order picking information. Workers could choose between monitor, smart glasses or smart watches. Every kind of mobile or stationary device could be used as emergency strategy, when the primarily used device malfunctions. In addition to the connection to the warehouse management system, the internal approval for the production server is needed. Due to a high risk of the possibility of manipulating the production-IT, every project, which will use the server of a production plant, is strictly controlled. The same applies to the permission for using the production Wi-Fi. Taking the participants' hardware related comments seriously, the possibility of buying specially produced smart glasses for our use case should be examined.

Shatterproof lenses, padded nose clips, adjustable temples as well as – if possible – a reduction of the weight would increase wearing comfort. Furthermore we have to meet many challenges of defining new processes on the shop floor. Foremen carry the responsibility of charging the smart glasses during the night in the future. They dispense the hardware at the beginning of the shift. During the working day the order picker has to make sure that the hardware will be charged during the breaks. The return to the foremen must be ensured through an adequate process. I case of hardware and software problems a 24/7 support must be guaranteed internally or externally by a supplier. Due to shared usage of the hardware, a hygienic concept must be developed. Finally, we have to develop a training concept for new and unskilled employees. When all these organizational obstacles will be overcome, a standard-production use is possible. Using the Pick-by-Vision system for several months could lead to further challenges not realized at the present moment. A continuous improvement process serves to mature the new smart glasses-based process. The findings of this CIP will guide the way towards a long term adoption or rejection of the technology (see Rogers' Diffusion of Innovation [69]). Figure15 shows this last step of the in Chapter 2 defined approach.

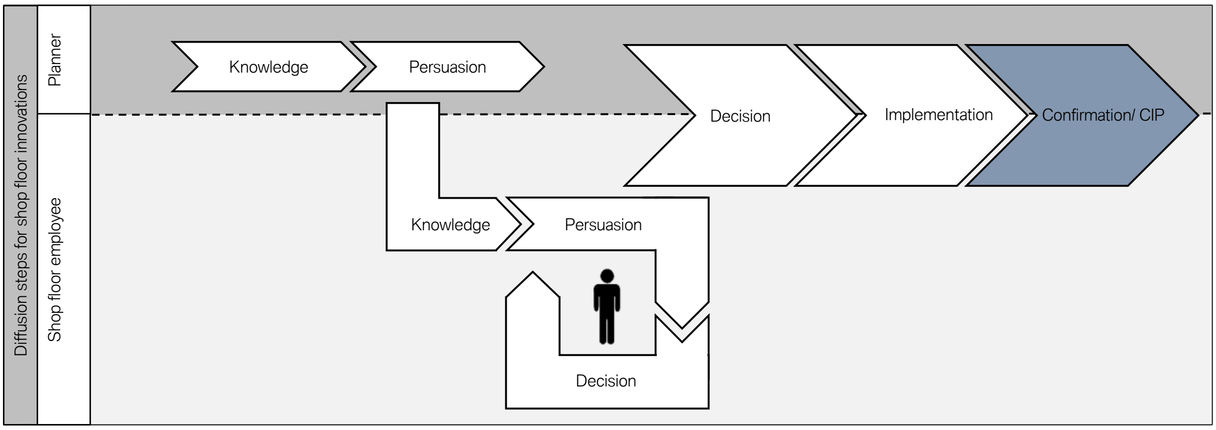

Fig. 15: Involvement of the users during the continuous improvement process

7.3 Further potentials

The technology of smart glasses opens a number of further research areas. In the field study described in this thesis, I displayed textual context-independent information. This was due to the lack of depth camera in the ODG R7 smart glasses. A context-sensitive display would be possible based on markers, but did not prove stable enough to test it under real production conditions. Therefore I recommend for this kind of visualization a Microsoft HoloLens, which offers the necessary technical requirements. With this hardware, a comparison between context-independent and context-sensitive display can therefore be made. However, with approx. 579g in weight it is too heavy to be used over a full shift. Thus, such a study can initially only be conducted over a shorter period of time.

Another application for smart glasses is the training of unskilled employees. In logistics, the fluctuation of logistics employees is often very high. For this reason, employees must be trained continuously. In order to run these training courses economically, virtual methods are preferable to high personnel expenditure, even though initial investment costs for hard- and software are higher. Augmented Reality, in particular guided order picking, can make a contribution to this. Language barriers in the multicultural environment of order pickers could also support learning success through symbol-based guidance. It is conceivable that this will enable employees, who do not speak the production language, such as refugees, who have not been in the country for a long time, to be integrated into everyday working life much earlier.

The following publication explores these two other research aspects. It compares context-sensitive and context-independent visualizations. In the case of textual information, I investigated the influence of language in order picking. ‘An Analysis of Language Impact on Augmented Reality Order Picking Training’ was presented on the 11th Pervasive Technologies Related to Assistive Environments Conference 2018.

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An Analysis of Language Impact on Augmented Reality Order Picking Training

Nela Murauer
BMW Group
Max-Diamand-Straße 5
80788 München
nela.murauer@bmw.de

Florian Müller
TU Darmstadt
Hochschulstraße 10
64289 Darmstadt
mueller@tk.tu-darmstadt.de

Sebastian Günther
TU Darmstadt
Hochschulstraße 10
64289 Darmstadt
guenther@tk.tu-darmstadt.de

Dominik Schön
TU Darmstadt
Hochschulstraße 10
64289 Darmstadt
schoen@tk.tu-darmstadt.de

Nerina Pflanz
BMW Group
Max-Diamand-Straße 5
80788 München
nerina.pflanz@bmw.de

Markus Funk
TU Darmstadt
Hochschulstraße 10
64289 Darmstadt
funk@tk.tu-darmstadt.de

ABSTRACT

Order picking is a difficult and cognitively demanding task. Traditionally textual instructions are helping new workers to learn different picking routines. However, the textual instructions are sometimes not written in the workers' native languages. In the area of Industry 4.0, where digital functions are finding their way into manufacturing processes, language-independent instructions are possible. Through a user study with 15 participants, we compare textual feedback in the workers' native language, textual feedback that is written in an unknown foreign language, and visual Augmented Reality (AR) feedback. We found that AR feedback is significantly faster and leads to a lower perceived cognitive load.

CCS CONCEPTS

• **Human-centered computing → Mixed / augmented reality** • **Human-centered computing → Empirical studies in HCI**

KEYWORDS

Order Picking; Augmented Reality; Assistive Systems

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1 INTRODUCTION

Manufacturing companies are currently undergoing a dynamic transformation from traditional flow production to a smart factory. Designing this change automotive logistics focus on the implementation of Augmented Reality (AR) in order picking processes, robotics, autonomous forklifts and autonomous tugger trains. In particular, AR-technology offers advantages to series production and training. Today foremen explain every process step to novice employees and accompany the worker for several days. This training procedure is time consuming and causes high personnel costs for the foremen. AR-training scenarios in head mounted displays offer the opportunity to guide the trainee with the aid of indoor navigation and the visualization of work instructions. Especially at order picking workstations, the guidance through the process is more important than the training effect. As orders vary in their amount and their composition of components or products, each order picking process must be supported by additional information. There are different visualization methods for order picking processes. *Pick-by-Paper* means picking with the aid of a paper-based picking list, *Pick-by-Voice* guides the worker with auditory navigation, *Pick-by-Light* points out the next target to an employee with a little light fixed below the box and *Pick-by-Vision* supports the picker by augmented additional information in head mounted displays. Especially *Pick-by-Voice* and *Pick-by-Vision* are suitable for enabling unskilled workers, such as novice employees or temporary staff, to perform at the workstation with the aid of step-by-step instructions. Compared to *Pick-by-Voice,* AR-assistance can display different information at the same time and, for example, overlay the path to the correct bin with arrows similar to a head-up display design in cars.

As team characteristics are multi-cultural and thus multi-lingual, we observed foreman training in different languages. Additionally, in some production plants the working language is not the local language. For this reason, we would like to address these language-barriers integrating different ways of information visualization in our AR design concept. Afterwards, we will analyze the impact of language on training efforts in our study.

2 RELATED WORK AND BACKGROUND

2.1 Augmented Reality Training

A number of authors have given their attention to the application of AR-supported training in the environment of production, dexterity and manual labor. This section introduces some of their works as an indicator of the current state of knowledge on AR. Reyes et al. aimed to replace the trainer for inexperienced students by an app, which teaches the handling of machinery [1]. The tool developed and implemented by [1] delivered good results since students accepted the AR instructions positively. This information compliments studies by Wiedenmaier and Wiedenmaier et al. [2, 3] finding shorter task completion times (TCT), better assembly quality, and lower human workload comparing HMD to paper-based instructions for the process of assembling a car door. Two separate and independent studies by [4] assessed the usability of virtual training in automotive manufacturing. Langley et al. observed error reductions in tasks performance after virtual introduction and training [4]. Participants were again for the most part positive concerning the overall use of the virtual training systems for assembly operation training.

2.2 Augmented Reality Order Picking

Some studies address order picking supported by AR-technologies. Guo et al. [5] compared in their order picking study card-mounted displays, head mounted displays (HMD), Pick-by-Light and Pick-by-Paper with 12 participants. The subjective workload, measured by NASA-TLX [6], was the lowest using a HMD. The task completion time was significantly shorter and the error rate was significantly lower subjecting to AR-instruction compared to the other methods. Odenthal et al. recruited 48 participants for a study comparing the delivery of assembly information by head-mounted or table-mounted Augmented Vision Systems [7]. For [7] AR increased the error detection capability significantly**,** but they concluded that error detection time increased as well. Kampmeier et al. [8] analyzed in their laboratory test the difference between paper-based and HMD-based assembly support. To estimate the impact of wearing the HMD on the worker, they added a third scenario, where the participants wore a HMD, but information was provided paper-based. After ophthalmological examination they concluded that using a HMD does not cause eye impairment. The resulting evidence shows that the workload is not significantly higher using a HMD. Deduced results were that quality and quantity of workers' performance renders HMD support more useful in order picking process rather than assembly tasks. Funk et al. [9] recommended a cart-mounted projector system. In a comprehensive study, they found that a cart-mounted system is faster and leads to less cognitive effort than traditional picking methods. Further, Funk et al. [10] advised a similar camera-projector system that is worn on the worker's head to assist during order picking tasks. Reif et al. [11] and Schwerdtfeger et al. [12] proposed the implementation of an attention funnel visualization [13] based on [14] for head-mounted displays to show workers the path to the target bin. Theis et al. [15] compared in their study with 60 participants different types of HMDs with a monitor. The performance of the group, which assembled with the aid of HMDs, was significantly lower in comparison to the screen-supported group. Tümler [16] shares the view that paper-based order picking is faster and thus preferable to HMD. After Tümler, estimation of the subjective cognitive workload is equally higher for HMD than paper-based tools.

An overview about Augmented Reality and Virtual Reality systems for manufacturing environments is presented by Buettner et al. [17].

Results are inconclusive at this point as the range of time, error rate and cognitive workload is not transferable from one use-case to another. We assume thus that neither the results nor the advantages and disadvantages are context independent. Hence, AR- support requires testing in the targeted work environment.

3 SYSTEM

To evaluate the use of both textual instructions and Augmented Reality instructions for order picking, we created three order picking assistance systems: a textual German system, a textual Finnish system, and an Augmented Reality system. All systems were implemented in Unity using a Microsoft HoloLens. In the following, we describe the three order picking systems in detail.

3.1 Textual Feedback: German

As a baseline condition, we implement a textual order picking system, which gives textual picking instructions that are written in German language. We choose German as a language for this textual baseline order picking system as German is the work-language in our factory.

The system shows the compartment to pick from and the quantity to pick in a text overlay that is at a fixed position in the worker's field of view. Using this fixed position, we ensure that wherever the worker is currently looking at, the picking instruction is visible and in the center of the worker's field of view. Figure 1(left) shows an example of a German picking instruction.

To place the previously picked object, the system also shows a textual instruction for the worker. Again, the place instruction is placed at a fixed position in the worker's field of view. Figure 1 (right) shows an example of a German placing instruction.

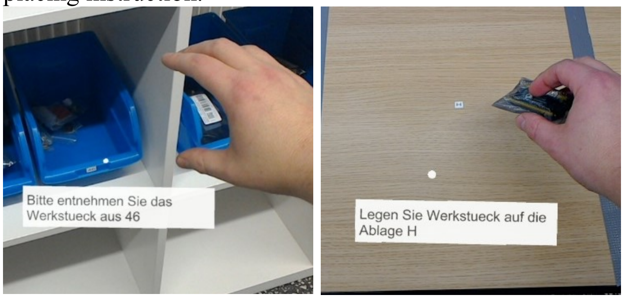

Figure 1: The text-based German picking instructing telling the participant to pick a part from a bin (left) and to place the previously picked part (right).

3.2 Textual Feedback: Finish

We are interested in assessing the effect of the language the instructions are written in on the worker's performance. Therefore, we argue to present the picking instruction in an unknown foreign language and assess the effect of the foreign language on the dependent variables. As a result, we chose Finnish as a language for the textual control condition as in our factory Finnish is a language that not only no one has experience speaking in but also no one has pre-knowledge of. For the Finnish textual instructions, we use exactly the same representation than in the German textual instruction, i.e., a textual overlay that is displayed on a fixed position in the worker's field of view. Figure 2 (left) shows an example of a Finnish picking instruction and Figure 2 (right) shows a Finnish placing instruction.

Figure 2: The text-based Finnish picking instructing telling the participant to pick a part from a bin (left) and to place the previously picked part (right).

3.3 Augmented Reality Arrow Visualization

Based on related work and our previous research activities, we build a 3D arrow visualization which shows the worker where to pick parts from and where to place them. The arrow is displayed at a dynamic position in the worker's field of view and is always facing the position to pick from or the position to place the currently picked part. The amount of items to pick and items to place is also displayed using a text label. Once the correct amount is picked or placed, the arrow starts pointing to the next target. If the last action is performed, the arrow is not shown anymore and the current picking round is finished. Figure 3 (left) shows an example of the Arrow picking instruction and Figure 3 (right) shows a placing instruction.

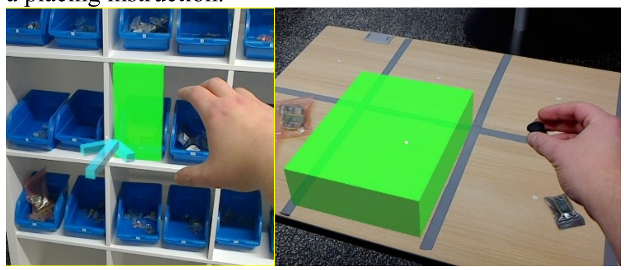

Figure 3: The Augmented Reality picking instructing telling the participant to pick a part from a bin using green rectangles (left) and to place the previously picked part (right).

4 EVALUATION

We scientifically evaluated the previously proposed order picking systems. In the following the design, procedure, participants and the results of the study are presented.

4.1 Design

We designed the study according to a repeated measures design with the used order picking system as the only independent variable consisting of three levels: German Text, Finnish Text, and Augmented Reality Guidance. As dependent variables, we measured the Task Completion Time (TCT), the number of errors that were made (ER), and the perceived cognitive load using the Raw NASA-TLX questionnaire (RTLX) [6].

4.2 Task and Study Setup

To compare the previously introduced order picking visualizations for the Microsoft HoloLens, we designed a study environment consisting of a picking area and a placing area. The picking area consists of two IKEA KALLAX shelves containing 48 traditional picking bins. We labeled the picking bins with a number from 1 to 48 to being able to identify them better. As items to pick and place, we use electronic boards with different shapes and sizes. Thereby one picking bin held one type of electronic board. For the placement area, we used a standard table (160cm x 80cm), which we divided into 10 equal placement areas. We used tape to optically mark the different placement positions. We labeled the different placement positions with letters from A to J.

We designed the picking and placing tasks to pick one item from each picking bin. This results in equally complicated picking tasks for each conditions. However, the order of the bins and the order of the placement areas were changed. Both picking area and placing area are depicted in Figure 4. For controlling the instructions that are shown on the Microsoft HoloLens device, we created a backend interface for the experimenter to control the content that is shown on the head-mounted display. The backend interface is also implemented in Unity3D and communicates with the Microsoft HoloLens using the HoloToolkit SharingService. Figure 5 shows the backend interface, which contains two buttons for indicating if a picking or placing task has been performed correctly or not. Also, the backend interface contains a routine to connect to the HoloLens application and to choose the order picking visualization according to the chosen condition. The experimenter uses this backend interface to control all aspects of the user study.

Figure 4: The setup that was used to conduct the user study. In the background there is the picking area containing of 48 picking pins. In the front is the placement area consisting of 10 placement spots

4.3 Procedure

We followed the same standardized procedure for every participant in our user study to ensure equal starting conditions. At first, we explained the participant the course of the study and gave a general introduction on order picking. After filing a consent form and informing the participants about the data that is being collected in the study, we collected the demographics and asked about previous experience with Augmented Reality. Then, we gave a general introduction to the Microsoft HoloLens and made participants familiar with mounting the HoloLens. As interacting with content on the HoloLens was not required for this study, we did not include any user interaction in the tutorial and in the application. As we were only interested in the effect of the visual instructions on the dependent variables, we excluded the picking detection and placing detection from the study and used a Wizard of Oz (WoZ) to forward the instructions once a pick or a place was done by the worker. Using this WoZ approach, we assured that the pick and place detection always worked perfectly.

We gave the participants some time to get familiar with the device. Once the participants indicated that they were ready to start the study, we started with the first picking system. To avoid ordering effects of the picking systems, we counterbalanced the order of the conditions using a Balanced Latin Square. Each picking condition was done with a task consisting of 48 items to pick and place. During the study, a researcher was observing the participant. The researcher also counted if the participants made an error. After the task was done, we repeated the procedure for the other conditions.

To recreate a realistic setting that would be found in an industrial order picking scenario, a researcher was there at all times if the participant had questions regarding the study. However, the researcher did not answer any questions about the picking task during the study. We deliberately designed the study in this way as this represents the reality in our company.

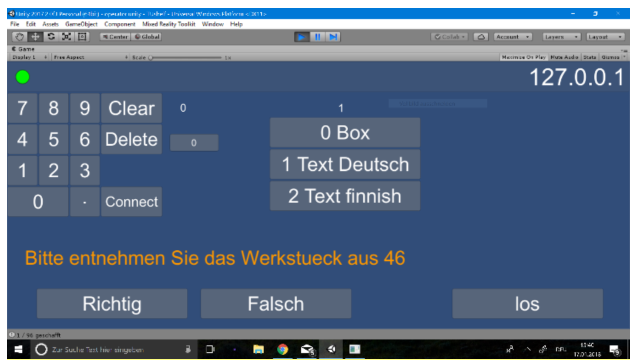

Figure 5: The backend which is used by the experimenter to connect to the HoloLens application and to control the shown order picking visualization. The interface on the bottom of the application enables the experimenter to log errors.

4.4 Participants

For our study, we invited 15 participants (3 female, 12 male) who were between 22 and 33 years old (M = 27.4 years, SD = 3.02 years). The participants were researchers with different backgrounds and students with different majors. Eight of the 15 participants had previous experience with the Microsoft HoloLens. Five of the 15 participants considered themselves as Augmented Reality experts. None of the participants was familiar with the positions of the items and the order picking tasks that were used in this study. The study took approximately 30 minutes per participant. All participants volunteered to take part in the study and did not receive a compensation.

4.5 Results

We statistically analyzed the Task Completion Time, the number of errors, and the perceived cognitive workload using the Raw NASA-TLX questionnaire. Mauchly's test of sphericity did not indicate a violation for all dependent variables. We used a Bonferroni correction for all post-hoc tests.

We statistically compared the Task Completion Time across the three order picking systems. The Augmented Reality system was the fastest (M=3.31s, SD=0.57s), followed by the textual instructions in German (M=4.25s, SD=0.97s) and the textual instructions in Finnish (M=4.37s, SD=0.92s). A one-way repeated measures ANOVA revealed a statistically significant difference between the conditions $F(2,28) = 11.674$, $p < 0.001$. A post-hoc test revealed a significant difference between the Augmented Reality condition and both textual conditions ($p<0.05$). The effect size estimate revealed a large effect ($\eta 2 = 0.455$). Figure 9 depicts the average TCT graphically.

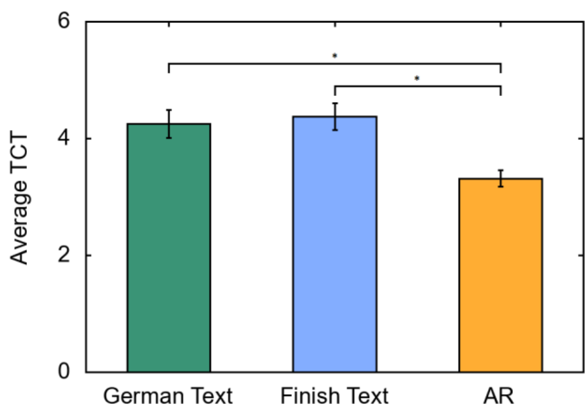

Figure 6: The average Task Completion Time (TCT) that was needed for completing one pick in our user study. The error bars show the Standard Error (SE). Bars that are marked with a * indicate a statistically significant difference.

Considering the errors that were being made by the participants, all order picking systems led to the same amount of errors (M=0.07, SD=0.258). This is equivalent to 1 error per condition. The different errors were made by different participants. Hence, a one-way repeated measures ANOVA did not reveal any significant difference ($p>0.05$). Figure 10 shows a diagram depicting the average errors.

Regarding the perceived cognitive load that was measured using the Raw Nasa-TLX (RTLX) questionnaire, the Augmented Reality order picking system led to the lowest RTLX score (M=19.13, SD=10.01), followed by the German textual order picking system (M=28.71, SD=12.33) and the Finnish textual order picking system (M=29.92, SD=11.83). A one-way repeated measures ANOVA revealed a significant difference between the conditions, $F(2,28) = 9.022$, $p = 0.001$. A post-hoc test revealed a significant difference between the Augmented Reality condition and both textual conditions ($p<0.05$). The effect size estimate revealed a large effect ($\eta 2 = 0.486$). The results for the average RTLX score are also shown in Figure 11.

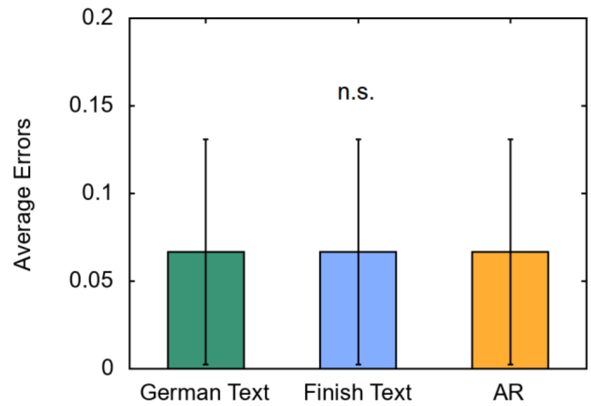

Figure 7: The average errors that were made while completing one pick in our user study. The error bars show the Standard Error (SE). Bars that are marked with a * indicate a statistically significant difference.

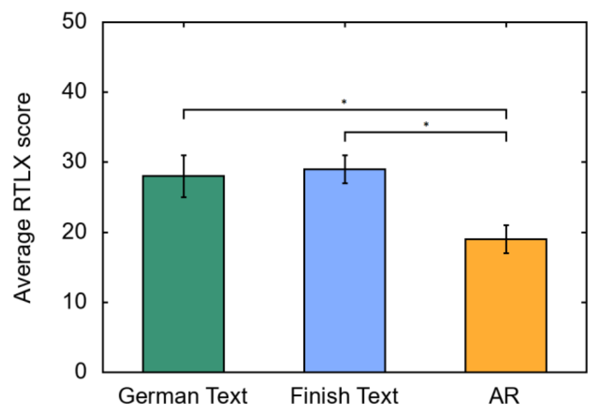

Figure 8: The average Raw NASA-TLX (RTLX) score that was scored for each condition in our user study. The error bars show the Standard Error (SE). Bars that are marked with a * indicate a statistically significant difference.

4.6 Qualitative Results

Through a semi-structured interview at the end of each condition, we also collected valuable qualitative feedback. In general, participants were mentioning the comfort of wearing a HoloLens. They stated that "at the end of the study wearing the HoloLens was becoming a little bit painful" (P3) and that "the HoloLens was getting a little uncomfortable with increasing time" (P4). Another participant stated that "the field of view of the HoloLens is a problem to see things in the arrow condition" (P7). That was also noticed by another participant by stating that for understanding the arrow visualization you "have to take a step back to grasp the whole picture" (P9). Also for the arrow feedback condition, some participants reported that "I completely lost the connection to what I was picking, as at some point I was only paying attention to the visual picking instructions" (P4, P10, P11, P14). However, they also enjoyed the comfort of the arrow based instructions as they stated that "the arrow-based instructions were really intuitive" (P5, P7, P15). They particularly liked that "for the arrow-based feedback [they] don't have to understand the feedback and can start right away" (P6, P8, P11). One participant even stated that while during picking, "[he] could turn off [his] head" (P12). For the textual instructions, participants stated that "It didn't make a difference for me if the feedback was displayed in German or in Finnish as I was only paying attention to the numbers and letters indicating the picking and placement locations" (P3, P4, P5, P9, P11, P12, P15).

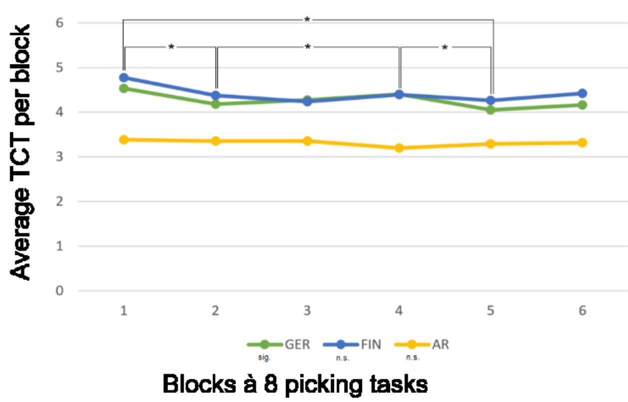

Figure 9: Learn effect for the groups using German, Finnish and AR

In order to assess a learn effect for the conditions, we divided the task into 6 sub groups consisting of 8 picking tasks per group. While we could not find a significant learn effect for the groups using AR and Finnish, there was a significant difference ($p>0.05$) between the blocks 1 and 2, 2 and 4, 4 and 5, and 1 and 5 (as depicted in Figure 9).

5 DISCUSSION

Through the conducted user study, we made several main findings that are summarized and discussed in this section.
We found that the arrow visualization led to significantly faster picking results than both textual conditions. We assume that this is due to the effort the workers have to put in to read the instructions first. The qualitative feedback revealed that with the arrow visualization, the participants could start with the picking right away. The processing time the participants needed for using the AR arrow visualization might have been less than processing a textual instruction.
Further, we found that the arrow visualization leads to significantly less cognitive effort based on the measured RTLX score than both textual instructions. This finding was also confirmed by the qualitative feedback that we received by the participants. We assume that this is also due to the reduced effort that participants need to understand the AR arrow visualization in comparison to a textual picking instruction. Based on these two findings of the performed user study, we can see a preference towards the arrow-based order picking visualization.
Another interesting finding of this study is that participants did not seem to pay attention about the language that is used for describing the picking instructions. This finding is mostly based on the qualitative feedback that we received by the participants.

6 CONCLUSION

AR visualizations support novice employees learning the order picking process irrespective of their native language background. It is an advantage of AR-supported that the foreman is relieved of the task to train incoming workers with a low level of experience.
Guidance by symbols rather than textual information also introduces an element to the training process, which renders the trainee more autonomous and enables unskilled workers to take up work not only quickly but also at a variety of workstations. This flexibility in job rotation is an enrichment for the worker and contributes to task variation for the single employee. Unskilled workers can become part of the staff quickly. In particular, production plants with high worker fluctuation will profit from the decreased training times under supervision and assistance of the foremen. Furthermore, the role of language in the training phase becomes less important using visual guidance to avoid language-induced communication problems. How far-reaching the AR-technologies and visual guidance should be, remains to be discussed. A healthy balance between automatization and autonomous behavior needs to be defined and upheld as decoupling of task comprehension and task execution inevitably comes in focus.

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Summing up the findings of the study explained above, I expect additional savings in task completion time using a context-sensitive guidance. Due to the lack of adequate hardware with the technical possibilities of the Microsoft HoloLens and acceptable wearing comfort, especially a tolerable weight, further research in an industrial context and during a full shift depends on further hardware development. Analyzing the learning effect after training, participants were able to work significantly faster than with the textual variant from the beginning and maintain the speed. Further long-term investigations are welcome. Language independence of picking was proven in the described study. However, the same can be said for textual information by the coding of the boxes with numbers or letters.

Another topic that has already been mentioned is the revision of the MTM time bricks for the calculation of AR-supported activities. After consultation with the MTM Company, our visualization was designed in such a way that the so-called eye travel times are eliminated by displaying the orders in the center of the field of vision. However, time savings of 22% is not only due to the elimination of eye travel times. I assume that the avoidance of body and head movements to the screen is calculable with the existing methodology. However, time bricks for parallel order picking and processing information provided in the field of view do not exist [19]. For this reason, the method must be broadened for smart glasses-supported work.

For further research, I also recommend investigating the effects of the shift times on the measurement variables. I proved an increase in mood and attention, which can be caused by the early start to the working day. In the evening shift, I therefore expect the results to be reversed. Further studies in this research area would be interesting. In addition, long-term studies, ideally in collaboration with ophthalmologists, should be conducted to investigate the long-term effects on the visual abilities of the employee. Kampmeier et al. come to the conclusion that a full shift usage of smart glasses is harmless [42]. However, they only refer to one day of laboratory study. For this reason, further investigations in industry with real order pickers should investigate ophthalmological issues.

Thinking of the vision of a smart factory, the smart glasses can also be combined with other wearables. For example, smart vests are conceivable, which use sensors to record the posture of employees and give them feedback on their posture in their glasses. A combination with a vibration bracelet, which provides haptic error feedback, was also suggested by the other participants in the Design Thinking workshop. Another idea is to display paths, where forklifts and tugger trains are driving, to mark theses red colored for safety reasons. This can only be done by locating the employee, which would have to be discussed with the works council.

Since order picking is a monotonous activity, which many employees exercise over many years, there is also great potential in the integration of playful elements, called gamification. Deterding defines the term gamification as 'the use of game design elements in non-game contexts' [70, p.9]. The concept is familiar to supermarkets, where customers are encouraged to buy by collecting loyalty points. Sailer [71], Günthner [72] and Korn [73] already investigated monitor- or projection-based motivation and performance motivation in order picking and assembly. Sailer presents an interesting research dealing with psychological impact of game elements regarding the fulfillment of psychological basic needs [71]. He based his research on Deci and Ryan's self-determination theory, which predicates that the three basic needs of humans are competence, autonomy and relatedness [74]. According to Sailer the game elements 'points', 'badges', 'team high-score' and 'performance graph' address an increased perceived competence, 'narrative' and 'avatar' an increased perceived autonomy and 'badges', 'team high-score' and 'narrative' an increased perceived relatedness [71]. In a preliminary study, I investigated, which game elements address best the three basic needs. For this purpose I have developed one prototype movie for every basic need. Figure 16 shows different movie contents.

Autonomy:	Competence:	Relatedness:
Narrative, avatar	Points, performance chart, badges	Narrative, team high score, badges

Fig. 16: Three different AR-gamification contents used in my simulation study

A publication in German explaining related work and the study in detail can be found in the annex of this thesis. Summing up the results of the study, experts consider the implementation of gamification appropriate for achieving motivation in monotonous order picking processes. Daily performance in repetitive activities becomes more tangible. Experts and employees liked mostly avatars and team high-scores as well as points and performance graphs, with the restriction that points and performance graphs should not be permanently displayed in the field of view. They demanded an only positive feedback, which does not correspond to the individual's performance but the team one's. Designing a motivation game, the avoidance of monotony instead of the increase of performance should be focused. Based on these findings a suitable AR-game should be designed for order picking tasks. I recommend testing a combination of order picking information and game elements provided in smart glasses to shape the change towards smart factories at order picking workstations.

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Annex

Simulationsstudie zur Erfüllung psychologischer Grundbedürfnisse durch Gamification in der Datenbrillen-unterstützten Kommissionierung

Nela MURAUER[1], Theresa HUBER[2]

[1] BMW Group, Innovationen und Industrie 4.0 in der Logistik, Max-Diamand-Straße 5, D-80788 München
[2] Lehrstuhl für Kommunikationswissenschaft, Universität Passau, Innstraße 33a, D-94032 Passau

Kurzfassung: Zunehmende Digitalisierung und die Weiterentwicklung von Augmented Reality (AR) Tools beeinflussen zunehmend die Arbeitswelt der Intralogistik. Die vorliegende Simulationsstudie beschäftigt sich mit dem Einsatz von AR-unterstützten Datenbrillen. Gamification bietet die Möglichkeit durch Einblendung von Spieldesignelementen monotone, immer wiederkehrende Arbeitsabläufe in der Kommissionierung motivierend zu gestalten. Es wurden drei Videoprototypen entwickelt, welche mithilfe von Spieldesignelementen wie *Punkten*, *Team-Bestenlisten* oder *Avataren* verschiedene psychologische Grundbedürfnisse adressieren. In fokussierten Experteninterviews evaluierten zwölf Probanden - Experten aus der Wissenschaft und Logistikspezialisten - inwieweit die verschiedenen Spieldesignelemente die psychologischen Grundbedürfnisse erfüllen.

Schlüsselwörter: Gamification, Augmented Reality, Kommissionierung, psychologische Grundbedürfnisse

1. Einleitung

Gamification wird durch die Digitalisierung und den damit verbundenen technologischen Fortschritt immer bekannter und beliebter. Die Implementierung von Spieldesignelementen in spielfremde Umgebungen ist nicht neu. Neben Bereichen wie der Gesundheitsbranche oder der Bildung, in denen das Konzept schon lange Anwendung findet, durchdringt die Idee der spielerischen Motivation auch immer mehr die Arbeitswelt. Jedoch finden sich wenige Studien, die sich mit Gamification in industriellen Produktionsumgebungen beschäftigen. Gemeinsam mit einem Industriepartner aus der Automobilindustrie werden daher Ansatzpunkte für ein Gamification-Konzept in der Intralogistik, genauer der manuellen Kommissionierung, erarbeitet. Die Aufgabe des Kommissionierers besteht darin, Waren aus einem Lager auftragsspezifisch zusammenzustellen. Dieser sogenannte Pick-Prozess soll dabei zukünftig visuell durch Datenbrillen unterstützt werden, um die Arbeit effizienter und fehlerfreier zu gestalten. Da der Werker dadurch lediglich den im Sichtfeld angezeigten Informationen folgen muss, wird vermutet, dass die Monotonie im Arbeitsvorgang gesteigert wird und der Anwender durch eine geringe kognitive Forderung abstumpft. An dieser Stelle soll der Einsatz von Gamification dabei helfen, nicht nur zu motivieren, sondern auch Monotonie abzubauen. Um Ansatzpunkte für ein solches Konzept zu finden, versucht der Beitrag aus einer psychologischen Perspektive herauszufinden, welche Grundbedürfnisse der Mitarbeiter durch den Einsatz von Gamification adressiert werden können.

Dazu wurden entlang der psychologischen Grundbedürfnisse *Kompetenzerleben*, *Autonomieerleben* und *soziale Eingebundenheit* drei Videoprototypen zur Durchführung einer Simulationsstudie entwickelt. Durch Überlagerungen und Animationen wurden Spielelemente in der Datenbrille während des Kommissioniervorganges am Arbeitsplatz des Industriepartners simuliert. Mithilfe leitfadengestützter Interviews evaluierten zwölf Probanden, externe Experten aus der Wissenschaft verschiedener Fachrichtungen und internen Logistikspezialisten, die ihnen in der Datenbrille vorgeführten Prototypen.

2. Stand der Wissenschaft

Es existieren vielfältige Definitionen des Begriffs Gamification (vgl. Sailer 2016), aus einer betriebswirtschaftlichen Betrachtungsweise von Werbach und Hunter (2012), im Kontext von Online-Applikationen von Zimmermann und Cunningham (2011) oder aus einer psychologischen Perspektive von Kapp (2012). Eine kontextunabhängige Definition liefern Deterding et al. (2011), welche unter Gamification *„die Verwendung von Spielelementen, die in spielfremden Kontexten eingesetzt werden“* verstehen. In den Bereichen Arbeit, Bildung, Crowdsourcing, Datenerhebung & Umfragen, Gesundheit, Marketing, soziale Netzwerke und Umweltschutz liegen bereits Studien vor (vgl. Sailer 2016). Gerade um Nutzer dazu zu motivieren, auf eine bestimmte Weise zu handeln, werden immer wieder spielerische Ansätze genutzt. So regt das Sammeln von Treue- oder Bonuspunkten die Kundenbindung in Supermarktketten an. Ein Beispiel für eine wissenschaftliche Studie der Spielifizierung einer nicht-spielerischen Tätigkeit ist die „Bottle Bank Arcade Machine“, ein Glascontainer, welcher die richtige Trennung von Glasflaschen durch akustische Signale und die Vergabe von Punkten belohnt (vgl. Henke und Kaczmarek 2017). Flatla et al. (2011) erzielen positive Effekte bei der Spielifizierung von eintönigen Kalibrierungsaufgaben. Den industriellen Einsatz von Gamification untersuchen bspw. Korn (2012), Korn et al. (2015), Günthner et al. (2015) und Sailer (2016). Korn (2012) setzt Gamification zur Unterstützung von älteren, körperlich beeinträchtigten Mitarbeitern ein. Darauf aufbauend vergleichen Korn et al. (2015) verschiedene Konzepte der Arbeitsfortschrittanzeige. Die ebenfalls körperlich beeinträchtigten Nutzer bevorzugen eine sich aufbauende Pyramide, welche durch Farbwechsel die Prozessveränderungen darstellt. Im Kontext der Kommissionierung realisieren Günthner et al. (2015) im Projekt GameLog eine Kommissionierliga zur Motivations- und Leistungssteigerung. Sie stellen positive Effekte hinsichtlich der Steigerung intrinsischer Motivation der Probanden fest. Sailer (2016) trägt zum Projekt GameLog durch Untersuchungen aus psychologischer Perspektive bei. Er erforsche die Wirkung einzelner Spieldesignelemente hinsichtlich der Erfüllung psychologischer Grundbedürfnisse. Spieldesignelemente sind dabei *Punkte*, *Abzeichen*, *(Team-) Bestenlisten*, *Leistungsgraphen*, *Avatare* und *narrative Elemente*. Die zu adressierenden psychologischen Grundbedürfnisse stützen sich dabei auf die Theorie der Selbstbestimmung von Deci und Ryan (1993), nach der „das menschliche Verhalten auf drei Energiequellen angewiesen ist“ (Deci und Ryan, 1993): die Bedürfnisse *Kompetenzerleben*, *Autonomieerleben* und *soziale Eingebundenheit*. Im Gegensatz zu vielen kognitiven Motivationstheorien bezieht die Theorie der Selbstbestimmung die Wirkung der sozialen Umwelt ein (vgl. Deci und Ryan, 1993). Nach Sailer (2016) ist das Adressieren aller drei Grundbedürfnisse durch Spiele und deren Beeinflussung des Umfelds möglich. Integration der Spieldesignelemente *Punkte, Abzeichen, Team-Bestenlisten* und *Leistungsgraphen* führt zu einer Steigerung des Kompetenzerlebens. Das Autonomieerleben wird durch *Narrativ* und *Avatare* positiv beeinflusst. Eine gesteigerte empfundene soziale Eingebundenheit ruft die Nutzung der Spieldesignelemente *Abzeichen, Teambestenlisten* und *Narrativ* hervor (vgl. Sailer 2016).

3. Entwicklung von Video-Prototypen

Für die Simulationsstudie wurden Prototypen in Form von Filmen entwickelt, die die spätere Umsetzung einer AR-Applikation in einer Datenbrille aus der Sicht des Mitarbeiters visualisieren sollen. Dazu wurde der Kommissioniervorgang des Testarbeitsplatzes mit einer kopfbasierten Kamera GoPro® HERO 5 gefilmt. Beim Schnitt des Films wurde darauf geachtet, dass alle Prozessschritte mindestens einmal enthalten sind. Mithilfe eines Storyboards wurden die einzelnen Einblendungsszenen erarbeitet. Neben der Einblendung für den Arbeitsvorgang nötiger Arbeitsinformationen wurden für drei verschiedene Grundbedürfnisse unterschiedliche Spieldesignelemente mit den Programmen Adobe® After Effects und Adobe® Premiere Pro integriert.

Das primäre Ziel des Spiels ist das Sammeln von goldenen Westen. Dabei wurde sich an der Arbeitskleidung der Kommissionierer orientiert. Die Farben der Westen stellen die Levels des Spiels dar. Es gibt 10 Levels: weiß, gelb, orange, grün, blau, braun, schwarz, orientiert an den Gürtelfarben im Karate, dazu bronze, silber und gold, nach den Farben der olympischen Medaillen. Durch arbeitsrechtliche Einschränkungen wird nur teamweise gespielt, ohne dass die Leistung des Einzelnen nachvollziehbar ist. Westen können durch Punkte und Münzen, welche durch fehlerfreie Arbeit gesammelt werden, erreicht werden. Da der Fokus dieses Gamification-Projekts nicht nur auf der Belohnung fehlerfreier Arbeit, sondern vor allem auf dem Abbau von Monotonie liegt, sollen zusätzlich Fertigkeitspunkte in Form von Sternen gesammelt werden. Drei Sterne führen automatisch zu einem höheren Level. Ähnlich der Tour de France, in der es Trikot-Halter gibt, ist es das Ziel jedes Teams der Halter der meisten goldenen Westen zu sein und zu bleiben.

Autonomieerleben: Narrativ, Avatar
Kompetenzerleben: Punkte, Leistungsgraph, Abzeichen
Soziale Eingebundenheit: Narrativ, Team-Bestenlisten, Abzeichen

***Abbildung 1**:* *Spieldesignelemente der Videoprototypen für die Adressierung der Grundbedürfnisse Autonomieerleben, Kompetenzerleben und soziale Eingebundenheit.*

Für die Adressierung jedes der drei Grundbedürfnisse wurde ein Videoprototyp entwickelt. Diese überschneiden sich in den Grundzügen, fokussieren sich aber auf verschiedene Spieldesignelemente. Das Autonomieerleben wird durch Kombination der Spielelemente *Narrativ* und *Avatar* umgesetzt. Ein Nichtspielcharakter informiert über den Spielmodus und den Spielerfolg. Ein *Avatar* symbolisiert den Spieler, welcher nach erfolgreicher Arbeit eine Weste in der Farbe des erlangten Levels trägt.

Im Film für das Bedürfnis des Kompetenzerlebens wird ein Leistungsgraph als permantentes visuelles Feedback-Element zur Anzeige des Spielfortschritts eingeblendet. Das Sammeln von *Abzeichen* in Form von Westen hält den Kommissionierer trotz monotoner Arbeit wach und aufmerksam. Der Prototyp für das Adressieren der sozialen Eingebundenheit baut auf die ersten Konzepte auf, jedoch wird am Ende des Kommissioniervorgangs eine *Team-Bestenliste* angezeigt. Mögliche Teams sind die verschiedenen Schichtgruppen.

4. Evaluation der Prototypen durch fokussierte Experteninterviews

Ziel der Evaluation ist es eine Aussage über die Erfüllung der Grundbedürfnisse durch die verschiedenen Spieldesignelemente sowie über deren Wirkung beim Nutzer treffen zu können. Dabei stützt sich die Methodik auf zwei Interviewformen: die des fokussieren Interviews, welche die Behandlung einer konkreten Situation wie z.B. eines gesehenen Films beinhaltet (vgl. Merton und Kendall 1946), sowie die des Experteninterviews als Sonderform des qualitativen Interviews. Der Experte wird hierbei als Informationslieferant angesehen (vgl. Kaiser 2014). Meuser und Nagel (1991) unterscheiden bei der Definition des Expertenbegriffs Betriebs- und Kontextwissen, wobei Betriebswissen Informationen über Abläufe und Regeln und Kontextwissen über das spezifische Arbeitsumfeld hinausgehende Informationen beinhaltet. Für beide Wissensbereiche, für die zwei unterschiedliche Interviewleitfäden entwickelt wurden, nahmen je sechs Experten teil. In der Befragungsgruppe des Kontextwissens waren externe Experten aus den Fachgebieten Gamification, AR, Psychologie und Unternehmenskommunikation. Die Befragungsgruppe des Betriebswissens setzte sich aus Spezialisten des Innovationsmanagements, der Logistikplanung sowie aus operativen Logistikern zusammen. Jeder Teilnehmer sah die drei Videoprototypen auf der Datenbrille ODG R7, welche zukünftig verwendet werden soll. Anschließend erfolgte die Befragung anhand des jeweiligen Leitfadens. Die Formulierung von Haupt- und Alternativhypothesen zu verschiedenen Themenclustern dienen der anschließenden Analyse der Expertenaussagen.

Tabelle 1: *Hypothesen.*

H1	Unter der Berücksichtigung der Zielgruppe und entstehender Abnutzungseffekte sind die Steigerung von Motivation und damit die Förderung der Grundbedürfnisse durch Gamification grundsätzlich möglich.
$H1_A$	Unter der Berücksichtigung der Zielgruppe und entstehender Abnutzungseffekte sind die Steigerung von Motivation und damit die Förderung der Grundbedürfnisse durch Gamification grundsätzlich ausgeschlossen.
H2	Das Spieldesignelement *Punkte* fördert durch unmittelbares positives Feedback das Kompetenzerleben des Nutzers.
$H2_A$	Das Spieldesignelement *Punkte* beschränkt durch unmittelbares positives Feedback das Kompetenzerleben des Nutzers.
H3	Das Spieldesignelement *Abzeichen* fördert Kompetenzerleben nur unter bestimmten Bedingungen.
$H3_A$	Das Spieldesignelement *Abzeichen* beschränkt Kompetenzerleben unter bestimmten Bedingungen.
H4	Das Spieldesignelement *Narrativ* befähigt eher die anderen Spieldesignelemente dazu Grundbedürfnisse zu erfüllen, als dass es dies selber tut.
$H4_A$	Das Spieldesignelement *Narrativ* ist fähig Grundbedürfnisse selbst zu erfüllen.
H5	Unter der Voraussetzung eines konstruktiven Wettbewerbs kann das Spieldesign-

	element *Team-Bestenliste* Kompetenzerleben und soziale Eingebundenheit fördern.
H5$_A$	Unter der Voraussetzung eines konstruktiven Wettbewerbs kann das Spieldesign-element *Team-Bestenliste* Kompetenzerleben und soziale Eingebundenheit beschränken.
H6	Um Autonomie im Sinne von Wahlfreiheit fördern zu können, braucht ein *Avatar* viel Arbeit.
H6$_A$	Um Autonomie im Sinne von Wahlfreiheit fördern zu können, braucht ein *Avatar* wenig Arbeit.

5. Ergebnisse

Die Studie zeigt eine positive Einstellung der Befragten gegenüber der Integration von Gamification in der Kommissionierung. Die *Hauptcluster Erfüllung psychologischer Grundbedürfnisse allgemein* und *Elemente Punkte und Leistungsgraphen* bestätigen eine Förderung der psychologischen Grundbedürfnisse. Die Kommissionierer weisen auf eine mögliche Unterstützungsfunktion hin, während für das Innovationsmanagements der Aspekt der Aufmerksamkeitsförderung durch höhere Motivation interessant erscheint (Ergebnis *Hauptcluster Elemente Punkte und Leistungsgraphen*). Spielifizierung vermindert Ablenkung im repetitiven Arbeiten und fördert die Konzentrationsleistung. Hier visualisiert das Spiel bisher nicht greifbare Leistungen im Produktionsprozess. Diese Art der Ansprache ist ein Kompetenzerlebnis - der Mitarbeiter erfährt Wertschätzung. Dennoch äußern Experten (sowohl des Betriebs- als auch des Kontextwissens) Zweifel an der Langlebigkeit des spielerischen Motivationsschubes und befürchten eine Gewöhnung an die Spielsituation. Um Aufmerksamkeitsminderung zu vermeiden, muss das Spielkonzept vielseitig sein und trotzdem den individuellen Geschmack der Mitarbeiter treffen (Ergebnis *Hauptcluster Kompetenzerleben*). Dies hält die Gewöhnung niedrig. Die Experten präferieren positive Rückmeldungen anstatt negativen Feedbacks und Abzugs von Leistungspunkten. An den Elementen *Punkte* und *Leistungsgraphen* stören die Befragten die dauerhafte Feedbacksituation, auch wenn gerade diese Elemente Kompetenzerleben begünstigen und das Interesse an einer Tätigkeit aufrechterhalten. Die Vergabe von *Abzeichen* kann bspw. als Kompetenzerlebnis wahrgenommen werden. Bei der Gestaltung von *Abzeichen* begrüßen einige operative Logistiker die Idee der Westensymbolik. Jedoch wird Kontextbezug der *Abzeichen* im Spiel höher gewichtet als der der Kontextbezug zum Arbeitsumfeld. Der *Avatar* wird positiv bewertet, sofern dieser durch den Mitarbeiter so individualisiert wird, dass er sich als Teil des Spiels sieht (Ergebnis *Hauptcluster Element Avatar*). *Team-Bestenlisten* können zusätzlich die soziale Eingebundenheit fördern. Teilweise negativ wird die wettbewerbsorientierte Ausrichtung aufgefasst, sodass eine gemeinsame *Team-Bestenliste* ein Einzelranking ersetzen soll. Das *Narrativ* des Spiels verstärkt eher die Wirkung anderer Spielelemente, als dass es selbst Grundbedürfnisse fördert. Unter der vorliegenden Datenlage fördert der *Leistungsgraph* nach Expertenmeinung kein Grundbedürfnis und kann vernachlässigt werden.

6. Fazit

Nach Abschluss der fokussierten Experteninterviews lässt sich festhalten, dass der Einsatz von Gamification motivationsunterstützend und aufmerksamkeitsfördernd ist. Bisher kaum wahrnehmbare Arbeitserfolge einer taktgebundenen Tätigkeit werden greifbar. Alle Haupthypothesen wurden bestätigt, wobei vor allem der Implementierung der Spieldesignelemente *Avatar* und *Team-Bestenlisten* in Kombination mit positivem Feedback als erfolgsversprechend betrachtet werden. Der Einsatz des *Avatars* sieht allerdings einen hohen Grad an Individualisierbarkeit vor. Die Spieldesignelemente *Punkte* und *Leistungsgraph* werden aufgrund der permanenten Feedbackeinblendung kritisch gesehen. Daher gilt es bei der Gestaltung des Gamification-Konzepts auf ein unregelmäßig eingeblendetes, positives Feedback, entkoppelt von der Leistung des Einzelnen zu achten. Abschließend bleibt zu empfehlen, den Spielfokus auf die Anreicherung der mototonen Tätigkeit durch kurzweilige, unterhaltende Elemente zu lenken, ohne durch spielerische Leistungsmessung effizienteres Arbeiten zu erwarten.

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Auswirkungen des Einsatzes von Gamification in einer Datenbrillen-unterstützten Kommissionierung auf Mitarbeiter und Prozess

Nela GEBAUER

BMW Group, Logistikplanung, Projekt Innovationen und Industrie 4.0
Max-Diamand-Staße 5, D-80788 München

Kurzfassung: Kern des Forschungsvorhabens ist die Untersuchung des Einsatzes von Datenbrillen in der automobilen, manuellen Kommissionierung. Zunächst wird ein für den Datenbrilleneinsatz geeigneter Supermarkt beim Industriepartner ausgewählt. Die Klassifizierung der Arbeitsplätze erfolgt anhand des Rasmussen Modells menschlicher Leistung. Anschließend werden in einem Vollschichtversuch im Realbetrieb die psychischen und physischen Auswirkungen auf den Mitarbeiter sowie die Auswirkungen auf die Fehleranzahl, die Fehlerart und die Durchführungszeit analysiert. Einer ggf. auftretenden Monotonie und abnehmenden Motivation aufgrund der datenbrillenbedingten Reduzierung des Verantwortungsumfangs des Kommissionierers soll durch den Einsatz von Serious Games entgegengewirkt werden.

Schlüsselwörter: Augmented Reality, Datenbrillen, Kommissionierung, Ergonomie, Gamification, Serious Games

1. Einleitung

Gemäß Jünemann ist die Aufgabe der Logistik, „die richtige Menge, der richtigen Objekte […], am richtigen Ort […], zum richtigen Zeitpunkt, in der richtigen Qualität, zu den richtigen Kosten“ bereitzustellen (Jünemann 1989). Die Komplexität dieser Aufgabe steigt mit der stetig wachsenden Variantenvielfalt und der zunehmenden Individualisierbarkeit in der Automobilindustrie. Um flexibel auf Nachfrageschwankungen reagieren zu können, gestalten immer mehr Automobilunternehmen ihre Produktion derivatunabhängig, sodass in einem Werk zeitgleich verschiedene Modelle gefertigt werden können (Roth 2016). Während viele Tätigkeiten der Logistik automatisiert durchgeführt werden, „spielt der Mensch u.a. aufgrund seiner Flexibilität bezüglich der Aufgabeneinteilung und der Fähigkeit, unterschiedliche Objekte leicht handzuhaben [in der Kommissionierung] eine wesentliche Rolle“ (Stinson & Wehking 2012). Das Prinzip, in dem die Bereitstellung der zu pickenden Teile statisch erfolgt und der Mitarbeiter durch Bewegung zwischen verschiedenen Bereitstellpositionen den Kommissionierauftrag bearbeitet, wird Mann-zur-Ware-Prinzip genannt (Klug 2010). Dabei bewegt sich der Mitarbeiter zu Fuß oder mithilfe von Fahrzeugen wie z.B. Routenzügen zwischen den Regalen. Eine Pickliste, ähnlich eines Einkaufszettels, enthält alle zu pickenden Aufträge, inkl. Ordernummer, Ort, Artikelnummer und Anzahl (Schwerdtfeger 2009). Da ein Kommissionierfehler in der Automobilproduktion zum Bandstillstand führen kann (Guo et al. 2015) ist das sogenannte „Zero defect Picking“ (Hompel & Schmidt 2003) eines der wichtigsten anzustrebenden Ziele.

Eine Technologie, mit deren Hilfe Unternehmen sich eine deutliche Verbesserung der Fehlerquoten erhoffen, ist die erweiterte Realität (Augmented Reality). Laut Tümler

(2009) versteht man unter „Mobile Augmented Reality […] die situationsgerechte Anzeige rechnergenerierter Informationen auf im Sichtfeld positionierten, vom Benutzer mitführbaren Anzeigegeräten, die die Bearbeitung primärer Arbeitsaufgaben nicht behindern". Mithilfe des Einsatzes von Augmented Reality-Technologien können mitarbeiterunterstützende Funktionen wie Indoornavigation (Rehman & Cao 2015), das Anzeigen des richtigen Regalfachs, das Anzeigen der richtigen Menge, das Anzeigen des Ablageorts (Guo et al. 2015) sowie eine Fehlererkennung (Schwerdtfeger & Klinker 2008) realisiert werden. Als Visualisierungsprinzipien nennt Tümler (2009) die Optical See-Through-, die Projection See-Through-, die Video See-Through-, die Look Around- und die Handheld-Technik (Tümler 2009). Ein Beispiel für letztere ist der Einsatz von Smartphones oder Tablets. Beispiele für die Optical See-Through-Technik sind Datenbrillen, wie z.B. die Google Glass oder die Epson Moverio BT-300. Ein Beispiel für eine Video-See-Through-Brille ist die Vuzix M100.

2. Stand der Technik

Es existieren einige Veröffentlichungen im Themengebiet Head Mounted Displays (HMD) in der Produktion und Logistik. Die Versuche, die sich in der Untersuchungsdauer und der Hardware unterscheiden, kommen dabei zu verschiedenen, sich widersprechenden Ergebnissen. Tümler (2009) ließ 20 Probanden über zwei Stunden hinweg ein Microvision Nomad ND2000-HMD tragend kommissionieren und verglich diesen Augmented Reality-Einsatz mit einer Papierliste. Dabei konnte er keine signifikanten Unterschiede der subjektiv empfundenen Beanspruchung zwischen beiden Methoden erkennen. Jedoch stellte er fest, dass die Probanden fast die vierfache Anzahl an Typfehlern mit der Papierliste gegenüber der Anzahl an Typfehlern beim Einsatz des HMDs machten. Die Differenz der Auslassungsfehler waren nicht signifikant. Die Ausführungszeit war bei der Papierliste aber 30% niedriger als bei dem verwendeten HMD, was Tümler (2009) auf die unpräzise Kalibrierung, die Latenz und auf den fehlenden Komfort bedingt durch lose Kabel zurückführte. Des Weiteren war ein Anstieg der Auslassungsfehler gegen Ende der Versuchsdurchführung zu beobachten, was durch weitere Untersuchungen hinsichtlich der Veränderung der Konzentration genauer analysiert werden kann (Tümler 2009).

Kampmeier et al. (2007) untersuchten den HMD-Einsatz in einem Versuch mit 45 Probanden, welche über 7,5 Stunden hinweg Montage- und Kommissioniertätigkeiten durchführten. Ihr Fokus lag bei der Untersuchung auf ophthalmologischen Kennwerten. Auch sie nutzten das Microvision Nomad-HMD. Sie kamen zum Ergebnis, dass die subjektiv erlebte Beanspruchung nicht signifikant von der der Papierliste abwich. Auch die Herzaktivität und die Konzentration zeigten keine signifikanten Unterschiede. 13% der Probanden gaben an Kopfschmerzen zu bekommen, was auf die wenig ergonomische Gestaltung des HMDs zurückgeführt wurde (Kampmeier et al. 2007).

Funk et al. (2015) führten einen Versuch mit 16 Probanden durch, in dem sie das Kommissionieren mit einem HMD (Pick-by-Vision) mit einem Cart-mounted Display, einer Papierliste und einem Pick-by-Voice-Verfahren gegenüberstellten. Sowohl die Durchführungsdauer, als auch die Fehlerrate waren bei dem Einsatz eines HMD (Epson Moverio BT-200) signifikant höher als alle anderen Verfahren. Auch die wahrgenommene Beanspruchung wies bei dem Einsatz des HMDs den höchsten NASA-TLX-Wert auf, unterschied sich jedoch nur signifikant gegenüber dem Cart-mounted Display (Funk et al. 2015).

Wiedenmaier (2004) führte einen Versuch mit 36 Probanden in der Montage durch.

Dabei setzte er ein hybrides Augmented-Reality-System, bestehend aus einem HMD (MicroOptical Clip-on) und einem Touch Panel Display, ein. Die 22 Montageaufgaben wurden mit dem hybriden System 23% schneller durchgeführt als mit einer Papieranleitung. Die Fehlerrate war aufgabenspezifisch unterschiedlich. Signifikante Unterschiede hinsichtlich der subjektiv empfundenen Beanspruchung waren nicht nachzuweisen (Wiedenmaier 2004).

Einen weiteren Vergleich verschiedener Kommissionierverfahren führten Guo et al. (2015) durch. Sie verglichen Pick-by-Paper, Pick-by-Light, ein HMD und ein Cart-mounted Display. Das HMD (ebenfalls von MicroOptical) war dabei mit einem in einem Rucksack getragenen Laptop verbunden. Bei der Studie mit 8 Probanden wiesen sie nach, dass das HMD signifikant niedrigere Durchführungszeiten aufwies als Pick-by-Light und Pick-by-Paper. Darüber hinaus hatte das HMD den niedrigsten NASA-TLX-Wert und wurde somit als am wenigsten subjektiv beanspruchend wahrgenommen.

Zusammenfassend lässt sich festhalten, dass sich die Ergebnisse der vorliegenden Untersuchungen hinsichtlich ihrer Ergebnisse bzgl. der Durchführungszeiten, Fehlerraten und der subjektiv empfundenen Beanspruchung deutlich unterscheiden. Dies lässt vermuten, dass die Auswirkungen auf Proband und Prozess aufgaben- und hardwarespezifisch sind. Da eine Vielzahl an Versuchen mit HMDs durchgeführt wurden, welche aus einem mit einem Display versehenen Helm bestanden, sind zudem die gewonnenen Erkenntnisse nicht auf den Einsatz von Datenbrillen mit höherem Tragekomfort, wie z.B. einer Google Glass, übertragbar.

3. Versuch

Aus diesem Grund soll im Rahmen des Forschungsprojekts der Einsatz von Datenbrillen in der automobilen, manuellen Kommissionierung erforscht werden. Der Industriepartner, die BMW Group, erhofft sich durch den Einsatz von Datenbrillen in der Kommissionierung Vorteile gegenüber dem bisherigen Prozess, einer Anzeige der Aufträge auf Monitoren, teilweise unterstützt durch eine Pickliste. Die vermuteten Vorteile reichen von einer Fehlerreduzierung, über Zeit- und dadurch Kosteneinsparungen, über ein verbessertes Anlernen neuer Mitarbeiter, bis hin zum flexiblen Einsatz von Mitarbeitern unabhängig von deren Qualifikation. Letzterer Aspekt könnte insbesondere beim Einsatz von leistungsgewandelten Mitarbeitern vorteilhaft sein, die teilweise über Jahrzehnte an demselben Kommissionierarbeitsplatz arbeiten. Die Vorgabe aller relevanten Informationen mithilfe von Augmented Reality könnte eine vermehrte Umsetzung von Job Rotation ermöglichen. Da die Gestaltung eines augmentierten Kommissioniersystems abhängig von den bisher divergierenden Zielen ist, soll zunächst folgende Frage untersucht werden:

Welche Ziele verfolgt die Industrie mit dem Einsatz von Datenbrillen in der Kommissionierung?

Zudem sollen verschiedene Kommissionierarbeitsplätze sowie deren einzelne Prozessschritte hinsichtlich ihrer Eignung für einen Datenbrillen-Einsatz geprüft werden:

Welche Prozessschritte in der Kommissionierung eignen sich für den Einsatz von Datenbrillen? Welche Funktionen eignen sich bei welchem Prozessschritt?

Die Klassifizierung soll angelehnt an Wiedenmaier (2004) anhand des Rasmussen-Modells menschlicher Leistung für die Kommissionierung durchgeführt werden. Laut Wiedenmaier (2004) eignen sich vor allem regelbasierte Tätigkeiten für den Einsatz von HMDs.

Basierend auf den in diesem Schritt ermittelten Ergebnissen wird ein Referenzarbeitsplatz ausgewählt, der in einem Feldversuch in der realen Werksumgebung als Versuchsumgebung dient.

Im Rahmen einer empirischen Studie sollen nutzer- und prozessbezogene Aspekte der Auswirkungen des Einsatzes von Datenbrillen in der Kommissionierung analysiert werden. Dabei sollen die Probanden am Referenzarbeitsplatz, wie in der Literatur vorgeschlagen (Tümler 2009), über die Dauer einer vollen Schicht kommissionieren. Um mögliche Einflüsse verschiedener Messzeitpunkte auszuschließen, wird der Versuch ausschließlich während der Frühschicht von 5.45 Uhr bis 14.45 Uhr durchgeführt. Während des Versuchs sollen ca. 25 erfahrene Kommissionierer je einen Tag mithilfe der Datenbrille und einen Tag mithilfe des herkömmlichen Monitors kommissionieren. Die Probanden nehmen freiwillig am Versuch teil. Die Bereitschaft zu freiwilligen Teilnahme soll nach Rosenthal & Rosnow (1975) durch das persönliche Anfragen durch die bekannte Versuchsleitung sowie durch kleine Geschenke gefördert werden, welche die Kommissionierer vor dem Entscheiden bekommen (Rosenthal & Rosnow 1975). Kern der Untersuchung sind folgende Fragen:

Welche psychischen und physischen Auswirkungen hat der Vollschicht-Einsatz auf den Mitarbeiter? Welche Auswirkungen hat der Vollschicht-Einsatz auf den Prozess?

Nach einer Erfassung personenbezogener Daten, wie Alter, Geschlecht, Kommissioniererfahrung, Erfahrung mit Datenbrillen, Augendominanz, Sehhilfe, Sehbeeinträchtigung sowie aktueller Beschwerden, werden dem Probanden seine Aufgabe und die Messmethoden erklärt. Im Anschluss wird dem Probanden die Möglichkeit gegeben offene Fragen zu klären. Um eine vermutete Abnahme der Aufmerksamkeit zu untersuchen, wird der d2-Aufmerksamkeits-Belastungstest zu Schichtbeginn und -ende durchgeführt (Brickenkamp 1976). Ebenfalls zu Schichtende ist als Methode zur Erfassung der psychischen und physischen Beanspruchung der NASA-TLX vorgesehen (NASA 1986). Zudem soll der Visual Fatigue Questionnaire die Müdigkeit der Probanden sowie aufgetretene Auswirkungen auf das Auge bewerten (Bangor 2000). Der Simulator Sickness Questionnaire dient zur Erfassung einer möglichen auftretenden Simulatorkrankheit in virtuellen Umgebungen (Kennedy 1993). Des Weiteren wird die Methode „Laut Denken“ angewandt, um weitere qualitative Ergebnisse zu erfassen (Wiedenmaier 2004). Dazu erfolgt entweder eine Videoaufzeichnung des Versuchs oder ein Protokollieren der Kommentare durch den Versuchsleiter.

Die Auswirkungen auf den Prozess sollen durch die Erfassung der benötigten Durchführungszeit, der Fehlerquote und der Fehlerart abgebildet werden. Guo et al. (2015) unterteilen die Fehlerart in Falschteil, falsche Anzahl und falsche Ablagebox (Guo et al. 2015). Schwerdtfeger (2009) nennt neben der falschen Anzahl und dem falschen Teil, Auslassungsfehler und kaputte Teile als Fehlerart (Schwerdtfeger 2009). Die im Rahmen des Versuchs gemessenen Durchführungszeiten sollen anschließend mit den theoretisch ermittelten Soll-Zeiten der Methods-of-Time-Measurement-Zeiten verglichen werden.

Zur Sicherstellung der fehlerfreien und rechtzeitigen Belieferung des Montagebands wird während des Versuchs ein Mitarbeiter als Springer zur Verfügung stehen.

4. Gamification

Da mithilfe der Datenbrille Funktionen, die vormalig durch den Mitarbeiter durchgeführt wurden, wie bspw. die Indoornavigation, die Verarbeitung der Information auf der Pickliste, das Scannen von Barcodes oder die Qualitäts- und Fehlerkontrolle, durch die Brille übernommen werden können, reduziert sich der Verantwortungsbereich des Kommissionierers mit der Integration jeder zusätzlichen Funktion. In einem Szenario, in dem alle denkbaren Funktionen systemseitig übernommen werden, besteht die Hauptaufgabe des Mitarbeiters folglich aus der Fortbewegung, dem Greifen und dem Ablegen. Es liegt die Vermutung nahe, dass die Wegnahme von Verantwortungsumfängen beim Mitarbeiter zu einer sinkenden Motivation, einer Monotonie und einer Frustration führen kann. Gemäß Gudehus (2010) ist die Leistungsbereitschaft abhängig von der Motivation und dem Befinden des Mitarbeiters.

Eine Möglichkeit zur Motivationssteigerung ist der Einsatz von Gamification. Korn et al. (2015) führten eine Studie mit beeinträchtigten Arbeitern durch, welche den Unterschied eines Augmented Reality Systems mit und ohne Integration von Serious Games untersuchte. Die Montage einer Metallzange wurde durch eine Projektor-basierte Anleitung der Montageschritte unterstützt, die in einer der beiden Versuchsgruppen durch eine spielerische Fortschrittsanzeige erweitert wurde. Die Ergebnisse zeigten eine signifikante Steigerung des subjektiv empfundenen Glücksgefühls und der Motivation zur Leistungssteigerung. Eine Störung der Arbeit konnte nicht nachgewiesen werden (Korn et al. 2015). Unklar ist jedoch, ob die gewonnen Erkenntnisse auf nicht beeinträchtigte Mitarbeiter sowie auf einen Kommissionierkontext übertragbar sind. Aus diesem Grund soll im Rahmen des Forschungsvorhabens folgende Fragestellung untersucht werden:

Wie verändern sich die identifizierten Auswirkungen auf Mitarbeiter und Prozess bei der Integration von Serious Games?

Dazu sollen Serious Games für den Referenzarbeitsplatz des ersten Versuchs entwickelt werden, welche die Monotonie mindern und die Motivation der Mitarbeiter fördern. Entscheidend ist die Gestaltung von Spielen, welche weitestgehend positive Auswirkungen mit sich bringen können. Eine spielerische Visualisierung, die ein leistungsbasiertes Ranking der Mitarbeiter untereinander ermöglicht, ist aufgrund möglicher negativer Auswirkungen nicht vorgesehen. Der Versuch soll analog des ersten Versuchs mit Integration der Serious Games durchgeführt werden, um die Datenbrillen-unterstützte Kommissionierung mit und ohne des Einsatzes von Gamification bestmöglich gegenüberzustellen.

Zusammenfassend sollen die gewonnenen Erkenntnissen der Versuche in der automobilen, manuellen Kommissionierung dazu dienen eine abschließende Aussage bzgl. der folgenden Zielfragestellung zu treffen:

Wie muss ein nutzerorientierter Einsatz einer Datenbrillen-unterstützten Kommissionierung gestaltet sein?

5. Bedeutung für Wissenschaft und Industrie

Mithilfe der empirischen Studie werden erstmals die Auswirkungen des Vollschicht-Einsatzes von Datenbrillen in der automobilen, manuellen Teilekommissionierung auf Mitarbeiter und Prozess im Realbetrieb untersucht. Im Gegensatz zu bekannten Studien werden, dem technologischen Fortschritt folgend, Datenbrillen mit einem höherem Tragekomfort genutzt. Durch die Integration von Gamification werden die Forschungsgebiete Gamification und Augmented Reality miteinander kombiniert und der Einsatz von Serious Games in der Logistik analysiert. Die Ziele der Industrie einer Fehlerreduktion, verkürzter Durchführungszeiten, einer höheren Mitarbeiterflexibilität sowie ein schnelleres Anlernen werden hinsichtlich deren Umsetzbarkeit überprüft.

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