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Mixed Reality in Learning Factories

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Abstract

Supported by rapid technological development, mixed reality (MR) applications are increasingly deployed in industrial practice. In manufacturing, MR can be utilized for information visualization, remote collaboration, human-machine-interfaces, design tools and education and training. This development makes new demands on learning factories in two major fields: One is the empowerment of users to work with MR in industrial applications. The second field is the utilization of the potential of MR for teaching and learning in learning factories. A great potential lies in the new possibilities of connecting digital content with the physical world. To analyze the potential applications of MR in learning factories in a structured way, an overview of potential MR applications based on the reality-virtuality continuum is presented with an analysis of case studies of applications in a learning factory including a mixed-reality-hackathon.

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Keywords: Mixed Reality, Augmented Reality, Learning Factories; Hackathon

1. Introduction

Mixed reality (MR) applications surround us in everyday life. This is most obvious in video games and entertainment, but MR is also present at live events, in retail, education, healthcare and engineering to highlight just a small selection [1]. In industrial practice, MR is increasingly utilized for information visualization, remote collaboration, human-machine-interfaces, design tools as well as education and training [2]. With MR, digital content can be connected with the physical world and both can be made available to the user at the same time. For example, in car

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manufacturing interactive see-through MR head mounted devices (HMD) can be used enabling designers to change the outer appearance of a car by augmented drawings making the design process more collaborative and effective [3]. MR is also frequently implemented to increase customer engagement in retail and marketing [4]. At the same time, MR is recognized as a powerful tool for teaching and learning [5] and for its ability to improve the efficiency of tasks by adopting to the user's experience level. An example concept for an augmented reality environment, which adapts to the data availability and the user's skill level, can be found for instance in the context of maintenance [7]. Furthermore, MR can enable long-distance learning [6]. The goal of this paper is to analyze the potential areas of applications of MR in learning factories in a structured way by providing a general, not hardware specific overview of potentially beneficial fields of application and use cases in teaching and learning environments on production engineering.

2. Mixed Reality in learning factories

2.1. Mixed Reality and the reality-virtuality-continuum

In a mixed reality environment or application, real and virtual objects are combined and "mixed" to create a user experience incorporating both the real and the virtual world. Real objects are characterized by having an actual objective existence. Contrary, virtual objects exist in essence or effect, but not formally or material [8]. With the continuous rise of MR application the terms "augmented reality" (AR) and "mixed reality" (MR) as well as "virtual reality" (VR) are sometimes used interchangeably today. As AR is a part of MR, it is important to define these terms. A comprehensive framework is given through the reality-virtuality-continuum shown in Fig. 1 based on *Milgram and Kishino* [8]. At both ends of the two dimensional continuum, fully real environments (reality) and fully virtual environments (virtuality) are located. In between, reality and virtuality are combined in MR environments with an increasing share of virtual elements from left to right. If an application within the reality-virtuality-continuum has a higher share of real elements, it can be classified as "augmented reality". Contrary, it can be referred to as "augmented virtuality". For an application to be classified as MR application, requirements originally designed for AR by *Azuma* in 1997 are adopted in this paper [9]. Although being more than 20 years old, the defined characteristics of AR are still valid and are also true for MR. Thus, three characteristics have to be fulfilled by an application to classify as an MR application. Firstly, real and virtual content has to be combined in an MR application or environment. Secondly, MR is required to be interactive in real time. Thirdly, MR needs to be registered in three dimensions. To make MR applications and environments visible and accessible for the user, hardware devices are required. In MR, these devices also enable the interaction of real and virtual objects. This is necessary for viewing virtual objects, as these cannot be viewed directly. Virtual objects have to be simulated to create a viewable representation utilizing a display device whereas real objects can be observed either directly or sampled and transferred into a digital model and resynthesized through a display device [10]. Different technological implementation concepts and actual hardware devices can be located on the reality-virtuality-continuum [10]. Tangible interfaces use physical objects to create virtual models. In Spatial AR, virtual objects are projected into the user's real environment. Holographic spatial AR allows a higher share of virtual objects and higher user immersion. Connected to the virtual environment, semi-immersive VR involves a significant emphasis of virtual objects over real objects and in immersive VR, the user is experiencing an almost total virtual environment. It is not within the scope of this paper to provide a survey of current MR hardware. Comprehensive surveys of MR technologies and applications can be found in different application contexts (e.g. [9]–[12]).

The selection of suitable concepts as well as actual hardware and software environments is one of the main challenges for productive implementation of MR applications. There are several approaches for selecting MR technology that are usually focused on one area of application. *Palmarini et al.* for example developed a process to select augmented reality technology for maintenance tasks [13]. A great potential of MR in the context of manufacturing lies in

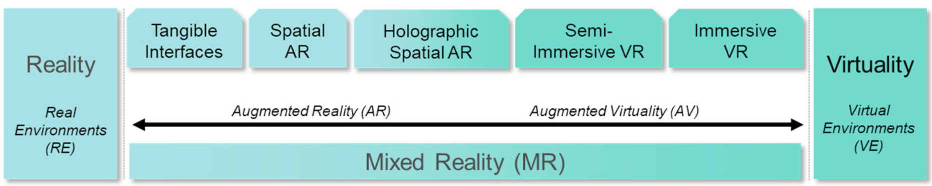

Fig. 1. Reality-virtuality-continuum based on [7] with allocation of implementation concepts.

assistive environments that includes not only on the job support but also for training and learning [14]. Today, MR technology is applied in learning factories to enhance teaching and learning success. *Abele et al.* recognize “blended learning” and “virtual learning factories” as innovative competency development approaches [15]. MR can enable learners to take control of their training and learning speed [16] and may be utilized to motivate learners for a specific topic [17]. By providing information in the right time and space it can improve the efficiency of education and training [18]. In the context of the digitalization of manufacturing and movements such as “Industrie 4.0”, MR becomes a vital part of learning environments [19].

2.2. The potential applications of MR in learning factories

MR holds great potential for learning factories in two main application areas. On the one hand, learning factories are predestined for learning about MR potentials, applications and implementation in the industrial context. As learning and teaching environments combine didactics and technology, learning factories can be a promising place for learning MR competencies. On the other hand, MR can be utilized in learning factories to enhance the imparting of knowledge and skills. Mixing digital content with the real world can support the understanding of processes, data, methods and systems. Furthermore, learning scenarios can be experienced by the users that would otherwise be too costly, dangerous or complex to conduct solely within a real environment. MR can extend the spatial, temporal and functional scope of a physical learning factory. For both application areas the capabilities and elements of MR can be utilized in learning factories. These elements are shown in Fig. 2 and described in the following text.

One capability of MR that enables implementation potential in learning factories is the possibility to visualize digital data and put it into spatial context with real machines, processes, production systems and products. It allows the digital augmentation and visualization of information, data, states and the indication of fields of action. MR enables new ways of providing instructions to learners and imparting knowledge and skills. The instructiveness of MR is enhanced by using not only visual elements but also sound or other means of natural user interfaces. Furthermore, new degrees of transparency can be achieved in a learning factory by augmenting digital process information into real machines or making information visible that are usually hidden to the human eye such as energy demand. MR opens new ways of interacting with technical systems. Interactive human-machine-interfaces can enhance the effects of education and training with technical systems. MR can be utilized to foster the immediate collaboration of learners by providing tools for interactive visualization. Extending the spatial perspective, MR can also break up the physical limitations of a learning factory. Global relationships, such as material flows or environmental impacts can be experienced immersive with MR. Applications can virtually extend the real infrastructure in a learning factory. Machines can be augmented with virtual parts demonstrating different configurations while saving the investment for the actual hardware and set-up times. In the same way, product variants can be simulated without the need for physicality. With MR, scenarios such as process breakdowns or emergencies can be experienced in a safe environment and appropriate actions trained. Finally, learning factories are a prime environment to learn about the capabilities of MR within an industrial context and to experience development methodologies and required tools as well as hardware devices.

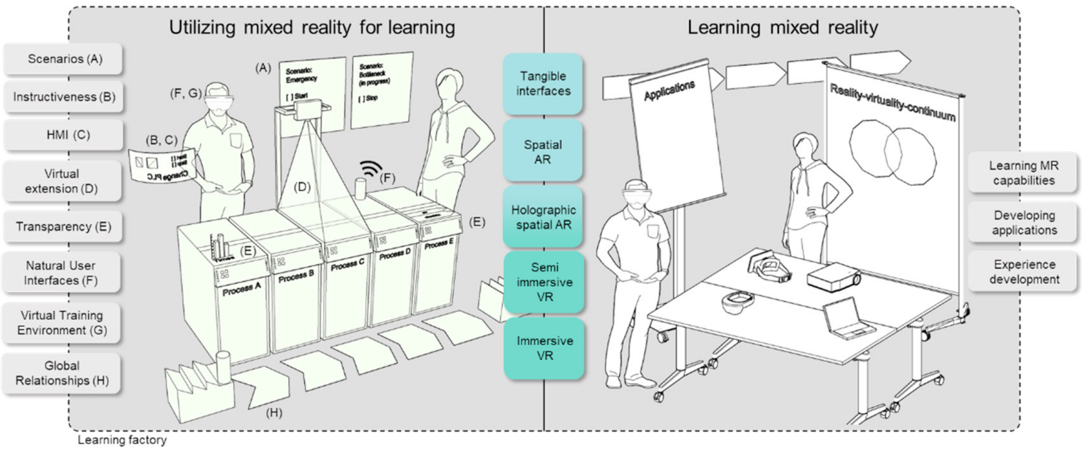

Fig. 2. The potential fields of applications of mixed reality in learning factories.

3. MR applications supporting the learning process in learning factories

MR applications can support the learning process by extending the real-world infrastructure with digital content. One major success factor of learning factories is the similarity of the physical learning environment to the real work environment of the learners. At the same time, this limits the scope of application to the available hardware equipment. MR can support the learning process by extending the scope of a learning factory by digital means while still sustaining the real-world applicability. In Table 1, three implementation cases of MR in the learning factory “Die Lernfabrik” at TU Braunschweig [20] are described as examples together with the fields of MR application according to Fig. 2.

Table 1. Examples for MR applications in supporting the learning process in learning factories

Implementation example	**Virtual simulated production processes in a physical production environment** – *Spatial AR*
Fields of MR application	HMI, Instructiveness, Scenarios, Transparency, Virtual extension
Description	Learning factories are aiming at representing real production environments either with real scale machines or on a more accessible model scale. Widely used model scale production lines in learning factories are using industrial components to generate a realistic manufacturing environment, aiming to have the same behavior as productive industry systems while being less expensive and avoiding potential dangers for learners. One challenge connected to the utilization of these systems is the difficulty to integrate processes creating emissions and wastes (e.g. painting, coating). Spatial AR or projection mapping can be utilized to introduce this kind of processes to scaled learning factories. Fig 3a shows a virtual galvanic process integrated in the “ExperienceLab” within “Die Lernfabrik”. Learners can influence the parameters of the simulation and see the results in form of energy demands, processing time and quality in the real-world production system. The product passes through the virtually projected process at the same processing time it would take in reality.
Implementation example	**Augmentation of energy flows –** *Holographic Spatial AR*
Fields of MR application	Natural User Interfaces, Scenarios, Transparency
Description	Energy flows in production systems are not visible to the human eye. This complicates the impartment of energy related topics within learning factories. With the assistance of mixed reality techniques, energy flows can be visualized at the location of the demand. This eases the impartment of energy related topics, as trainees can directly see the result of their actions and it allows the spatial connection to energy demanding components. Fig. 3b shows an application developed visualizing the energy demand of an oven process module with the help of holographic spatial augmented reality incorporating a NUI reacting to voice commands.
Implementation example	**Augmentation of instructions and states -** *Holographic Spatial AR*
Fields of MR application	HMI, Instructiveness, Natural User Interfaces, Transparency
Description	Communicating instructions, e.g. for machine operation or maintenance, can be difficult depending on the complexity of the object and the task. Usually written texts, verbal descriptions or demonstration are used for giving instructions. MR offers the potential to instruct more precisely by simplifying the abstraction process (e.g. from text to action) thus enabling a more efficient learning experience. Further, MR has the potential to be digitally interconnected with the object in focus. This enables precise instructions depending on the actual state of the object. Fig. 3c shows an application interfacing with a 3D-printer for machine-state visualization and a guided maintenance process. Here, a holographic head-mounted device (HMD) retrieves data from the 3D printer and guides the user to perform necessary actions, e.g. an extruder change.

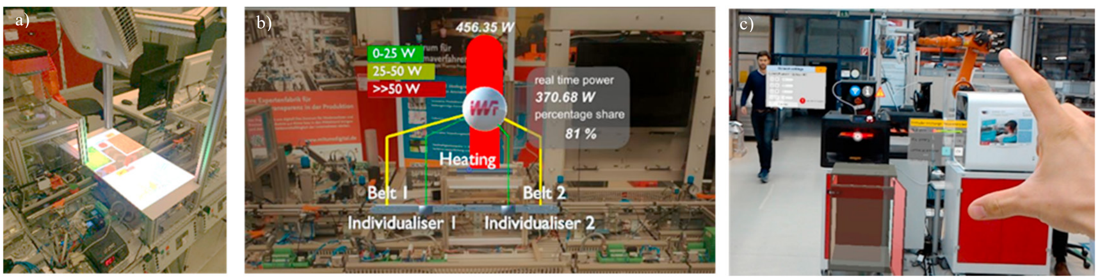

Fig. 3. Implementation examples of mixed reality applications in a learning factory: (a) Virtually simulated production process in a real-world model scale production system; (b) Holographic augmentation of energy demand spatially connected to the process components; (c) Interactive visualization of process states and maintenance instructions.

The dissemination of new technologies and concepts such as MR is usually hampered as for effective adaption their potential has to be understood before it can be put into application. For the goal of lowering the entry barriers to new MR technologies within learning factories, a hackathon can be a promising format enabling learners to experience novel technologies they usually do not have access to. In a Hackathon, the participants set out to intensively work on a challenge in teams or alone while being provided with the necessary tools, data and equipment. To test the feasibility of the hackathon concept, the MR hackathon "1. Braunschweiger HoloHack" was organized within the learning factory "Die Lernfabrik" at TU Braunschweig, Germany. In this three days long event, the Microsoft HoloLens was used as hardware device and the participants were challenged to develop applications that can enhance the production of the future and living in cities. A survey-based evaluation was conducted during the event among the participants to assess the potential benefits of organizing a hackathon in a learning factory and the results are displayed in Fig. 4. The HoloHack was confirmed as a good format to get to know a new technology intensively (scored 4.4 out of 5, based on 22 respondents). The location learning factory was also rated very positively (4.7/5). The participants' self-assessment of their ability in mixed reality, design, coding/hacking and content development in the HoloHack topic areas has increased from an initial 2.5/5 to 3.2/5 as a result of the hackathon.

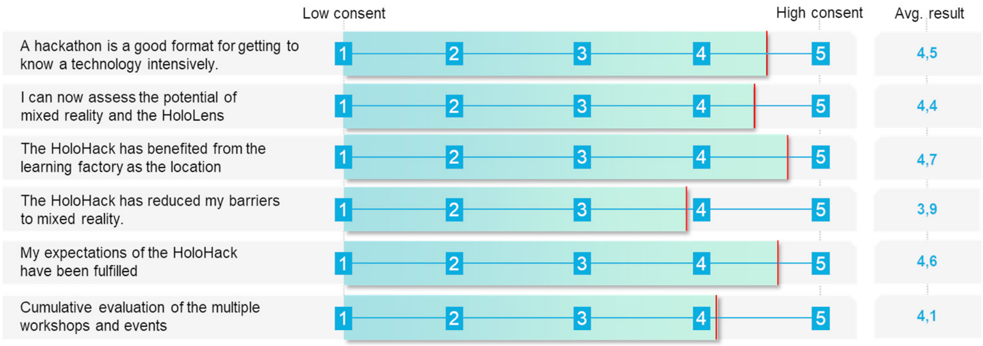

Fig. 4. Evaluation results of the HoloHack participants (n=22).

4. Learning MR applications in Learning Factories

With the increasing implementation of MR in industry and education, imparting knowledge and skills required for MR utilization and development are becoming increasingly necessary. Training workshops in learning factories are one possibility to make the potential of MR in industrial application understandable and to empower users as well as developers. An exemplary structure for an MR training is shown in Fig. 5 based on a design sprint method [21]. At first, learners should be exposed to MR applications that are already implemented in a learning factory to develop an understanding of the technological potential and the importance of user interaction. At this point the software tools required to create an MR application can be introduced exemplarily for one device. A programming walkthrough of a sample application has proven as an effective method. Having learned about the potential and the limitations of MR in the industrial context by experiencing different use-cases and software-hardware combinations for visualization, an ideation phase follows. In this phase, concepts for MR applications in a factory environment are generated by the learners under supervision of trainers. Subsequently, the generated ideas are tested by prototyping. The goal is to separate potentially beneficial from non-effective ideas. In the prototyping phase it is not necessary to implement the ideas in working applications. Usually going vocally and textually through the user journey is sufficient at this point. The refined application concepts resulting from the prototyping phase are transformed into a mock-up realization. Depending on the desired skill development of the learners, the realization of a usable mock-up can be undertaken by the learners themselves or the trainers. The resulting MR experience then requires testing in the learning factory and further refinement. Once the testing phase is passed, it can be implemented in the targeted application environment.

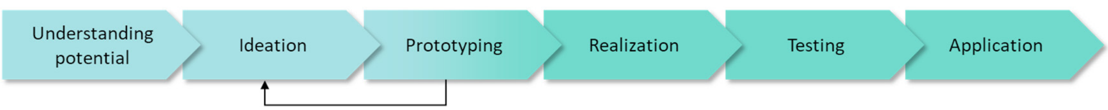

Fig. 5. Phases for learning on mixed reality in learning factories.

Going through the phases helps the learners to understand the potential benefits and limitations of industrial MR applications even without actually developing a productive application. Learning factories are a highly suitable place for learning about MR as it is highlighted by the results of the *HoloHack* challenge described section 3. The realization, testing and application phases involve in most cases software development and require basic IT skills, although heritage of MR in the gaming industry allows the usage of intuitive software development environments.

5. Conclusion and outlook

In Mixed Reality, the real world and the virtual world are combined into one user experience. This extends the opportunities for physical learning factories significantly. Learning factories are a place of education and training for industrial, factory-related topics. The physicality of learning factories and thus their connection to hardware is the cornerstone for effective learning. Virtual environments on the other hand have a high degree of flexibility and are quickly adaptable, as they are not bound by physical hardware. This allows learners to experience processes, methods and scenarios that are not available in hardware. Combining the advantages of the real and virtual world in learning factories to mixed learning realities unlocks great potential for enhancing learning success. Learning factories can utilize the capabilities of MR to improve imparting knowledge and skills. Furthermore, learning about MR and developing skills to generate MR applications will be one important part of future learning factories' fields of action.

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