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A Mixed-reality Learning Environment

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Abstract

The Industry 4.0 vision anticipates that internet technologies will find their way into future factories replacing traditional components by dynamic and intelligent cyber-physical systems (CPS) that combine the physical objects with their digital representation. Reducing the gap between the real and digital world makes the factory environment more flexible, more adaptive, but also demand broader skill of human workers. Interdisciplinary competencies from engineering, information technology, and computer science are required in order to understand and manage the diverse interrelations between physical objects and their digital counterpart. This paper proposes a system architecture for a mixed-reality based learning environment, which combines physical objects and visualization of its digital content via Augmented Reality. It allows to make the dynamic interrelations between real and digital factory visible and tangible. The proposed learning environment is not meant to work as a stand-alone solution, but should enrich existing academic and advanced training curricula.

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Training Systems, Advanced Interaction, Digital Factory, Factory of the Future, Virtual Reality, Industry 4.0

1. Motivation

The arising connection between the real physical world (like our homes and factories) and the digital world (support by internet technologies) brings more and more intelligent objects into our everyday lives and work contexts, i.e. by the so-called Internet of Things. It implies a revolution for the future factory environment, too. Following the Industry 4.0 vision[1], we expect the digitalization to promote intelligent devices, which are able to learn from experiences, to communicate with each other, and to take decisions towards self-optimization. Alongside this extensive automation, the human worker has been acknowledged as the most flexible entity in the production system, who plans, controls, manages, and trouble shoots. Thus, the demands for the employees broad and interdisciplinary skills increase simultaneously. Various interdependencies result from the involved smart objects, which may act in a dynamic and distributed way instead of being static and predictable. This paradigm shift, as described by the Industry 4.0 vision, requires a change of mindset in production environments, too. Todays production workers will initially have difficulties to keep track of the digital information behind the physical production environment. The challenge

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is that the digital mechanisms are invisible in nature. Professions in manufacturing or electronic engineering have to be enriched by interdisciplinary competences from computer science in order to make employees cope with their new requirements. For instance, usage of Cyber-physical systems (CPS) in the factory involves understanding of classical production engineering but also competences in internet, sensor, and information technologies. Therefore, innovative and appropriate qualification is needed. Classical learning environments for engineers are rather formal with focus on acquisition of theoretical knowledge, e.g., by seminars and E-Learning tools. The transfer to the real factory environment is inhibited due to lack of practical experiences and exploration of the newly acquainted knowledge. Furthermore, E-Learning offers only limited user interaction possibilities restricted to point-and-click interactions. Teaching the complex interplay between real and digital world, i.e. the principles of CPS or the Internet of Things, requires that the learning environment incorporates both worlds, too. In the light of the mentioned learning challenges within future production environments or smart factories and other environments, we suggest a comprehensive approach combining current trends from human-machine interaction and insights from psychological and pedagogical science with the aim of developing interactive learning environments integrating real and virtual world. After reviewing the current State of the Art, as summarized in the next section, this paper presents a system architecture of a learning environment based on mixed reality, which makes experiencing the new paradigms possible. It combines the flexible and extensive presentation of virtual information together with real world objects, which enable actual experience of physical consequences. Our approach further incorporates ideas for integrating such a learning environment into existing educational and organizational processes.

2. State of the Art

The forseen learning environment should combine current trends from human-machine interaction with appropriate psychological and pedagogical concepts. Therefore, the relevant state of the art comprising the topics mixed reality, reality-based interaction, gamification and blended learning is summarized and evaluated for being used in an interacte learning environment hereafter.

Mixed reality environments contain a combination of real and virtual world information. First applications in the context of production were virtual assembly instructions, augmenting the real workspace in order to support assembly workers in air plane manufacturing[2]. This context-sensitive overlay of virtual objects over the real environment is known as Augmented Reality. Other mixed reality applications emphasize the virtual content without connecting it to the real environment, i.e. Virtual Reality systems. The potential of both Augmented and Virtual Reality for learning purposes has been elaborated in previous work, i.e. COGNITO k, VISTRA[3], AR handbook[4], and manual workstation[5]. For instance, using head mounted displays or glasses providing information at the time and place when and where it is needed can be a promising opportunity for learning on-the-job. Furthermore, assembly tasks can be practiced in virtual environments[3]. Additional enhancements regarding pedagogical concepts enhance the suitability for learning[6]. However, most of the mentioned technologies and concepts focus technical tasks like assembly where a distinct process should be internalized. But, the Industry 4.0 paradigm will not only require shop floor personnel to be trained efficiently but rather addresses all workers to understand the principles and paradigms of an arising networked, digitalized future factory. A recently published concept makes the characteristics of the Internet of Things tangible, i.e. users can experience the merging of real and virtual world[7]. However, this concept does not focus requirements and application scenarios of production environments. We argue that there is high potential for such a mixed reality approach for learning and qualification purposes, i.e. making the Industry 4.0 paradigms experienceable and tangible. For this purpose reality-based interaction[8] which combines physical experiences with digital information seems to be the means of choice for getting across these paradigms, mainly characterized by combination of real and virtual world[7]. Comparable concepts as blended interaction[9] or embodied interaction[10] address a tangible learning experience by encouraging to actually handle with and make use of objects. These approaches of being-in-the-world and thinking-through-doing depict new developments in human-machine interaction and stress the importance of replacing simple point-and-click interactions as used in classical E-Learning environments (i.e. mouse, desktop, and keyboard). Bodily experiences have also proven that they positively impact learning related cognitive processes. Yet, its potential for learning purposes has not been exploited. First interactive applications in the industrial field indeed integrate real and virtual world[11,12] but they lack elaborated learning contents, pedagogical concepts, and appropriate hard- and software use. Another important factor is motivation of users to actually interact within the learning environment. One way to address this is usage of gamification elements [13], which are playful features enabling new ways of knowledge communication, increasing experiences of being involved, motivating, and offering incentives for learning and performance. Despite many applications of such Serious Games in the context of learning [14], there is no concept for using gamification appropriately within the Industry 4.0 era [15]. Furthermore, they are usually decoupled from real objects and do hence only represent the digital world.

The combination of formal theoretical sessions [16] with active testing and self-exploration possibilities [17,18] in the industrial domain is called blended learning. For instance, academic curricula for engineering studies incorporate regular tutorials, in which students practically apply their knowledge acquired in lectures. In the context of further education for professionals, who already worked in production for several years, practically relevant learning content can be taught in so-called teaching and learning factories. They represent a realistic factory environment which encourages employees to try out different activities or decisions and experience their consequences [19]. The main goal is the development of competences, i.e. knowledge, skills, motivation, interest, abilities, and behaviors related to the requirements of the specific working tasks [20]. In order to achieve this, teaching and learning factories apply additional concepts like mistakes as positive learning experience [21] and social team learning [22]. The learning content is limited to the extent that only knowledge is taught, which is important in nowadays factories. There are no extensive learning concepts to teach the complex interplay between real and virtual world in the factory of the future.

3. Concept

3.1. Vision

We suggest that technologies in human-machine interaction like mixed reality concepts, reality-based interaction, and gamification are promising to be integrated into new learning environments, which address the challenges of future factories. Our vision is an interactive, mixed reality based learning environment, which makes these complex and invisible relations experienceable and thereby understandable for todays and tomorrows production environments. Thereby, new possibilities regarding communication and optimization or the enhancement of physical objects by software components towards smart objects can be explored, played through, and experienced. As discussed in the previous chapters, the requirements towards the worker continuously change and demand in future a broader understanding and competences-oriented learning comprising several disciplines from engineering and information technology. Therefore, the next intruding evolution is to use existing Augmented Reality technologies to represent the digital world and combine this with various real world elements. These real world elements are primarily any kind of smart objects such as CPS in the industrial domain or other embedded devices in the consumer domain. All of these smart objects have in common that they realize a dedicated subtask in a decentralized network. For the responsible person managing such a network in a productive environment it is inevitable to have a strong and profound overall understanding of the resulting interdependencies. Otherwise, it will not be possible to take full advantage of the new paradigms and resulting benefits. Since our vision of the learning environment should not address one specific discipline but help various roles from several disciplines to gain a deeper understanding we propose a modular programming framework for the CPS. Therefore, previous ideas and concepts of an app-based framework for modular programming as shown in [23] are further developed to be used as the basis of this programming framework. By using code snippets, basically meaning software components with encapsulated functionality, we put less focus on programming aspects but rather on understanding the interdependencies of these functionalities. Thus, we also incorporate beginners and other persons, who are not directly related to programming as for example an automation engineer. Furthermore, the learning content should not promote only one feasible solution, since in real world several solutions are possible where depending on the circumstances and requirements the best one has to be determined. This means that the content needs to be structured in such a way that the user is motivated to try out the different degrees of freedom, to tweak on different adjusting screws, and experience the resulting consequences. The user is encouraged to push the system to its limits, try out risky or error-prone configurations, make faults and eventually learn from these. Approaches from gamification inspire the playful interaction with the learning content and gain additional motivation. Furthermore, the individual differences of the learner regarding demographic factors und available qualification and prior knowledge needs to be considered. Learning sessions with varying content, degree of interactivity or difficulty level enable a self-controlled adjustment to the own state of knowledge and interests in

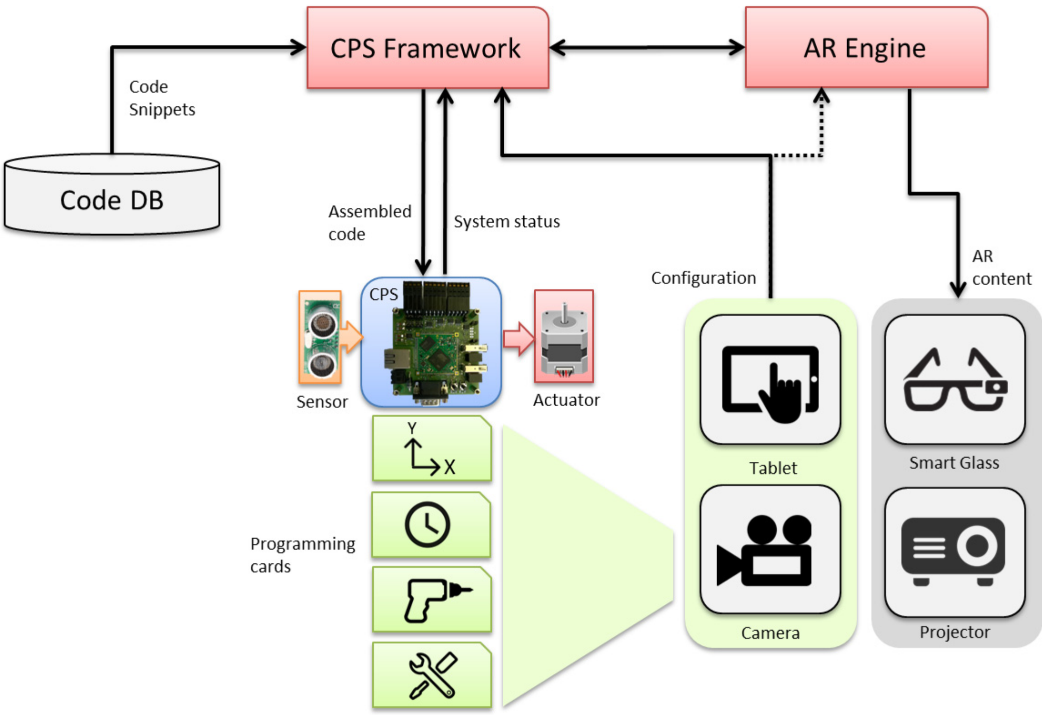

Fig. 1. System Architecture

advanced training. The promoting elements are presented to the learner by using mixed reality in an intuitive and self-explaining manner, so that the learning content is both challenging as well as manageable.

3.2. System Architecture

The proposed system architecture, as shown in figure 1, comprises a set of CPS, which are configured/programmed via an appropriate framework (CPS Framework). The digital domain is visualized by the Augmented Reality Engine (AR Engine). The underlying software components, encapsulated and pre-compiled software components referred to as code snippets are provided by a code database (Code DB). The CPS Framework realizes the programming and configuration of the CPS. It automatically compiles the chosen code snippets and their configuration. The resulting binaries are loaded onto the different CPS. The code snippets used for that are provided by the Code DB, which holds all code snippets for each representation (e.g. given by cards). It is furthermore used to realize the overall operation and communicate the current status information to the AR engine, responsible for their visualization. The AR engine furthermore realizes the analysis of the camera necessary to determine the position of the CPS and potential cards assigned to them. Its main task is to provide the AR content towards the learning environment. This could be realized by a projector directly projecting the visualization on the surface or other modalities like a smart glass or the same tablet as used for configuration.

The CPS components can be equipped with different sorts of sensors and actuators such as proximity sensors, light barriers, servos, and many more. Our CPS components were developed within several research projects and consist of an off-the-shelf System-on-Module, which is combined with a customized circuit board providing GPIOs and other connectors for attaching external devices. For running the code that realizes the functionality of each CPS a Linux-based operating system is used.

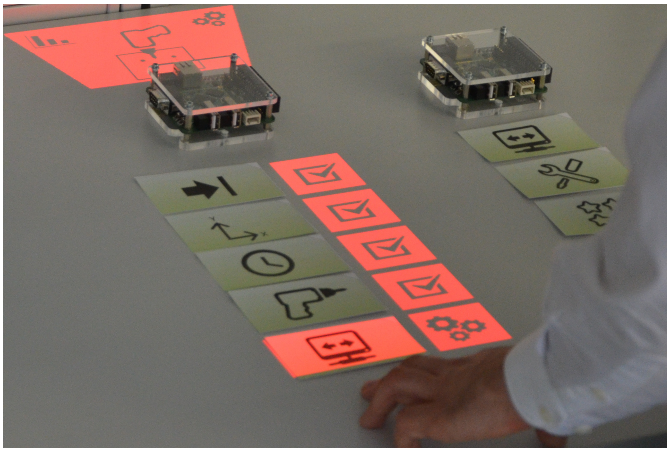

Fig. 2. Exemplary Learning Environment

3.3. Use Case

The learner chooses one of the possible learning session by using the tablet. He wants to learn how sensors, actuators need to be connected to a CPS and how these communicate with each other by designing and setting up a simple production process composed of three steps (e.g. drilling holes, fixing screws, and a final quality check). Before starting the configuration, the learner needs to work out an idea how to realize the required production process in a decentralized manner. For this purpose he can use several CPS, sensors/actuators, and code snippets. So he needs to develop a concept which CPS takes over which sub-task of the overall process, which sensors/actuators are required, and how the code snippets need to be configured accordingly. Once this is done he connects the sensor/actuators to the CPS and brings them in the designated process order. Afterwards, he starts the configuration user interface (UI) provided through the tablet, where the software programming of the CPS is done by choosing and configuring the code snippets. These code snippets are illustrated by self-explaining icons which represent the respective encapsulated functionality.

So he needs to align these icons in a possible order for each of the CPS. Besides that parameters related to the depicted production can be changed from the default values (e.g. throughput, processing time). Once the configuration was finished the CPS components are fitted with the resulting software. Afterwards, the system behavior can be experienced. All process steps are simulated by vivid animations representing the digital consequences, enhancing the real interactions made tangible by the sensors and actuators of the CPS. Thus, the user can always understand the current process step and status of the system, since direct feedback is provided at all times by augmenting the physical world with the digital. Furthermore, he can adjust the made configuration and come step-by-step to the best solution for the posed constraints. Figure 2 shows an exemplary learning environment with three CPS, programming by cards and the visualization by a projection solution.

4. Conclusion & Outlook

The challenges of new paradigms and technologies finding their way into production environments require manufacturing enterprises to invest in advanced training of their employees. Since future workers require interdisciplinary competencies from multiple domains such as engineering, information technology, and computer science, these aspects have to covered by convenient learning environments. Otherwise, it will not be possible to take full advantage of the new paradigms and resulting benefits. In this paper a concept and system architecture of a mixed-reality based learning environment, combining physical objects and visualization of its digital counterpart was introduced. It allows making these complex and invisible relations experienceable and thereby understandable for todays and tomorrows production environments. Thereby, it was designed to not address one specific discipline but help various people from several disciplines to gain a deeper and profound understanding. Furthermore, the expected benefits over traditional learning concepts were outlined and estimated. The relevant State of the Art for reality-based interaction, gamification, and blended learning was described. The requirements given by the vision of a learning environment combining real and virtual world where used to evaluate how these concepts can be applied and combined. A system architecture, comprising several types of interaction and AR modalities was presented. A descriptive use case illustrated how this concept can be applied for a specific learning session.

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