An Industry 4.0 Production Workplace Enhanced by Using Mixed Reality Assembly Instructions with Microsoft HoloLens

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Figure 1: LEAD Factory setting with Microsoft HoloLens

ABSTRACT

Every emerging technology raises the question which already existing processes and solutions can be replaced or adapted. Before implement these technologies they should be evaluated on their positive or negative impacts on already existing approaches. Furthermore, technical resources, organizational conditions and human factors have to be considered. In order to measure these impacts an appropriate industry scenario or use case should be defined. To foster the technology introduction in real world industry scenarios existing work processes were investigated and adapted. Prototypical implementations should give required insights to evaluate new technologies in defined use cases.

In this work we introduce a Mixed Reality (MR) assembly instruction in manufacturing domain to support the worker in ensuring a zero failure culture. In an existing workstation of a scooter production line at the LEAD Factory at Graz University of Technology (TU-Graz) we introduced a emerging technology implemented on the Microsoft HoloLens. Based on this technology the existing textual instruction of one workplace was replaced by an interactive 3D assembly instruction. This paper describes the prototypical implementation of a MR assembly instruction with Microsoft HoloLens and summarizes the upcoming challenges as well as considerations and decisions during the implementation.

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CCS CONCEPTS

• **Applied computing → Computer-assisted instruction**; • **Human-centered computing → Empirical studies in ubiquitous and mobile computing**; *Mobile devices.*

KEYWORDS

mixed reality, special engineering domain, manufacturing, industry 4.0

1 INTRODUCTION

Sophisticated new technologies emerge every year. However, a big challenge is how to integrate these technologies in well-established factory settings. Not every new technology is suitable to support production lines. Introducing new technologies in existing processes and production lines must be considered wisely in order to create a positive influence on the production performance.

We introduce a Mixed Reality solution which should support the production worker to ensure zero failure culture. The term Mixed Reality (MR) describes the merging of real and virtual world in general [13]. MR is strongly related to Augmented Reality (AR) which is a subset of MR [14]. Within this project MR is accomplished by using the see-through head-mounted device (HMD) Microsoft HoloLens. The focus is to support the shop-floor worker to deliver a working product without failures. In industry 4.0 settings in which small lot sizes and small variations of the product are created, the possibility of failures increases since the human is more involved in the production process than in machine serial production.

2 RELATED LITERATURE

This section summarizes the explored literature in the research field. First, the current research on worker assistance is discussed and then related research on MR in production processes is presented.

2.1 Cognitive worker assistance

In industrial working processes, manually assembly and thus worker support has retrieved increasing attention in the recent years, since the complexity in production is steadily increasing [25]. To support the worker in the production process various assistance systems are used which focus on the challenge of reducing the physical and/or cognitive load on the worker [3]. According to Reinhart [18], assistance systems can be classified into three main categories: perception assistance, decision assistance and physical assistance. The research in this paper focuses on cognitive worker assistance which is being defined as a group of the first two categories (perception, assistance). Cognitive assistance provides assembly-related information, such as part lists and assembly instructions, and assists during the information handling process [20] of the employee. The comparison of worker assistance systems can be done by conducting comparative studies and observing selected measures such as efficiency, performance or quality [2]. Also, a subjective evaluation based on the feedback of test subjects can be conducted [12]. For the comparison of assistance systems, Reinhart [18] proposes three design fields that can be explored and adapted to the assembly lines: information degree, information design and information device. While the first two fields focus on changing the amount and structure of the provided work-related information of assistance systems, focusing on the third field allows to compare different hardware in the same environment. By setting two of the three design fields, one can reduce the bias when comparing the third one.

2.2 Mixed reality in production

MR has received growing attention in the recent years, especially in the field of worker guidance in production [15]. The continuous progress of MR technology opens up a wide range of possible applications in the field of industrial environments. MR can be applied in assembly, collaborative work, logistics, quality management and maintenance use cases[11]. The expected advantage of Augmented and Mixed Reality compared to other forms of assembly instructions is, that it allows to retrieve real time targeted situation-specific information which is embedded into the working area of the employee, allowing him to see all the relevant information in the correct place of the workstation [17]. Although various comparative studies have been conducted on the field of industrial AR applications and improvements in various measurements could be shown [8, 16, 26], only little literature exists on the implementation and comparison of HMDs using AR/MR technology in worker guidance systems [19]. In recent studies, the evaluation of AR/MR applications focuses on three types of measurements: effectiveness evaluation, usability evaluation and quality evaluation [9]. These types of measurement can be collected for the assessment of an MR application using various methods and also other influencing factors of a system which are still unknown [24]. Those various methods and unknown factors lead to different results in studies, depending on the task complexity, the user interaction methods and the rendering of the instructions that are evaluated.

3 CONCEPT

The main criteria for an accurate assembly of complex machine parts is a very clear and comprehensible instruction guideline, as well as a sophisticated work preparation. Usually, manual instructions are displayed in computers or sometimes even still exist in paper-based form. Text, drawings and diagrams are often used to visualize assembly information. In many cases, these instructions are separated from the work places. Therefore, workers are forced to alternate between instructions and the assembly work. This distraction may result in worse the product quality as well as in increasing time effort to complete the assembly process [10]. We target this issue by placing the instruction within the field of view of the worker by using 3D visualization with MR technology. Within the next few years, 3D visualization is likely to replace text-based instructions in many domains. Studies showed that learning through visualization [6] and learning by doing [7] are effective ways for learning and knowledge transfer. This strengthens the approach of using MR technology for educational use cases. Furthermore, this technology also eliminates language barriers, which can save a great amount of the costs necessary for the translation of text instructions. As an additional feature, HMDs allow the user to work with hands free. This lets the user fully concentrate on current assembly and minimizes the distraction from work.

The basis for the MR-based assembly instruction is an already existing digital image-text guide provided by the Institute of Innovation and Industrial Management (IIM). The approach of this work is not to create a complete set of 3D visualized assembly instructions, but to develop a functional prototype within a short time by using existing instructions with the latest technology. Since our target group are experienced assembly workers, it is meaningful to limit the 3D visualization to more complex steps. This is done by a partially augmented solution. The existing text manual is provided as additional information besides the 3D visualization. Usually there is existing CAD data for the models, but none for the used mechanical tools like screwdrivers or wrenches. The ratio between benefits and costs for a CAD reconstruction of the tools, is not appropriate. Instead, necessary tool information is still presented in text form, if no CAD data is available. In the scope of this work only the first out of five work packages was implemented. A modular expandable application is designed to enable the quick and easy expansion of additional workstations.

In order to gain focus on assembly work, it is important to animate 3D holograms in front of the user. This prevents unnecessary head movements, which results in better ergonomics during work. With spatial mapping, holograms can be assigned properly.

4 METHODOLOGY

This work follows agile software development principles [4]. At first we identify the current AS-IS situation with experts of mechanical engineering domain. The next step is to identify the challenge, followed by a scenario description of the TO-BE situation. This approach was already used in previous EU Horizon 2020 projects in smart manufacturing domain [5]. In FACTS4WORKERS we built an information system to support the production line by providing additional product data to the shop floor worker. After the TO-BE situation is developed, the first iteration of the software prototype starts. We follow the prototyping approach which facilitates communication between target users and software developers [1]. At the end of each iteration the prototype is tested on-site at the production line of a learning factory. After the prototype reaches a suitable state the next step is to set up a qualitative evaluation, which should mainly investigate the impact of the MR prototype on the quality of assembly work. Since this work focuses on the introduction of new technologies in existing production lines, a detailed summary of the test setting and evaluation results will be given in future publications.

5 IMPLEMENTATION

The software application was developed with Unity 3D and deployed on the first generation of the Microsoft HoloLens. As an example data set, a sub assembly of a scooter was kindly provided by the IIM. The scooter model was chosen because it has a component structure that is not too complex and is functionally understandable. The scooter assembly is subdivided into five different work packages (WPs). In the course of this work, the assembly of the first WP is implemented. The completion of this assembly is divided into 22 steps. During assembly, a number of things must be taken into account to ensure the functionality and safety of the assembly. Difficult tasks such as bearing installation and clearance, screw connections and plug connections require technical know-how.

Nevertheless, a 3D visualization is important to ensure a zero failure assembly process. Components are only displayed and animated at the respective step in order that the user does not loose track of a large number of components at the start of the assembly process.

5.1 Software-Tools

A comprehensive user interface (UI) design is necessary to gain a clear and comprehensible assembly instruction. The UI has to be intuitive but should not distract the shop-floor worker from performing the assembly step. We established a 3D-based assembly instruction with a suitable development workflow. The standard exchange format STEP [22] is used as input for preparing the CAD model. Since the HoloLens can only display mesh geometry, the CAD format is converted accordingly. Then the assembly animations are manually designed in the 3D creation suite Blender. The MR scenario is then created within Unity. Figure 2 summarizes the assembly manual creation workflow. In order to reduce the time needed to develop an MR-based assembly instruction, not all parts of the instruction are converted to 3D instructions due to time and feasibility constraints. This means that only parts and no tools are animated. Information according to the use of tools, as well as component designations are shown as textual overlays.

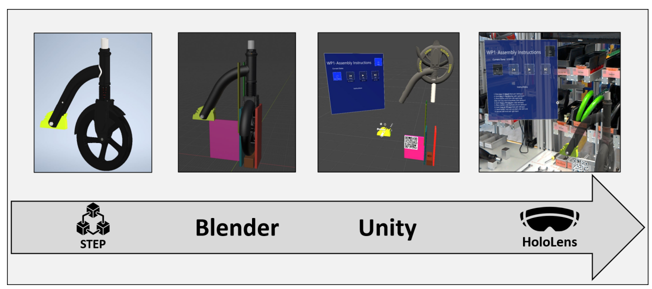

Figure 2: 3D-based instruction creation workflow

5.2 Spatial Mapping

The Vuforia tracking software [23] is used to display the assembly instructions relative to the mounting device. The tracking software creates a spatial anchor which is then used to display content fixed in place. Since the mounting fixture stays stationary within the workplace, it was used as a tracking object. In the first iteration of the MR prototype, object tracking and recognition was used to match the mounting fixture mesh model to the corresponding real-world structure. Eventually it turned out that this approach was not suitable for the specific scenario because the object detection was not as reliable as expected. In the course of the 2nd iteration we switched to image recognition. A QR Code which is placed on the mounting fixture ensures the spatial allocation of the holograms. This approach fixed the problem with the deviation of the superimposed 3D model. Figure 3 shows the deviation of virtual superposition on the model of object tracking in comparison to image target detection.

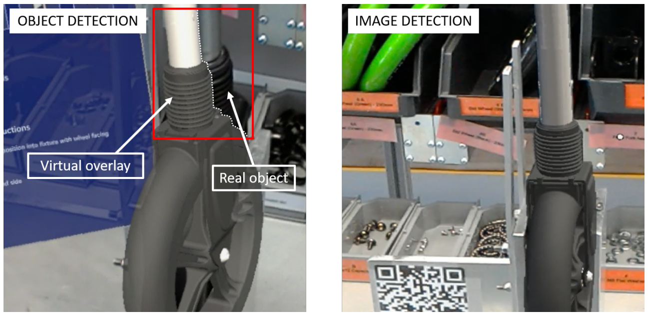

Figure 3: Deviation of virtual superposition on the model while using object tracking compared to image tracking

5.3 Application

The main menu of the application is divided into two different sections. In the first section the assembly instructions of the respective work packages of the scooter can be selected. In the second section under CAD Models, the user can choose between the work packages. Furthermore, the entire scooter model can also be displayed. QR code scanning is used to augment the corresponding model on the workstation. This visualization fosters the understanding of the component before assembly. The UI for the assembly instructions is divided into two areas. On top are the control elements for the animation. The previous, next and current assembly steps can be selected for playback. These actions can be controlled by click interaction as well as speech recognition. The use of voice control allows the user to fully concentrate on the 3D animation and minimizes additional head movements. Furthermore, it makes the assembly easier if both hands are freely available. Figure 4 shows the main parts of the HoloLens UI.

Figure 4: HoloLens UI

6 DISCUSSION

Some constraints have to be considered while implementing the assembly use-case with 3D instructions. The creation of 3D animations and other 3D instruction material should not be a complex and time consuming process. The most important constraint which should be considered is if the effort to produce such an instruction counterbalances the costs which are caused by an assembly error. The decision of which specific process step should be implemented as a 3D animation often is a big challenge and it is difficult to anticipate which part of the assembly process is critical. Even if a process was identified as critical, all necessary data (CAD files, instructions) must be available or have to be prepared by engineering or production planning employees. Since 3D manuals are a very new field in mechanical engineering factory settings, new processes have to be designed. The key questions which arise are: who is responsible for creating such manuals, how to manage the update and release processes of such manuals and how to handle small changes (product variations). We already introduced such an industry setting and defined roles within a company [21]. Since the creation of such manuals is still a very time consuming process, the level of detail of such manuals has to be considered: Is it important for the learning transfer that every screw in the 3D animation is rotating while mounted? How physically accurate has the manual to be to ensure that the product will be assembled correctly? To get a feedback if the manual is correct and has the designated purpose, a feedback loop muss be introduced so that the manual will be improved.

7 CONCLUSION

A lot of constraints have to be considered, when introduce new technology and processes in manufacturing. It could be necessary to define new roles and job positions in manufacturing processes. With transition to Industry 4.0 new challenges arise for the manufacturing industry. Smaller lot sizes and small product variations increase the complexity of production. We introduced an MR solution to support the shop-floor worker during assembly. To create and implement a suitable 3D-based assembly manual the content have to be prepared very well-considered. In the next step the implemented prototype will be evaluated in order to make a valid assessment of the introduction of MR technology in existing production lines.

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