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Editors

Learning Factories of the Future

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Preface

The 14th International Conference on Learning Factories (CLF 2024) took place from April 17–19, 2024, at the University of Twente, The Netherlands, continuing the successful CLF conference series targeting the latest research and development in the field of learning factories. Without question, engineering education related to design and manufacturing is crucial to keep up with the demands of today's society. Moreover, lifelong learning, rather than one-off activities, is key to enabling the workforce to keep pace with rapidly evolving technologies and methodologies. Interactive learning factories play a vital role in this process, providing hands-on experience and practical application of theoretical concepts, thereby enhancing adaptability and innovation. With this in mind, the aim of the conference was to share the latest insights and to foster cooperation towards excellent learning factories of the future. The conference covered topics such as learning factory design, Industry 5.0, digital twinning and VR/AR, 5G/6G in learning factories, AI for manufacturing systems, human-centred work design, human-robot collaboration, sustainability in learning factories, as well as cross-learning factory product/production systems.

With the International Association of Learning Factories (IALF) as a strong academic network in the background, nearly 40 academics joined the scientific committee to review and ensure the high quality of each contribution. A total of 85 papers were accepted and eventually presented in person in 18 parallel sessions. As usual in the CLF conference series, CLF 2024 was accompanied by other activities like the annual IALF General Assembly, a keynote session, technical demos in learning factory environments, and numerous networking occasions to facilitate interactions and knowledge exchange.

We would like to take this opportunity to warmly thank all the IALF for their continuous interactive cooperation and support for this successful conference series. We would also like to thank the numerous reviewers—without their involvement, the creation of such a broad and high quality conference programme would not have been possible. We also kindly thank all the authors who have dedicated much of their time and effort to contribute to CLF 2024. We truly believe that, thanks to all these efforts, the final conference programme consisted of high quality contributions to the learning factories of the future. Only together can we contribute to a successful transformation of our manufacturing industries and our economies!

We are also grateful to the Faculty of Engineering Technology and in particular the Department of Design, Production, and Management (DPM) for their support. Last but not least, we would like to sincerely thank all the members of the CLF 2024 organising committee for their great support in organising the conference and making this professional meeting a success. We hope that the participants found the event interesting,

valuable, interactive, and enjoyable, and that they enjoyed their stay in Enschede and its beautiful surroundings.

Sebastian Thiede
Eric Lutters
Chairmen of CLF 2024

About the Editors

Prof. Dr.-Ing. Sebastian Thiede is a full professor of Manufacturing Systems at the University of Twente (Netherlands) and the chairman of the Department of Design, Production and Management (DPM) within the faculty Engineering Technology. Prof. Thiede is interested in innovative technologies, methods, and tools for the planning and operation of manufacturing systems and factories. Prof. Thiede is the ambassador of the Smart Industry route within the Dutch National Science Agenda (NWA) and besides that the associate member of CIRP, the International Academy of Production Engineering, as well as the member of IALF, the International Association of Learning Factories.

Prof.dr.ir Eric Lutters is a full professor for Information driven Product Development & Engineering at the University of Twente. Prof. Lutters is interested in digital twins/prototypes/masters, virtual/augmented reality, sustainability, (non-deterministic) decision making, and uncertainty in development cycles. Prof. Lutters focuses on integrating research and education (also in lifelong-learning) in topics related to product development as a link between design and (production) engineering. Prof. Lutters is a fellow of CIRP, the International Academy for Production Research, as well as the member of IALF, the International Association of Learning Factories. Next to his work in Twente, he is the professor extraordinary at the department of Industrial Engineering at the University of Stellenbosch, South Africa.

An Augmented Reality Intelligent Guide for the Automotive Industry

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Abstract. Throughout the 21st century, there has been a rise in interest of increasing inter-connectivity and smart automation in the realms of industrial production, often called the 4th industrial revolution. Thus, interest in areas such as virtual, mixed, and augmented reality has increased as new devices and technologies related to these areas are seen as a possible solution to increase Industrial efficiency, create safer work environments for employees, and more effective training.
In this project, a HoloLens app was developed, capable of identifying and showing to the user various zones where a specific vehicle in a production line requires checking and in which users have full spatial perception.
Each vehicle is composed of several zones and each of these zones is associated with specific stations in a sequential order, so the user will only be able to see the zones associated with the station that is being treated. Using a specific "gesture" users can change the zone's status in the database to indicate that the zone has been checked. These changes will be visible and the vehicle, stations, and zones will be updated to reflect the modifications.
Various scripts in C# and PHP were used to allow modifications to the behaviour of the objects and database in the augmented reality scene through the access to a RESTful service in Unity.

Keywords: Augmented Reality · Microsoft Hololens · Fourth Industrial Revolution · Vuforia

1 Introduction

As we enter the fourth industrial revolution, various industries embrace cutting-edge technologies such as the Internet of Things (IoT), Cyber-physical Systems, Artificial Intelligence (AI), and Mixed Reality (MR). In addition to increasing productivity and efficiency, these technological advancements are also changing the basis of education, training, and work practices in a variety of fields [1].

During the critical assembly process in the automotive manufacturing industry, human errors such as misassembling parts or forgetting components, can happen even with precautions. Moreover, quality control also requires a set of measurements and audits to the shapes, flush, gap and compontens, before the car is ready for shipment. This comprehensive post-assembly inspection seeks to address this by finding and fixing mistakes. The emphasis then turns to confirming assembled components. Learning factories and augmented reality (AR) are complementary tools that improve product outcomes by improving quality control and streamlining the verification process.

The term “Learning Factory” applies to an educational setting in an Academic Institution or Industry where students or employees acquire real-world knowledge through simulation or real on-site production processes to acquire practical skills. This concept proves rather important as one of the prime examples of the “Learning by doing” principle, highlighting the value of hands-on learning over theoretical methods, such as lectures and simulated workshops [2]. Learning factories have the potential to redefine training by offering a dynamic, experiential learning environment that surpasses conventional approaches and guarantees that people gain real skills in line with the changing needs of the manufacturing industry.

With this context, technologies such as Augmented Reality (AR) and Virtual Reality (VR) emerge as tools to build realistic learning and simulation environments and, at the same time, provide instructions and support for operators in several contexts. Thanks to the advances in these technologies, and the increase in availability and accessibility to devices such as smartphones or MR Headsets, many consider that it is only a question of time until these technologies are implemented and used in the next generation of factories [3].

AR is a technology defined by an enhancement of the view of the user’s perspective of reality, allowing for the superimposition of virtual content into a user’s view, an overlap of reality-enhancing technologies (Figure 1) [4].

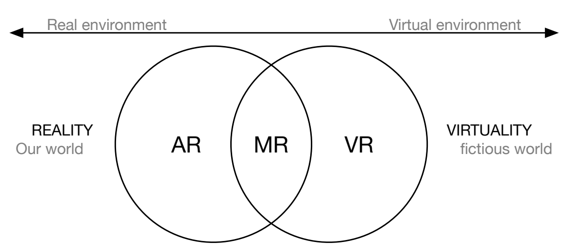

Fig. 1. The Reality-Virtuality continuum

AR has the potential to play a significant role in a Learning Factory, due to the capability to visualize data of machinery or production processes in a spatial view. Not only interaction between humans and machines is enhanced, but it also allows the use of guided instructions as visual cues and other information in the overall learning experience. Moreover, the learning environment can also be made safer and cheaper [5].

The end goal for this project was the design, development and use of an AR Application to improve the quality control process in an automotive factory by providing real-time visual feedback to workers during the verification stage of the assembly process. Workers will be dynamically shown visual cues about where the parts of a specific car must be checked to pass the quality control assessment, disappearing once the checking is complete.

2 Related Work

Putta [6] researched the most effective technique for an augmented reality application for the HoloLens that utilized QR codes and Vuforia 3D model recognition to recognize Volvo Automotive Vehicles. It is additionally proven that the device's recognizing ability lessens as the distance between the device and the vehicle increases. For close range (up to 60.96 cm) recognition, QR codes are more suited, and for ranges up to 152.4 cm, 3D recognition is more suitable.

Frantz et al. [7] explore the use of Microsoft's HoloLens for neuronavigation in neurosurgery. They address the challenges in tracking and Hologram stability through Vuforia target recognition, thus increasing stability in an application for the Neuronavigation field. They concluded that AR has the potential to improve surgical procedures, but there is still room for development.

Knopp et al. [8] addressed some challenges related to the recognition of movable objects using the Microsoft HoloLens Headset, and concluded that this device can function efficiently in a versatile and productive setting. For that, they had to integrate machine learning technologies and a remote computer with superior hardware and image processing capacity.

Ullah and Rabbi [9] classified and compared all tracking techniques used in augmented reality, from the sensor-based approach, considered accurate and robust but costly and limiting in terms of mobility, and the Vision-based approach, which is considered precise, with minimal delay, but can be computationally intensive and lacking robustness. On the other hand, Hybrid tracking, which combines sensor and vision tracking, is thought to be the most reliable and accurate. However, it is also the most expensive and computationally challenging.

Guo [10] discusses the challenges and opportunities in using mixed reality technologies in Learning Factories. The paper concludes that in the context of Industry 4.0, mixed reality systems provide a creative and innovative setting with up-to-date teaching methods and learning resources that reflect the most recent findings in education and training.

In summary, the introduction of AR and VR technologies in several stages of the industrial process is a growing trend, with the potential to improve several aspects of the production process. Moreover, the possibility for simulation and experimentation in a safe and flexible environment also stimulates the learning process for tasks that are potentially complex and error-prone.

3 Problem Analysis and Implementation

In an automotive factory scenario, the production line is where parts are sent to be assembled to form a vehicle. After assembly, the parts are measured to assess the correct relative position and the fulfilment of the assembly parameters, such as gap and flush between parts. The usually high number of parts and measurements to do makes this process slow and error-prone, because the operator has to go over a sequence and, in the course of the task, may forget to measure some or measure multiple times.

The app developed within this work assists in this goal. Accomplished by combining elements such as the database, various scripts inside the Unity game engine simulator scene and the AR HoloLens device, it is possible to present to the user an overlay of elements that aid in the verification process and allow for a reduction of the risk of human error. Moreover, providing an up-to-date connection to the database makes the process of confirming the checking of the zone much easier and efficient.

In more detail, the system is composed of three main components: the database, the scene (implemented in Unity game engine) and the production line, where cars are being assembled and which serve as the target for overlaying Information about the process (Figure 2).

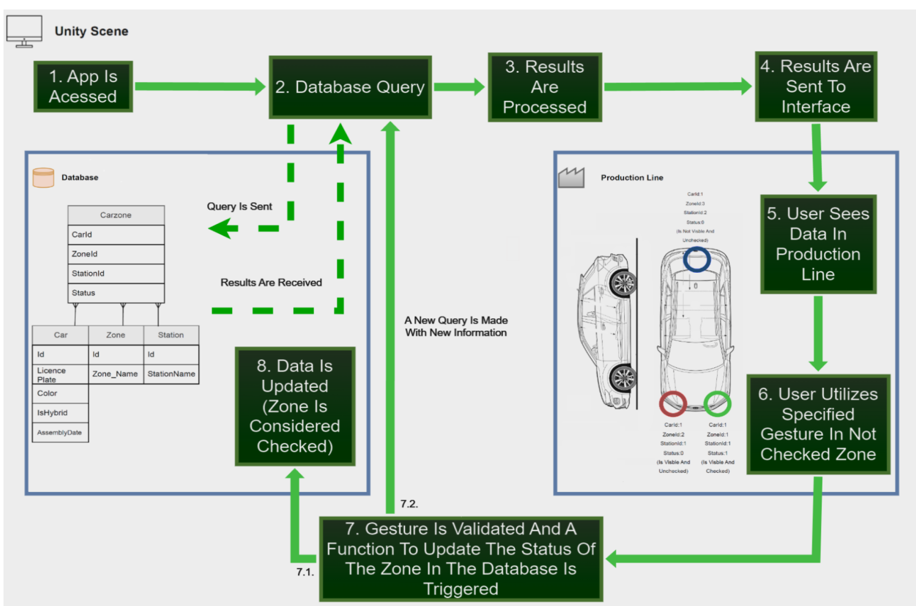

Fig. 2. Main architecture of the system

The benefits of introducing AR in this process is threefold: a) it becomes possible to optimize this process, by providing visual clues to which points were already measured and which are still missing; b) it can provide information about the measurement results, thus showing a complete perspective on the process; c) provide a training scenario for operators, improving their productivity and work quality.

The user has real-time visual feedback on the state of each zone (checked or unchecked). This information is presented along with the data referring to the station of assembly, car and zone itself. The user can alter the status of the zone by realizing a specific gesture that is captured by the device, which then triggers the change of status and allows the user to move to the next zone by providing visual feedback that the zone was checked. This immersive learning experience allows operators to visualize the correct assembly steps, reducing the likelihood of human errors such as assembling the wrong parts.

This AR application emphasizes experiential learning for the acquisition of practical skills, which is in line with the tenets of learning factories. Incorporating this technology into manufacturing education for the verification process changes the traditional approach to learning and guarantees that operators acquire both theoretical and practical expertise. Integrating this technology into the manufacturing education process, changes the conventional approach to learning and guarantees that operators acquire the practical expertise required in a technologically sophisticated industrial setting in addition to theoretical knowledge, drastically improving both the quality and efficiency of the product.

4 Results

Quality control in the assembly part of the automotive industry requires several measurements that have the objective of validating the functionality and aesthetics of the car parts. This requires that the operator goes over dozens of locations and assess the gap and flush of the car's assembly, making corrections as necessary (Figure 3).

Typically, the operator follows a well-defined sequence, although it might be necessary to measure several times the same point to check for minor corrections. This takes time and many operators might be working on the same car, requiring good communication and coordination. Moreover, there is no way to skip some points that might not be necessary to measure. In fact, some of the points may depend on previously measured one, because of potential correlations with other sets of points. These contribute to slower processing and more time to finish the quality assessment of each car.

The objective of this project is, as mentioned above, twofold: assist in the training of the operators and provide a tool for providing up-to-date instructions to the operators during the manufacture process.

Each operator carries a HoloLens device capable of overlaying virtual components on the user's field of vision, complementing the real world visual perspective, relative to a certain car, its zones and its properties. In addition to this, the app can recognize and track this specific car in the real world.

Fig. 3. Measuring gap and flush in the final assembly line (source: https://www.nextsense-worldwide.com/)

This feature takes on significance in the context of learning factories because it provides operators with a visual cue that indicates the completion of zone checks and the readiness to move forward with the verification process. The workflow is streamlined by this real-time feedback, which makes it easier for operators to oversee and monitor the status of various production line zones. It improves the learning process and encourages a more effective and understandable approach to verification procedures in the dynamic setting of a learning factory by offering a clear and prompt indication (Figures 4 and 5).

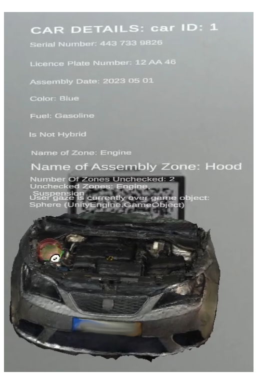

Fig. 4. Running in Unity editor (Image Target)

Fig. 5. Running in HoloLens (Model Target)

The number of operators in this section of the assembly line is considerable, reaching a few hundredths over three daily shifts. It is important to have the necessary tools for both training the staff and optimizing the assembly and quality control process.

5 Conclusions

In conclusion, the project's importance goes beyond creating an augmented reality (AR) application for quality assurance in the car industry. The application plays a crucial role in improving overall productivity and raising the standard of the final product by tackling the ongoing problem of human error in assembly processes. A more efficient manufacturing process is achieved by the AR Application's dynamic visual guidance, which reduces errors and expedites the verification stage. Moreover, this creative solution is a prime example of how technology can be easily incorporated to deliver useful, real-world skills in the setting of a learning factory, where experiential learning through hands-on experience is critical.

By bridging the gap between theory and application, this approach aligns with the core principles of learning factories and highlights how advanced technologies can revolutionize industrial practices and educational frameworks in the context of a learning factory by reducing human error, increasing efficiency, and improving product quality.

Acknowledgment

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