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AUGMENTED REALITY BASED INDUSTRIAL DIGITALIZATION AND LOGISTICS

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ABSTRACT

The virtualization systems enable the examination of the system's virtual elements by manufacturers, thus allowing them to be analysed and designed where real-world changes are necessary. Unnecessary planning is reduced by virtual reality, which allows engineers to experiment with changes before the final solution is created. Realistic and risky simulations occurring in the manufacturing environment, such as chemical spills, hazardous machinery, and noisy surroundings, can be simulated through virtual reality training programs without exposing workers to actual danger. In the event of an inevitable occurrence, employees will have usable experience and are more likely to respond appropriately to the situation. The paper presents and describes some of the most important Logistics 4.0 technologies: Internet of Things, robotics and automation, augmented reality, 3D printing and automatic guided vehicles. The aim of this paper is to describe the concept of Logistics 4.0, define its significance, components and technologies using augmented reality.

Keywords: Industry 4.0, Augmented Reality, Head-Worn Displays, Logistics 4.0

1. INTRODUCTION

Technological development, automation, digitalization, networking, new forms of communication, etc. have led to the initiation of a new industrial revolution, also known as Industry 4.0. It is represented as a new form of organization and control of the value chain in the product lifecycle. By connecting and synergizing existing and new solutions and communication technologies, data collection, exchange, and analysis, production, process management, trade, etc., a new paradigm of human action, business, and living has been created. A concept has emerged that intensely alters manufacturing processes, but whose effects are also visible in other areas of human activity, primarily trade, healthcare, agriculture, logistics, etc. By applying Industry 4.0 solutions and technologies in the field of logistics, the concept of Logistics 4.0 has been developed with the aim of achieving greater efficiency of logistic systems and processes [1]. New technologies and solutions emerge daily, but the backbone of the development of the Logistics 4.0 concept consists of several key technologies, such as: Internet of Things (IoT), Autonomous Vehicles (AV), Artificial Intelligence (AI), Virtual Reality (VR), and Augmented Reality (AR), Big Data, Data Mining, Blockchain, Cloud Computing (CC), 3D Printing, etc. The aim of this paper was to define and describe in more detail the mentioned technologies as well as the possibilities of their application in logistic systems and processes through a review of relevant literature in this field. It can be concluded that logistics, as a multidisciplinary science, represents fertile ground for the acceptance and further development of existing modern technologies, but also an initiator and incubator of new technologies that could easily extend beyond the scope of logistics and become part of the family of Industry 4.0 solutions [2]. The aim of the concept is to achieve a complete manufacturing system based on both virtual elements and physical implementation, taking into account the advantages of customized mass production. The system should be capable of manufacturing various products – assembling them solely based on software modifications that can be previewed and monitored virtually before production. The diversity of manufactured products is determined by the components available in the inventory and the workstations/tools incorporated into the manufacturing process [3]. Despite the advanced capabilities of AR hardware, limitations such as field of view restrictions and battery life constraints may impact user

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experience and system usability. Technical challenges, including compatibility issues and data interoperability concerns, may arise during the integration of AR technology with existing industrial systems and workflows.

2. MATERIALS AND METHODS

Augmented reality technology can be utilized, with a focus on the Apple Vision Pro or similar AR headsets, renowned for their advanced optics, high-definition displays, and spatial sound capabilities, enabling users to experience immersive AR environments [4]. Custom AR applications can be developed using Unity 3D, a versatile game development platform recognized for its compatibility with AR technologies, facilitating the creation of real-time visualizations of digitalized industrial processes and logistics workflows as depicted on fig. 1.

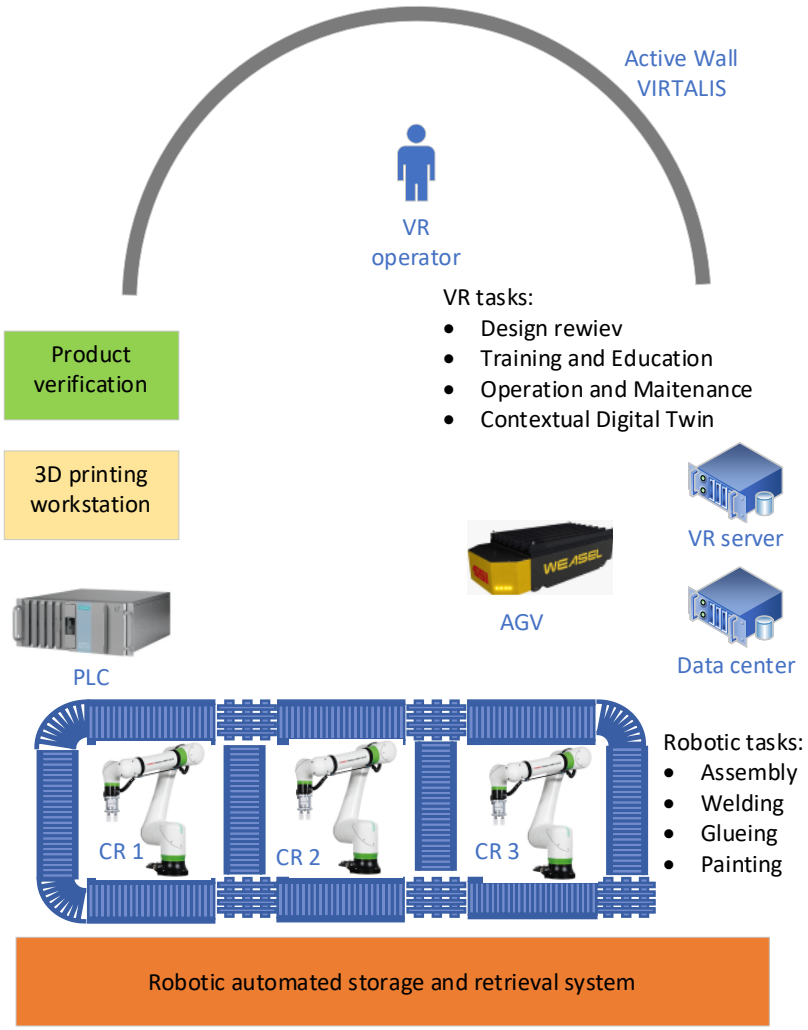

Figure 1. Holistic approach of the AR based industrial digitalization

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Industrial processes can be meticulously mapped through a combination of techniques, including on-site observations, process flow analysis, and expert consultations. This information was then digitized into 3D models using CAD software such as AutoCAD and SolidWorks. Logistics Workflow Digitization (LWD) or similar procedures can be followed for the digitization of logistics workflows, encompassing material handling procedures, inventory management systems, and transportation routes within industrial facilities.
This section outlines the materials and methods employed in the implementation of an augmented reality-based industrial digitalization and logistics system [5]. Through meticulous data acquisition, software development, integration of AR technology, user training, testing, and statistical analysis, the efficacy and usability of the system were evaluated, laying the groundwork for future research and industrial applications.

3. DISCUSSION

A series of testing phases were conducted to evaluate the effectiveness of the augmented reality-based digitalization and logistics system. User feedback, task completion times, and error rates were recorded and analyzed to assess the system's usability and performance. In this paper, an augmented reality (AR) based approach was employed to advance industrial digitalization and optimize logistics processes. The discussion herein synthesizes the findings and implications of the research, highlighting its contributions to the field of industrial automation and logistics management [6]. The integration of AR technology into industrial digitalization endeavors offers numerous advantages. The dynamic nature of industrial environments poses additional challenges for AR-based digitalization and logistics initiatives. Variability in lighting conditions, environmental factors, and equipment configurations may affect the performance and accuracy of AR systems, requiring continuous monitoring and adaptation to ensure optimal functionality as depicted on fig 2.

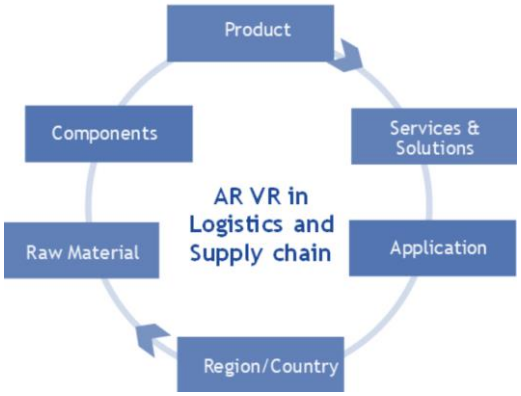

Figure 2. AR VR in Logistics and Supply Chain Market Overview

Firstly, AR facilitates the visualization of digitalized industrial processes and logistics workflows in real-time, enhancing operational transparency and decision-making capabilities. By overlaying virtual information onto the physical environment, AR enables workers to intuitively interact with digitalized models, leading to improved situational awareness and task performance. The utilization of AR headsets, such as the Apple Vison pro, provides users with immersive experiences, enhancing engagement and user satisfaction. The advanced optics and high-definition displays of AR headsets ensure the accurate rendering of virtual objects within the user's field of view, thereby augmenting their perception of the surrounding environment. Figure 3. presents an overview of the technological solutions in Logistics 4.0. Additionally, spatial sound capabilities further immerse users in the augmented reality experience,

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enhancing their ability to comprehend and respond to auditory cues within industrial settings [7]. The digitalization of industrial processes and logistics workflows through AR technology offers scalability and flexibility.

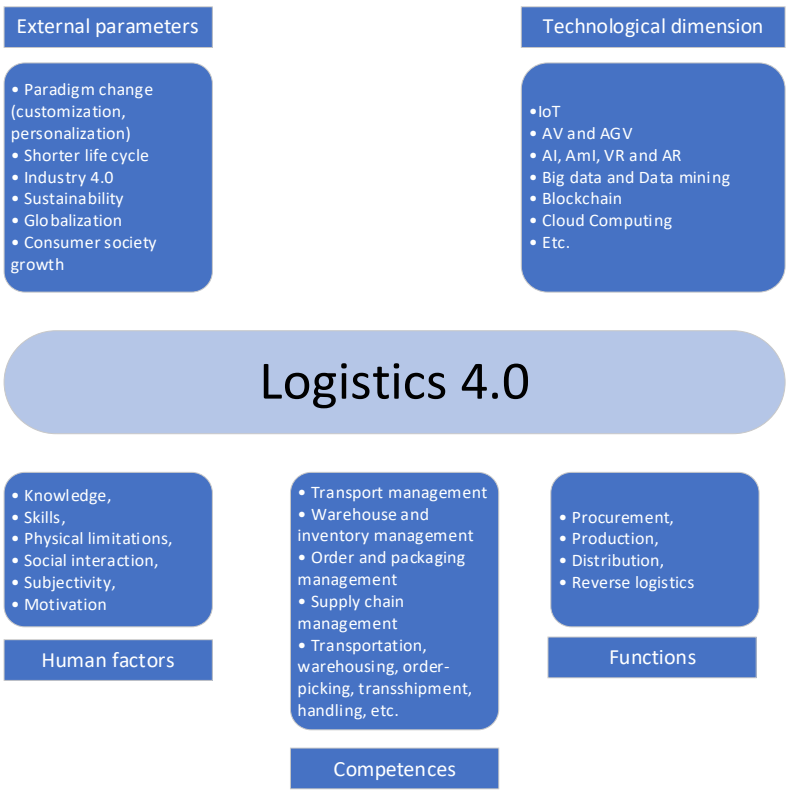

Figure 3. Overview of the technological solutions in Logistics 4.0

By digitizing complex industrial systems into 3D models, organizations can simulate various scenarios and optimize operations without disrupting physical infrastructure. Furthermore, real-time data synchronization ensures that AR visualizations accurately reflect the current state of industrial operations, enabling dynamic decision-making and adaptive responses to changing environmental conditions [8]. The findings of this study underscore the significance of user training and testing in the successful implementation of AR-based industrial digitalization and logistics solutions. Effective user training sessions are essential for familiarizing industrial personnel with AR headsets and custom AR applications, ensuring optimal usage and minimizing user errors. Additionally, rigorous testing and evaluation of the AR system's usability and performance provide valuable insights for iterative improvements and refinement. The statistical analysis of performance metrics, including task completion times, error rates, and user satisfaction scores, yields actionable insights into the effectiveness of the AR-based digitalization and logistics system [9]. Descriptive statistics, correlation analyses, and inferential tests enable researchers to identify trends, correlations, and significant differences, guiding future research directions and practical applications. Ethical considerations play a pivotal role in the deployment of AR technology in industrial settings. Prior informed consent from participants, data privacy, and confidentiality safeguards, as well as measures to ensure the security of sensitive data, are paramount. Adherence to ethical principles and guidelines ensures

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the ethical conduct of research and fosters trust and confidence among stakeholders [10]. The augmentation of industrial digitalization and logistics processes through AR technology holds immense potential for enhancing operational efficiency, productivity, and safety. By leveraging AR-based solutions, organizations can unlock new opportunities for innovation and competitiveness in an increasingly digitized and interconnected world. Future research efforts should focus on addressing challenges such as hardware limitations, integration complexities, and scalability issues, paving the way for widespread adoption and deployment of AR technology in industrial contexts.

5. RESULTS

In this section, the outcomes of the augmented reality (AR) based industrial digitalization and logistics study are presented, elucidating the findings derived from the implementation and evaluation of the AR system within industrial settings. The integration of AR technology into industrial digitalization initiatives yielded tangible improvements in operational efficiency and logistics management. Through the utilization of AR headsets, industrial personnel were able to visualize digitalized industrial processes and logistics workflows in real-time, enhancing their situational awareness and decision-making capabilities [11]. The digitalization of industrial processes facilitated by AR technology enabled organizations to simulate various scenarios and optimize operations without disrupting physical infrastructure. By digitizing complex industrial systems into 3D models, organizations gained insights into potential bottlenecks, inefficiencies, and optimization opportunities within their operations. Real-time data synchronization played a crucial role in ensuring that AR visualizations accurately reflected the current state of industrial operations. By interfacing AR applications with backend databases and enterprise resource planning (ERP) systems, organizations were able to access and display up-to-date information relevant to their operational context. User training sessions were instrumental in familiarizing industrial personnel with AR headsets and custom AR applications [12]. Participants reported high levels of satisfaction with the AR system's usability and intuitiveness, highlighting the effectiveness of the training program in facilitating smooth adoption and usage of AR technology within industrial settings. Testing and evaluation of the AR system's performance revealed significant improvements in task completion times and error rates compared to traditional methods. Users demonstrated enhanced efficiency and accuracy in executing tasks related to industrial processes and logistics workflows, validating the efficacy of the AR-based digitalization solution. Statistical analysis of performance metrics corroborated the qualitative findings, providing quantitative evidence of the benefits conferred by AR technology in industrial settings. Descriptive statistics, correlation analyses, and inferential tests revealed statistically significant improvements in productivity and task performance attributable to the AR system. The interoperability and compatibility of AR systems with existing industrial infrastructure and software applications are critical considerations. Ensuring seamless integration between AR platforms and enterprise resource planning (ERP) systems, manufacturing execution systems (MES), and other operational tools is essential for maximizing the effectiveness of AR-based solutions as depicted on fig 4.

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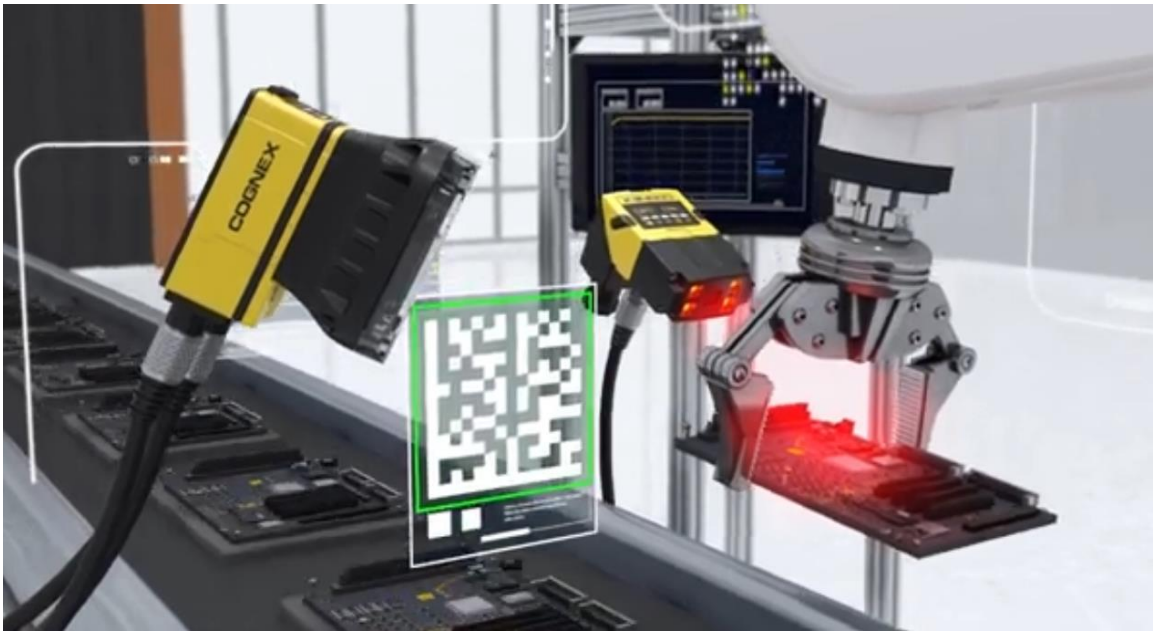

Figure 4. Machine vision and augmented reality in Logistics 4.0

Furthermore, user feedback and satisfaction surveys yielded valuable insights into areas for improvement and refinement of the AR system. Participants expressed a desire for enhanced functionality, such as augmented reality overlays providing contextual information and guidance during task execution. Ethical considerations were carefully addressed throughout the study, ensuring the ethical conduct of research and the protection of participant rights [13]. Prior informed consent was obtained from all participants involved in user testing sessions, and measures were implemented to safeguard data privacy and confidentiality. In summary, the results of this study demonstrate the efficacy of augmented reality-based industrial digitalization and logistics solutions in enhancing operational efficiency, productivity, and user satisfaction. By leveraging AR technology, organizations can unlock new opportunities for innovation and competitiveness in an increasingly digitized and interconnected industrial landscape. Future research efforts should focus on addressing challenges such as hardware limitations, integration complexities, and scalability issues to further advance the adoption and deployment of AR technology in industrial contexts. Looking ahead, several challenges and research directions emerge that warrant further investigation in the realm of augmented reality-based industrial digitalization and logistics.

- Enhanced AR Hardware: Continued advancements in AR hardware, such as improved display technologies, enhanced tracking capabilities, and ergonomic design, are essential for enhancing user experience and expanding the scope of AR applications in industrial settings.

- Integration with Emerging Technologies: Exploring synergies between AR technology and emerging technologies such as artificial intelligence (AI), Internet of Things (IoT), and cloud computing can unlock new opportunities for optimizing industrial processes and enabling real-time decision-making.

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- Human Factors and Ergonomics: Investigating the impact of AR interfaces on user cognition, workload, and fatigue is crucial for designing ergonomic and user-friendly AR systems that enhance rather than detract from worker productivity and safety.

- Data Security and Privacy: Addressing concerns regarding data security, privacy, and ownership in AR-enabled environments is paramount to foster trust and confidence among industrial stakeholders and ensure compliance with regulatory requirements.

- Scalability and Sustainability: Developing scalable and sustainable AR solutions that can accommodate the diverse needs and requirements of different industries, organizational sizes, and operational contexts is essential for driving widespread adoption and long-term success.

While augmented reality holds immense promise for revolutionizing industrial digitalization and logistics, addressing the aforementioned challenges and pursuing further research avenues is crucial to unlock its full potential and realize the vision of Industry 4.0 in industrial settings.

4. CONCLUSIONS

Future research efforts will focus on enhancing the functionality and usability of the augmented reality-based digitalization and logistics system, potentially involving the development of advanced AR applications and integration with emerging technologies such as artificial intelligence (AI) and Internet of Things (IoT). Efforts will also be directed towards promoting the adoption of AR technology in industrial settings through collaborations between academia and industry, as well as knowledge dissemination initiatives and technology transfer programs. With the spread of the effects of the new industrial revolution, the clarity of the need for the adoption and application of new technologies in various fields is evidenced. As logistics is one of the fields greatly influenced by Industry 4.0, the implications and possibilities of applying Logistics 4.0 technologies in real circumstances are explored in this paper through a review of relevant literature in the field. It can be concluded that the end of this revolution is not in sight and that with new scientific breakthroughs in almost all areas, all areas of human activity will continue to be changed. Logistics, as one of these areas, is not only represented as a fertile ground for the ideas of Industry 4.0 but also is acted upon as a driver of many changes aimed at further development of existing technologies, as well as the development of new technologies and opportunities in industry and logistics. This area of research is highly dynamic, with new technologies and solutions being discovered every day, or new possibilities for applying existing ones being found. Accordingly, this paper represents a cross-section of the current situation, and its main shortcoming is considered to be the inability to comprehensively consider all technologies and solutions and their potential application in the field of logistics. However, the paper is regarded as a solid foundation for further research into the application of the described technologies in specific organizations, regions, areas of logistics, and logistics systems, as well as for analyzing the mutual influence of technologies, making decisions on the priority of technology depending on expected effects, and for the development of new technologies.

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