

## USE OF AUGMENTED REALITY IN INDUSTRIAL PROCESSES

Ali Emre Topbaş<sup>1</sup>, Gintaras Dervinis<sup>2</sup>

<sup>1</sup>*KTO Karatay University, Akabe, Alaaddin Kap Cd. No:130, 42020 Karatay/Konya, Turkey*

<sup>2</sup>*Utenos kolegija Higher Education Institution, Maironio str. 18, Utena, Lithuania*

### Abstract

This article, based on detailed review and synthesis of scientific literature, implements the main research objectives - to analyze and demonstrate the features of the application of augmented reality in industry; areas where its integration is justified; to compare it with similar technologies, such as virtual reality and also to demonstrate the capabilities of augmented reality in a real application through a practical experiment using the industrial augmented reality system EcoStruxure Operator Advisor for visualization of the Programmable logical controllers laboratory.

The reason for this study is the growing need for new and advanced technological solutions in the context of "Industry 4.0". The need to optimize operations and increase productivity is increasing in various industries, and Augmented Reality (AR) integrated with other Industry 4.0 technologies such as Internet of Things (IoT) and Artificial Intelligence (AI) has become a great tool to overcome these challenges.

**Keywords:** Augmented Reality, Virtual Reality, Automation of Industrial Processes, Industry 4.0

### Introduction

Augmented reality (AR) technology, developed over the past decade, has rapidly become one of the most advanced tools for integrating relevant digital information into the user's real world and fundamentally changing the user's perspective on the increasingly complex industry and the processes taking place in it. As an immersive technology, AR allows users to overlay visible physical objects with virtual elements with actual data in real time, thereby improving situational awareness and supplementing with contextual data. AR has shown great potential for transforming industrial operations, increasing productivity and overall efficiency, and reducing human error (Hernandez et al., 2021; Ong et al., 2008). The relevance of augmented reality is particularly evident in the context of Industry 4.0, which emphasizes the integration of advanced technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and Computer Vision in manufacturing. AR is one of the key tools for the ongoing digital transformation of industries (Wang et al., 2016). AR's most advanced feature is its ability to transfer real-time digital data through interfaces into a physical environment, where the user can simultaneously access both virtual and real information elements. This feature distinguishes AR from other technologies, such as Virtual Reality (VR), which uses a completely synthetic environment and thus separates users from the physical world. The ability to augment real-world data with contextual information and present it to the user in real time is particularly relevant in industrial processes where accuracy, real-time decision-making, and physical interaction are crucial, such as in the areas of assembly, maintenance, and quality control (Fuchs et al., 2011; Bimber & Raskar, 2005). The goal of this research is to explore how AR is applied in various industrial processes, evaluate its specific advantages over VR, and analyze the different methods of AR implementation. The purpose of this study is to analyze how augmented reality applications are developed to meet the specific requirements of industrial environments. It is also important to assess the opportunities and challenges that AR technologies offer when implementing and operating such systems to increase operational efficiency and employee safety. The subject of this study is the application of AR technologies in various industrial areas, including manufacturing, maintenance, training, and quality control. These areas are critical to the successful operation of the industry. AR

technologies offer solutions to several key challenges, such as reducing errors, increasing employee efficiency, and reducing downtime.

The study analyzes the problem of how to effectively apply augmented reality in the optimization of industrial processes. In particular, to eliminate certain technical limitations, such as latency, hardware limitations and the accuracy of the tracking task in dynamic environments (Zhou et al., 2008). The study also analyzes how AR technologies can be integrated into existing workplaces and applied in various industries, and examines the long-term sustainability of AR in industrial applications. In order to ensure the long-term viability of AR, it is necessary to address not only technical issues, but also issues of user training and ergonomics, and adaptation to new technologies. All aspects are very important for the successful integration of AR into industrial processes. (Azuma, 1997).

The research methodology will be based on a comprehensive literature review covering the research conducted on the application of AR in industrial environments, with a special focus on empirical data. After conducting an analysis of case studies from various industries, the research will highlight the main trends, advantages and challenges related to the integration of AR. This includes a study of the technological infrastructure used for AR implementation – for example, hardware, software and user interfaces, as well as the human factors influencing its implementation. A comparative analysis of AR and VR in industrial applications will also be carried out, highlighting the reasons why AR is often more suitable than VR in certain industrial contexts where interaction with physical objects is necessary (Fuchs et al., 2011).

By focusing on these key aspects, this study aims to contribute to the growing body of knowledge about the application of augmented reality in industry, providing insights into both its current use cases and future possibilities. Augmented reality is set to become an indispensable tool in future industrial operations, especially as industries increasingly integrate Industry 4.0 principles across industries and increase the level of automation, connectivity, and data-driven decision-making.

## 1. What is AR?

Augmented reality is a technological innovation that allows real-world environments and digital information to be combined in real time, offering a novel way to interact with both physical and virtual elements simultaneously (Schmalstieg, 2017). Unlike virtual reality, which creates a completely synthetic virtual environment and completely isolates the user from the everyday world and the tasks performed in it, AR only supplements the real world with digital content, transferring it to the physical world visible to the user. This integration allows for the creation of a composite view in which virtual objects coexist with objects in the physical environment and indirectly interact with each other. Thus, creating conditions for a more interactive and context-aware user experience (Bimber & Raskar, 2005).

In order to understand the respective applications of VR and AR, it is necessary to identify their fundamental differences. VR completely replaces the user's perceived physical environment with a completely virtual environment, which is suitable for use in simulations, games and training, which allow for complete immersion in an imagined virtual world. Meanwhile, AR only supplements the real environment, applying additional layers of information that users have access to, while remaining in their direct physical environment with real-world information. This capability is especially useful in industrial environments, where workers must work with real-world objects but also interact with digital components. For example, AR can project assembly instructions or diagrams directly onto devices, providing data in real time, without distracting the worker from performing physical tasks (Bimber & Raskar, 2005). AR systems are a combination of various technologies. Various sensors, cameras and GPS are used to identify and interpret the user's environment. Then, advanced algorithms process the sensor data to precisely align digital objects with real-world objects, a process called "registration" (Schmalstieg, 2017). The strong progress in computer vision and machine learning technologies in recent years has significantly improved the applicability of AR in industry and increased its accuracy, i.e., virtual content generated by AR more accurately overlays physical objects.

This allows the user to convey information more realistically and informatively, and responds more accurately to the context.



**Figure 1. Workers examining machinery with augmented reality glasses**

Source: <https://alegerglobal.com/en/augmented-reality/>

A key advantage of AR technology is the ability to provide users with contextual information in real time, without distracting them from their current tasks or stopping their work. This functionality is especially important in industrial areas, where AR can effectively provide visual instructions or data sets supplemented with relevant information while operators continue to operate machines or work with physical objects (Tatic, 2017). For example, AR can help technicians perform complex maintenance procedures, instructions, by displaying detailed steps directly on the machines, which reduces the need for external instructions or maintenance (Fuchs et al., 2011). This hands-free real-time feature is a key difference from other information presentation systems and increases the demand for AR in various sectors

In addition, AR supports dynamic, two-way interactions between users and their augmented environment. Users can manipulate virtual objects, interact with a digital interface, or receive feedback from the AR system. Therefore, AR is not only a visualization tool, but also a tool for real-time problem solving and decision-making. For example, in quality control processes, AR technology allows digital models to be overlaid on physical components so that inspectors can quickly detect defects or nonconformities, capture them, or urgently submit them for correction (Ong et al., 2008).

The contextual information provided by AR is a key difference that distinguishes it from VR. VR can successfully create immersive simulations for training or prototyping, but the technology used isolates users from the real-world context, as they are completely immersed in a virtual digital space. Unlike VR, AR extends tasks that require constant interaction with the physical world, and is therefore particularly relevant in manufacturing, logistics, and healthcare, where live contact with subjects is required (Ong et al., 2008; Ferrari, 2019). In manufacturing, AR can display various operational data, important parameters such as temperature or performance indicators, by projecting them directly onto machines and allowing workers to monitor the operation of systems or equipment without leaving their work places (Bimber & Raskar, 2005).

The development of AR has led to the emergence of Mixed Reality (MR), which combines elements of AR and VR to create more complex mechanisms for interacting with physical and virtual objects. MR allows users to experience digital content in three-dimensional space while maintaining a clear view of the real world. Despite these similarities with MR, AR remains unique in that it focuses on augmenting real-world environments with additional content, rather than creating entirely virtual spaces.

In summary, AR is a rapidly evolving technology that fundamentally changes the way users perceive and interact with their environment by seamlessly integrating digital information into the user's physical world. The functionality of providing contextual information in real time, exactly where and when it is needed, makes AR a valuable and useful tool in many industries. The potential of AR is further enhanced by its compatibility with new technologies such as artificial intelligence, the Internet of Things (IoT), and machine learning, which expands its scope of application. As AR

technology continues to develop, it is expected to play an increasingly important role in various fields, including industrial processes, healthcare, education, and entertainment (Wang et al., 2016).

## 2. In Which Areas is AR Used in Industrial Processes?

Augmented reality is widely used in various industrial processes and offers significant benefits in the areas of manufacturing, maintenance, quality control and training. In each of these areas, AR capabilities are used to increase the efficiency, accuracy and safety of industrial operations.



**Figure 2. AR Glass using in Industrial Process**

Source: <https://alegerglobal.com/en/augmented-reality/>

### Manufacturing

Augmented reality in manufacturing has become a valuable tool for increasing production efficiency and reducing defects and errors. By AR systems for the operator can be projected assembly instructions, schematics, and operational data directly onto machines or workstations in real time, allowing workers to perform tasks more accurately (Reljic, 2021). For example, AR can superimpose step-by-step assembly instructions onto complex objects, thereby reducing the likelihood of errors and speeding up the assembly process (Fuchs et al., 2011). In addition, AR can facilitate the training and integration of new workers into production lines by providing them with interactive, relevant instructions in real time as they perform tasks, thereby reducing learning time and increasing productivity (Wang et al., 2016).

### Maintenance

The application of AR technologies in technical maintenance is useful when additional information related to the problem being solved is needed and it must be provided at the workplace in real time during service or repair. Service or maintenance specialists can access digital technical maintenance manuals, service instructions, diagrams or diagnostic information using AR equipment. And this information is linked to the serviced equipment and presented (projected) directly on it (Ong et al., 2008). Using such an assistance tool during service allows for faster identification of problems, more efficient and faster troubleshooting of problems or failures. For example, using AR, it is possible to provide the service specialist with detailed maintenance procedures in real time, overlaid on relevant nodes. This makes it easier for technicians to perform complex repair work without the need to additionally use paper manuals or digital information sources, moving away from the process itself (Fuchs et al., 2011). Previous studies have shown that the use of augmented reality technologies in maintenance procedures can reduce downtime and improve the quality of work performed (Tang et al., 2003).

## Quality Control

In quality control, augmented reality allows you to speed up and improve the procedure itself, because this technology allows you to compare data from both the real world and the digital world in real time, which are obtained from models, digital twins, etc. AR systems project digital models, their information or reference images onto physical products. This allows inspectors to conveniently visually evaluate and compare real products with reference products or standards (Ong et al., 2008). The use of AR technologies in product inspection allows you to detect defects, non-conformities or deviations from quality standards faster and more effectively than is possible using traditional inspection methods. Using AR technology and overlaying digital information on products during the quality assessment process, defects or defects can be identified faster. Comparative content allows the inspector to identify problems more effectively and easily and make the necessary adjustments in the product manufacturing process (Bimber & Raskar, 2005).

## Training

The application of AR technologies in the training process has shown that by digitizing educational content and transferring it to real-world learning scenarios, learning becomes more engaging, interactive and attractive. This is a huge benefit in training of specialists, but also for involving the younger generation in this process. Research shows that training using AR technology can improve learning outcomes and help trainees better remember complex tasks and solution procedures. They are given the opportunity to understand and interact with the educational material more clearly and apply it in practice. This excellent method allows trainees to work with both digital and physical aspects of tasks. AR technology can present the trainees with digitized real-world scenarios and at the same time provide him with feedback on the problem being solved in real-time. This allows trainees to improve their skills in a controlled, yet realistic environment. (Zhou et al., 2008).

In summary, the application of augmented reality in industry and its processes offers many advantages that can increase operational efficiency, quality, and training effectiveness. By integrating digital contextual information into the physical environment, AR helps improve production processes, simplify maintenance, ensure strict quality control, and create an immersive training experience. As AR technology continues to develop, its role in industry is expected to only expand, further changing the way industries operate and employee training methods (Wang et al., 2016).

### 3. Why AR Instead of VR?

Augmented reality and virtual reality are immersive technologies, but they are quite different and designed for different purposes. In addition, depending on the area of application, they offer different advantages. VR creates a fully simulated - virtual environment, while AR supplements the real-world image with digital contextual information. Due to this fundamental difference, AR is particularly useful in certain industries where user interaction with objects in the physical world is particularly important (Arena, 2022)

#### Integration with the Physical Environment

In industry one of the main advantages of augmented reality over virtual reality is its ability to seamlessly integrate into the real physical world or real manufacturing process. AR enriches the real-world experience by directly projecting digital content, such as instructions, guides, diagrams, or operational data, onto physical objects or environments (Bimber & Raskar, 2005). This integration of different types of data allows users to simultaneously operate on both augmented digital information and information from physical objects. In this way, it facilitates tasks that require constant interaction

with the physical world. For example, in manufacturing, AR can overlay assembly instructions to machines, helping workers perform complex procedures without requiring them to leave their working places or use separate guides (Fuchs et al., 2011). Meanwhile, VR requires users to fully immerse themselves in a simulated virtual environment. This could limit their engagement in real-world tasks and lead to inefficiencies and security vulnerabilities (Arena, 2022).

### **Real-Time Contextual Information**

AR provides real-time contextual information that is directly related to the user's current environment and activities. This capability is often useful in maintenance and quality control processes, where AR technologies can be used to transfer diagnostic data, maintenance procedures, or quality standards onto real equipment or products under inspection (Ong et al., 2008). For example, technical personnel can use AR functionality to view detailed maintenance instructions or performance indicators for equipment that are projected onto the machines they are currently servicing. This helps them make informed decisions and perform repairs more efficiently and quickly. VR typically immerses users in a fully virtual environment that may be disconnected from real tasks or real equipment, and does not offer the same level of contextual relevance as augmented reality.

### **Usability and Accessibility**

Compared to VR, AR systems are generally more affordable and easier to implement in existing industrial environments. AR functionality can be implemented on more common devices such as smartphones, tablets, and smart glasses, which are often more convenient and cost-effective than the specialized VR equipment that this technology requires. These advantages make AR a simpler and more practical choice for many industrial applications. The technology can be integrated into existing workflows without major and fundamental changes to infrastructure or processes. In contrast to AR, VR usually requires the creation of special physical spaces and additional equipment to create an immersive environment. This can be expensive and difficult to implement in industry and can be more disruptive (Schmalstieg, 2017).

### **Safety and Efficiency**

In industries where safety and efficiency are paramount, the use of augmented reality offers obvious advantages, as it allows workers to remain immersed in real-world situations while interacting with additional digital information. AR provides workers with access to real-time data and instructions without distracting them from their tasks. This can help reduce accidental errors and improve overall safety. For example, AR can provide online instructions for complex procedures or hazardous tasks, allowing workers to remain focused on their tasks while receiving real-time assistance (Fuchs et al., 2011). VR, on the other hand, indirectly isolates the user from the physical environment and limits their perception of reality, which in turn increases safety risks and can reduce work efficiency (Stefan et al, 2023).

### **Enhanced Training**

AR has shown itself well in the areas of specialist training. Using this technology in the training process, it is possible to reveal or simulate situations that are as realistic or as close to the real world as possible, to create attractive, engaging and interactive training. This technology allows you to improve learning outcomes and knowledge acquisition, because in many cases, real working conditions and the environment are simulated during work (Azuma, 1997). And this in a way corresponds to real working conditions and situations, and trainees receive information better and faster and understand it. VR can also create realistic learning situations, but this technology still lacks

a connection with the real world and the objects in it. This partially limits its effectiveness and efficiency in training that requires a connection with physical objects.

A comparison of the key differences between augmented reality and virtual reality technologies is presented in the table. The focus is on applications in industrial environments.

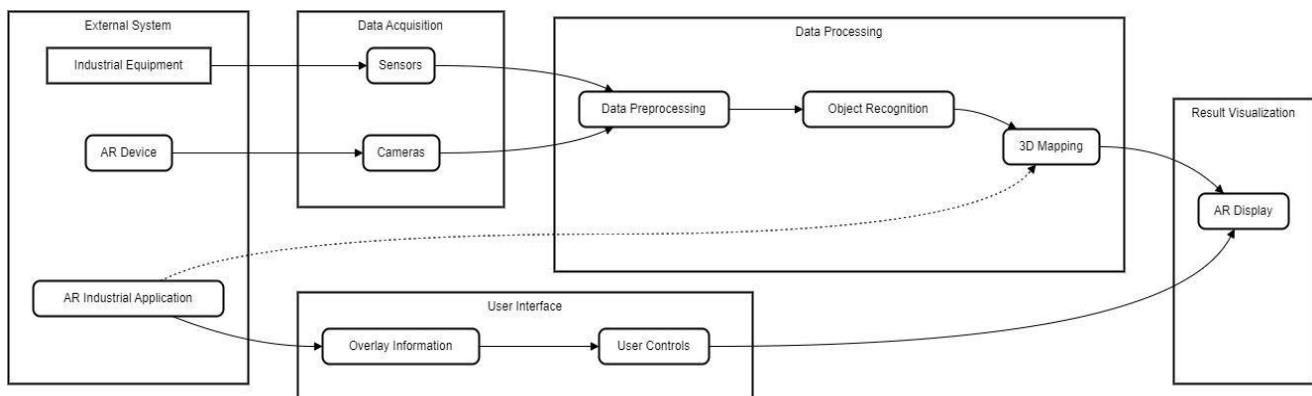
**Table 1. Differences between Augmented Reality (AR) and Virtual Reality (VR)** (Source: made by the authors)

Feature	Augmented Reality (AR)	Virtual Reality (VR)
Devices	Smart AR glasses, tablets, Projectors	Headsets, VR glasses
Common Industrial Uses	Maintenance, repair, quality control	Training, simulation
Immersion Level	Real-world overlay with digital	Fully immersive virtual world
Interaction with real world	Yes	No

In summary, while both AR and VR have unique applications, AR in industrial environments has more advantages, such as the ability to integrate with the physical world, provide contextual information in real time, and thus increase usability and safety. By combining digital content with the real-world environment, AR ensures more efficient and effective interaction with physical operations, making it an excellent choice for advanced industrial applications (Bimber & Raskar, 2005; Fuchs et al., 2011; Wang et al., 2016).

#### 4. Augmented Reality Usage Methods

Augmented reality is increasingly used in industry, which uses various technologies to convey information to the user and which have their own advantages and at the same time allow improving business processes. The most common AR methods used in industry are marker-based AR, projection-based AR and wearable AR devices. Each of these methods has its own advantages and even specific challenges. And it largely depends on the specific industrial application task.



**Figure 3. Diagram of an AR Industrial Application**

Source: made by the authors

#### Marker-Based Augmented Reality

Marker (Tag)-based augmented reality is one of the most popular AR applications in industry. This technology uses visually encoded markers or tags, such as QR codes, barcodes, or reference markers. Typically, AR systems recognize them in the environment, identify and assign digital content to a specific physical object. To recognize tags and markers, an AR system uses video cameras and image recognition software solutions. (Bimber & Raskar, 2005).

In industry, marker-based augmented reality is most often used in assembly, service or repair processes of equipment and machines, and production control, with the aim of facilitating and speeding up tasks. For example, markers can be attached to equipment or certain components and, when scanned, provide contextual information in real time. This can be various operational data, relevant parameters, or assembly and maintenance instructions. (Fuchs et al., 2011). This method has the advantage of allowing for precise alignment of digital content with physical objects, facilitating efficient workflow and reducing the likelihood of errors (Qeshmy, 2019), and does not require special conditions such as lighting quality.

### Projection-Based Augmented Reality

Projection-based AR uses projectors to project digital information directly onto physical surfaces. This technique creates an augmented environment in which virtual content is superimposed onto real-world objects, allowing users to interact with both real and virtual objects simultaneously (Bimber & Raskar, 2005). Projection-based AR is particularly useful in industrial environments, where visual information is superimposed on large surfaces or complex assemblies.

In practical applications, projection-based AR can be used to display interactive instructions or real-time data directly onto work surfaces or machines. This approach is particularly useful when multiple users are accessing the information at the same time, viewing and interacting with the same information. This is very effective in team-building or troubleshooting scenarios. When physical space is a limiting factor, projecting information onto large or complex geometric surfaces is an excellent choice and solution for implementing AR technologies.

### Wearable Devices

Wearable AR devices, such as smart glasses and AR headsets, offer a more immersive way to implement AR. These types of devices allow digital information to be integrated directly into the user's field of vision, allowing hands-free interaction with both digital and physical elements (Arena, 2022). Wearable devices are equipped with sensors, cameras, and displays that ensure a seamless transition from digital content to the real world.



**Figure 4. Examples of the wearable devices: Microsoft HoloLens, Epson Moverio, Meta2**

Sources: <https://learn.microsoft.com/tr-tr/hololens/hololens1-hardware>; [Epson Moverio BT-45CS Smart Glasses - Brochesia](#)

In industrial environments, when performing tasks that require constant interaction with physical objects, wearable AR devices show much more positive potential in such cases. For example, maintenance technicians can use smart glasses to obtain additional information in real-time through access to repair instructions, various diagnostic data, or visual equipment information, while having their hands free to perform maintenance (Ong et al., 2008). The hands-free capability of wearable devices improves situational awareness and operational efficiency by providing real-time, contextual information without distracting attention from the task at hand (Reljic, 2021).

---

## Comparative Analysis

Each method of AR has its own advantages and disadvantages or limitations. Marker-based AR is very simple and easy to implement, does not require specific environmental conditions, accurately matches digital content, but requires additional detectable markers. Projection-based AR is great for environments that require large-scale visualizations, but is usually limited by the physical space required for projection. Wearable augmented reality devices offer more useful features and also allow hands-free use. However, they also have certain limitations, such as ease of use and transportation or limited field of view (Syed, 2023).

In summary, the choice of AR method depends on the specific requirements of the industrial application, including the space requirements, the type of interaction, and the user's mobility needs. Each method - marker-based, projection-based, or wearable - has its own unique characteristics and advantages that can be exploited to increase efficiency and productivity in industrial environments.

## 5. Augmented Reality Application Development

Developing industrial augmented reality applications is a complex process. This process involves evaluating the User Experience (UX), the complexity and specifics of the hardware implementation process, as well as the software development process (Dunleavy & Dede, 2014). The assessment of each of these parts allows to optimize the workflow, reduce costs, but at the same time expand the functionality and application areas of AR systems.

### Hardware Integration

The critical success of AR application development depends on how the hardware is properly selected and how it is integrated into the overall system. Depending on the features and requirements of a specific industrial field of application, which methods of interaction the user will use, how visual information will be presented to the user, finally, in what environmental conditions the AR system must function, AR devices are selected accordingly: whether it is AR smart glasses, or smartphones, or tablet computers or projectors. (Arena, 2022).

- **AR Smart Glasses:** Globally recognized devices such as Microsoft HoloLens, Google Glass and Meta2 AR allow the user to combine information from the real visible world with digital content and control it hands-free. These technical solutions make their way in those areas of human activity where constant contact or interaction with physical objects is necessary and additional digitized information is required (Reljic, 2021). An important aspect, this type of devices must be ergonomic and must be comfortable during long-term use (Pierdicca, 2017). It should also be compatible with AR software and have a screen quality optimization feature.
- **Smartphones and Tablets:** It is a fairly versatile and easily accessible part of the AR platform for users. In this type of device, the information of physical devices received through the built-in camera and other sensors can be combined/supplemented with digital content and presented to the user for use (Tomioka, 2013). These devices are mostly used for lower cost AR solutions, as well as where user mobility is required and additional staff training is not required due to previous experience using them. In many cases, the integration of this type of devices into the system requires additional calibration of cameras and optimization of sensor accuracy.
- **Projectors:** In projection augmented reality systems, digital information (in the form of virtual objects) is projected directly onto the working surfaces of real objects, usually in a stationary environment, using projectors. This approach is applicable in cases where large-scale visualizations are required in a large collaborative work environment (Liu, 2024). Integration into an AR system includes matching projectors to physical surfaces, the need to ensure sufficient accurate brightness and color reproduction, and consideration of environmental factors such as ambient lighting conditions (Bimber & Raskar, 2005).

## User Experience Design

User experience design is an extremely important part of the AR development phase to ensure that AR applications are efficient, productive, and informative and intuitive. There are several key aspects to consider when designing user experience for AR applications:

- **Interaction Design:** During design, special attention should be paid to how users will interact with the AR application. This must combine the creation of intuitive voice commands, gesture controls and interface elements that are used to seamlessly interact with digital content (Shen, 2010). For example, in a maintenance application, users/technicians can use hand gestures to control virtual layers to move from one level to another, or give voice commands to access different groups of instructions (Fuchs et al., 2011).
- **Contextual Relevance:** In order to ensure that the system works effectively, it is necessary that the digital information additionally provided through augmented reality is relevant and practically applicable. When creating user experience, it is necessary to evaluate how to present information so that it immediately meets the needs and importance of the user and does not distract the user's attention and does not overload him with excessive useless information (Syed, 2023). For example, real-time data headers displayed on machines should be short and clear and directly related to the task at hand (Ong et al., 2008).
- **Usability Testing:** Extensive software and user interface usability testing with real users and in the intended industrial environment is required. These tests help identify potential usability problems, optimize interface design, and ensure that the application meets users' needs and expectations (Hollerer & Feiner, 2004). User feedback can help you continuously improve the design and increase the overall effectiveness and functionality of the app.

## Software Development

When developing AR software, its development stages need to assess its functionality, i.e., the creation of useful and necessary functions for the user, as well as integration with hardware and compatibility with industrial processes for which the AR application is being developed. The essential phases of software development are:

- **Software Design:** AR software implementation must seamlessly integrate with the hardware used, process information received from sensors in real time, and generate relevant digital content for the user (Arena, 2022). To ensure the smooth application of augmented reality in industrial process systems, such software must process various types of data received from cameras, sensors, and other user interfaces.
- **Algorithm Development:** When developing augmented reality applications and developing their functionality, it is necessary to create algorithms that would allow and ensure the most accurate and reliable recognition of objects, their tracking, and spatial planning. The algorithms being developed must ensure that the digital content being created must correspond to physical objects as accurately as possible, the generated digital information must be aligned with the information of the object itself. It must also be dynamic and adaptive to the changing surrounding environment or user actions. (Syed, 2023).
- **Integration and Testing:** In order for the system to operate reliably and properly, and have the desired functionality, it is a prerequisite that the software together with the integrated hardware must be tested only under real operating conditions. This stage analyzes how the AR system operates reliably and how it behaves when operating conditions, lighting, user movements, etc. change. Comprehensive testing allows you to identify, evaluate and avoid possible technical problems before implementing the AR system in a real process with its specific conditions.
- **Maintenance and Updates:** For elimination problems that arise after the system is installed in the industry, there is another very important stage, which is the constant updating and

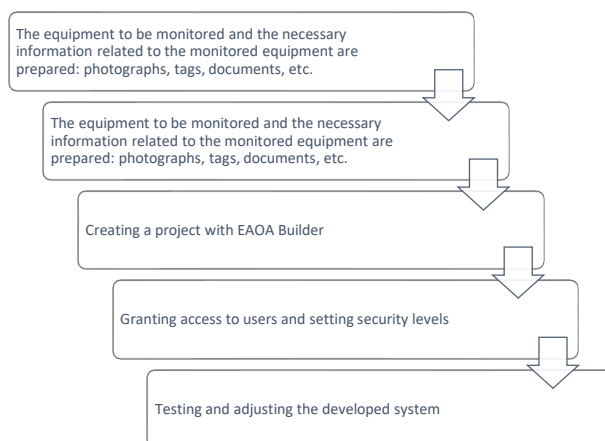
maintenance of the system. This stage takes into account user feedback on the work of the operating system and the satisfaction of their needs. Also, this stage involves adapting the system to specific working conditions and at the same time adapting it to new changing needs of the industry. Regular system updates allow you to improve its functioning, expand functionality, and ensure reliable and uninterrupted work with both hardware and software. (Ong et al., 2008).

In summary, it can be stated that when developing AR for industrial use, this task should be viewed holistically. It is not only the selection of the right hardware that is very important here, the user experience must also be reflected in the user interface being created. By evaluating these areas, developers can make AR solutions that help manage and control complex industrial processes, increase their productivity, improve production accuracy or quality.

## 6. Application Development with ECOSTRUXURE *AUGMENTED OPERATOR ADVISOR*

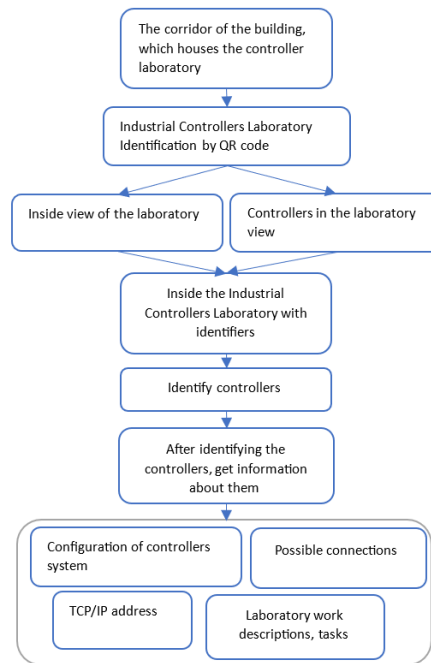
The augmented reality project was developed using Schneider Electric's companies' industrial software EcoStruxure Augmented Operator Advisor (EAOA) and used in the Industrial controller's laboratory.

The development of the application consists of five main stages: setting the work objective, collecting and preparing the equipment and information for use, developing the project on the EcoStruxure Augmented Operator Advisor Builder website, and testing and adjusting the operation of the developed system.



**Figure 5. Application development algorithm**

The EAOA software package application was developed and applied in the Industrial Controllers Laboratory. The purpose of this application is to obtain interactive information about the equipment in the laboratories.



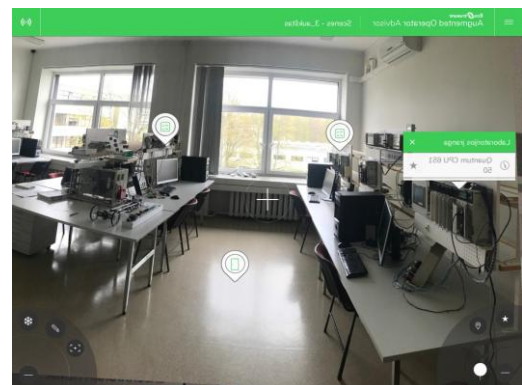
**Figure 6. Schematic diagram of the proposed object identification task**

Thanks to this software, a person who visits the laboratory for the first time has the opportunity to get acquainted with the equipment in the laboratory without even entering the laboratory; students who perform laboratory work with the controllers located here can start work even when the lector is not present, since all the necessary information (laboratory work description, controller configuration, TCP/IP address) is provided and accessible by pointing a tablet, phone or VR glasses to the designated laboratory work location.

A QR code was used to identify the premises. After recognizing the QR code, EAOA identifies the object and allows entry into the premises and obtain information about the equipment present. A visual object recognition method was used to identify the equipment.

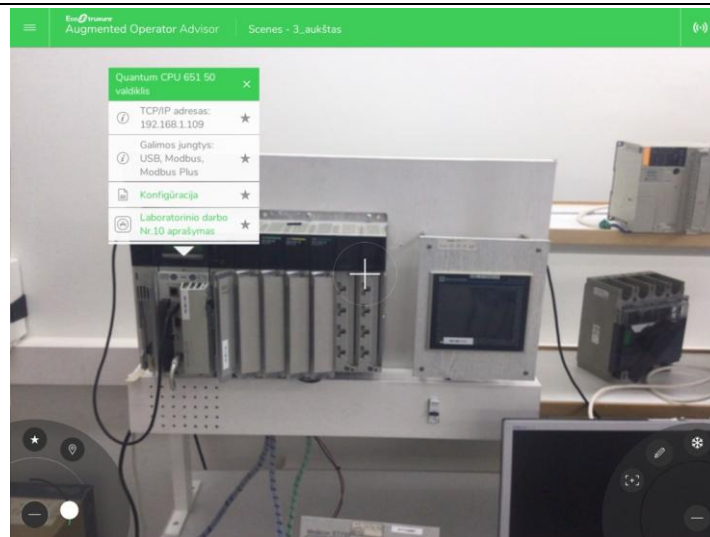


**Figure 7. Example of tags used to facilitate object recognition**



**Figure 8. EAOA operator screen image when lab tag is recognized**

When equipment in the laboratory with tablet, phone or Epson Moverio augmented reality glasses are recognized using EcoStruxure Augmented Operator Advisor software, the operator screen image is augmented with information related to the recognized equipment, which can be used in further operations.



**Figure 9. Image on the operator's screen after recognizing the controller in the laboratory**

An example was given here of the AR application of the industrial equipment EcoStruxure Augmented Operator Advisor, which is designed for use in industry but can also be adapted for use in educational and scientific institutions.

## Conclusions

1. **Augmented Reality as a Transformative Technology:** AR has become a transformative technology that seamlessly integrates digital information to enrich the user's interaction with the physical world. Unlike virtual reality (VR), which immerses users in a completely synthetic-simulated environment, AR only supplements the real world with digital content. This is especially important in industries where interaction with physical and virtual elements is very important.
2. **Industrial Applications of AR:** The application of AR in industrial processes, including manufacturing, maintenance, quality control and training, demonstrates its versatility and importance. AR increases the efficiency of operations by adding contextual information in real time to the user's immediate field of vision through additional information visualization equipment. This capability is very useful in equipment assembly, real-time diagnostics, defect detection and operator training, especially when training new employees, thereby increasing productivity and reducing errors.
3. **Comparison with VR:** Unlike VR, which creates a completely virtual environment and isolates users from their physical surroundings, AR supplements the real world with additional digital layers/data, but does not distract from physical processes that require constant interaction with real physical objects. This is an important and obvious advantage of AR over VR in industrial environments.
4. **AR Usage Methods:** Industry uses various techniques and methodologies to augment the real-world manufacturing process with digital content through AR. The most widely used and developed are: marker(tag)-based AR, projection-based AR and wearable devices, each with unique advantages and selected based on specific application requirements. Marker-based AR typically uses visual tags/markers such as QR codes to activate digital content, while projection-based AR projects information onto physical surfaces by recognizing them from the image. Wearable devices such as phones, tablets or AR glasses enable the use of digital content, but require careful integration with hardware and software to ensure efficient operation and ease of use.
5. **Development of AR Applications:** Developing AR applications and implementing them in industry is a responsible and complex process. The main stages of this process are hardware integration, user environment design and software development. The most important

requirements for implementing AR in industry are its reliability, convenient and user-friendly use, and most importantly, that the system is functional and effective in performing the intended tasks in industry. And this is usually achieved through the appropriate selection of hardware and its compatibility, through the creation of a user interface that must be easy for the user to understand and informative. And of course, another important factor is that the projected additional digital information, which is projected onto real objects, must be precisely positioned and have interaction with the user.

It can be concluded that the integration of augmented reality into real industrial processes gives them more informativeness, flexibility and other positive features, such as employee safety. Having previously reviewed the aspects of the use of AR, it can be concluded that this technology has a promising future in industry and can be successfully used. Especially in those areas where complex processes take place, there is a high turnover of employees and assistance is needed in training new specialists or retraining existing ones and the general aim is to increase operational efficiency.

## Reference list

1. Arena, F., Collotta, M., Pau, G., Termine, F. (2022), An Overview of Augmented Reality. *Computers* 2022, 11(2), 28; <https://doi.org/10.3390/computers11020028>
2. Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators & Virtual Environments*, 6(4), 355-385. <https://doi.org/10.1162/pres.1997.6.4.355>
3. Bimber, O., Raskar, R. (2005). *Spatial augmented reality: Merging real and virtual worlds*. Springer. <https://doi.org/10.1007/978-1-4419-0358-8>
4. Dunleavy, M., Dede, C. (2014) Augmented Reality Teaching and Learning. Handbook of Research on Educational Communications and Technology. Springer. 2014, DOI 10.1007/978-1-4614-3185-5\_59, p.735-745
5. Ferrari, V., Klinker, G., Cutolo, F. (2019), Augmented Reality in Healthcare, *Journal of Healthcare Engineering* 2019:1-2, <https://doi.org/10.1155/2019/9321535>
6. Fuchs, H., Zurita, S., Wöhrmann, C. (2011). Augmented reality for industrial applications. *Journal of Engineering Research & Studies*, 2(4), 65-73. <https://www.researchgate.net/publication/265453546>
7. Hernandez, M., Reyes, G. (2021). Augmented Reality as an Innovative and Efficient Technology to Increase Quality in Manufacturing Processes. Springer. pp 95–118. DOI:10.1007/978-3-030-69314-5\_5
8. Hollerer, T., Feiner, S. (2004). Mobile augmented reality. In *Handbook of Augmented Reality* (pp. 1-42). Springer. [https://doi.org/10.1007/978-1-4614-0064-6\\_1](https://doi.org/10.1007/978-1-4614-0064-6_1)
9. Liu, H., Zhao, L., Peng, Z., Xie, W., Jiang, M., Zha, H., Bao, H., Zhang, G. (2024). A Low-Cost and Scalable Framework to Build Large-Scale Localization Benchmark for Augmented Reality, in *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 34, no. 4, pp. 2274-2288, April 2024, doi: 10.1109/TCSVT.2023.3306160.
10. Ong, S. K., Nee, A. Y. C. (2008). Virtual and augmented reality applications in manufacturing. *International Journal of Virtual and Augmented Reality*, 3(2), 78-89. <https://doi.org/10.1007/s11554-007-0015-3>
11. Pierdicca, R., Frontoni, E., Pollini, R., Trani, M., Verdini, L. (2017). The Use of Augmented Reality Glasses for the Application in Industry 4.0. In: De Paolis, L., Bourdot, P., Mongelli, A. (eds) *Augmented Reality, Virtual Reality, and Computer Graphics. AVR 2017. Lecture Notes in Computer Science()*, vol 10324. Springer, Cham. [https://doi.org/10.1007/978-3-319-60922-5\\_30](https://doi.org/10.1007/978-3-319-60922-5_30)
12. Qeshmy, D., Makdisi, J., Ribeiro da Silva, E., Angelis, J. (2019), Managing Human Errors: Augmented Reality systems as a tool in the quality journey, *Procedia Manufacturing*, Volume 28, Pages 24-30, <https://doi.org/10.1016/j.promfg.2018.12.005>.
13. Reljić, V., Milenković, I., Dudić, S., Šulc, J., Bajčić, B. Augmented Reality Applications in Industry 4.0 Environment. *Appl. Sci.* 2021, 11, 5592. <https://doi.org/10.3390/app11125592>
14. Schmalstieg, D., Höllerer, T. (2017), *Augmented Reality: Principles and Practice*. IEEE, DOI: [10.1109/VR.2017.7892358](https://doi.org/10.1109/VR.2017.7892358)
15. Shen, Y., Ong S. K., Nee A. Y. C. (2010). Augmented reality for collaborative product design and development, *Design Studies*, Volume 31, Issue 2, 2010, Pages 118-145, <https://doi.org/10.1016/j.destud.2009.11.001>.

16. Stefan, H., Mortimer, M., Horan, B. (2023) Evaluating the effectiveness of virtual reality for safety-relevant training: a systematic review. *Virtual Reality* 27, 2839–2869. <https://doi.org/10.1007/s10055-023-00843-7>
17. Syed, T. A., Siddiqui, M. S., Abdullah, H. B., Jan, S., Namoun, A., Alzahrani, A., Nadeem, A., & Alkhodre, A. B. (2023). In-Depth Review of Augmented Reality: Tracking Technologies, Development Tools, AR Displays, Collaborative AR, and Security Concerns. *Sensors*, 23(1), 146. <https://doi.org/10.3390/s23010146>
18. Tang, A., Lo, M. (2003). Augmented reality for industrial applications. *Industrial Technology Journal*, 8(2), 41-50. <https://doi.org/10.1016/j.indtech.2003.07.002>
19. Tatić, D., Tešić, B. (2017) The application of augmented reality technologies for the improvement of occupational safety in an industrial environment, *Computers in Industry*, Volume 85, 2017, Pages 1-10, <https://doi.org/10.1016/j.compind.2016.11.004>.
20. Tomioka, M., Ikeda, S., Sato, K. (2013), Approximated user-perspective rendering in tablet-based augmented reality. [2013 IEEE International Symposium on Mixed and Augmented Reality \(ISMAR\)](https://doi.org/10.1109/ISMAR.2013.6671760), DOI: [10.1109/ISMAR.2013.6671760](https://doi.org/10.1109/ISMAR.2013.6671760).
21. Wang, X., Xu, Z., Liu, H. (2016). The integration of augmented reality with machine learning and the Internet of Things. *Journal of Advanced Computing*, 4(3), 225-245. <https://doi.org/10.1016/j.jac.2016.02.005>
22. Zhou F., Duh H.B.L, Billingham M. (2008). Trends in Augmented Reality Tracking, Interaction and Display: A Review of Ten Years of ISMAR. [2008 IEEE/ACM International Symposium on Mixed and Augmented Reality \(ISMAR\)](https://doi.org/10.1109/ISMAR.2008.4637362), DOI: [10.1109/ISMAR.2008.4637362](https://doi.org/10.1109/ISMAR.2008.4637362)

## PAPILDYTOSIOS REALYBĖS NAUDOJIMAS PRAMONĖS PROCESUOSE

**Ali Emre Topbaş<sup>1</sup>, Gintaras Dervinis<sup>2</sup>**

<sup>1</sup>*KTO Karatay Universitاس, Akabe, Alaaddin Kap Cd. No:130, 42020 Karatay/Konya, Turkija*

<sup>2</sup>*Utenos kolegija, Maironio g. 18, Utena, Lietuva*

### Santrauka

Šiame straipsnyje atlikus išsamią mokslinės literatūros apžvalgą ir sintezę įgyvendinami pagrindiniai tyrimo tikslai – išanalizuoti ir parodyti pridėtinės realybės taikymo pramonėje ypatumus; sritis, kuriose pasiteisina jos integravimas; palyginti su panašiomis technologijomis, kaip virtuali realybė, parodyti jos pranašumus ir pademonstruoti AR galimybes realia aplikacija, naudojant pramoninę pridėtinės realybės sistemą EcoStruxure Operator Advisor, valdiklių laboratorijos vizualizavimui. Straipsnyje pateikiami papildytos realybės (AR) kūrimo principai, pritaikymai ir pranašumai pramoninėje aplinkoje. Pabrėžiamas skirtumas tarp AR ir susijusių technologijų, tokių kaip virtuali realybė (VR), pabrėžiant unikalų AR gebėjimą perdengti skaitmeninę informaciją fiziniame pasaulyje, palengvinant sąveiką realiuoju laiku nepašalinant vartotojo iš aplinkos. Straipsnyje toliau nagrinėjami pagrindiniai AR pramoniniai pritaikymai, įskaitant gamybą, techninę priežiūrą, kokybės kontrolę ir darbuotojų mokymą, ir parodoma, kaip AR padidina veiklos efektyvumą pateikdama kontekstinę informaciją ten, kur jos labiausiai reikia.

Metodai, naudojami AR diegti pramoninėse aplinkose, pvz., žymekliais pagrįsta AR, projekcijomis pagrįsta AR ir nešiojami įrenginiai, yra išsamiai aptariami, parodytant technologinę pažangą, skatinančią AR integraciją į sudėtingus pramoninius procesus. Be to, straipsnyje aprašomi žingsniai, susiję su AR taikomųjų programų kūrimu pramoniniais tikslais, nuo aparatinės įrangos integravimo iki programinės įrangos kūrimo ir vartotojo patirties kūrimo.

Lyginant AR su VR, straipsnyje pabrėžiamas puikus AR tinkamumas užduotims, kurioms reikia sąveikos su fiziniais ir skaitmeniniais elementais, todėl jis idealiai tinka praktiniam pramoniniam darbui. Išvadose atkreipiamas dėmesys į didėjančią AR svarbą didinant veiklos tikslumą, mažinant žmogiškąsias klaidas ir gerinant darbuotojų veiklą. AR technologijai toliau tobulėjant, tikimasi, kad jos taikymas pramoninėse aplinkose plėsis ir suteiks didelių pranašumų įvairiuose sektoriuose.

Straipsnyje naudoti mokslinės literatūros šaltinių analizė, bei praktinis eksperimentas, kurio metu sukurta valdiklių laboratorijos pridėtinės realybės aplikacija EcoStruxure Operator Advisor bazėje.

**Raktiniai žodžiai:** Papildyta realybė, virtuali realybė, gamybinių procesų automatizavimas, Pramonė 4.0