Review

Augmented Reality Applications in Industry 4.0 Environment

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Abstract: New technologies, such as cloud computing, the Internet of Things, wireless communications, etc., have already become part of our daily lives. This paper provides an insight into one of the new technologies, i.e., augmented reality (AR), as part of the manufacturing paradigm Industry 4.0 (I4.0). The aim of this paper is to contribute to the current state in the field of AR by assessing the main areas of the application of AR, the used devices and the tracking methods in support of the digitalization of the industry. Searches via Science Direct, Google Scholar and the Internet in general have resulted in the collection of a large number of papers. The examined works are classified according to several criteria and the most important data resulting from them are presented here. A comprehensive analysis of the literature has indicated the main areas of application of AR in I4.0 and, among these, those that stand out are maintenance, assembly and human robot collaboration. Finally, a roadmap for the application of AR in companies is proposed and the most promising future areas of research are listed.

Keywords: augmented reality; industry 4.0; manufacturing; environment; industrial digitization

1. Introduction

The Industry 4.0 (I4.0) concept transforms the current industrial environment through the digitization of production, automation and the integration of the production site into a comprehensive supply chain. This concept consists of full network integration and real-time information exchange [1]. The latest technologies, such as the Internet of Things (IoT), cloud manufacturing (CMFg), Big Data, augmented reality (AR), etc., are used in combination with concepts and techniques of traditional industrial production [2]. These technologies enable the establishment of smart factories, all with the aim of optimizing production processes by minimizing production costs, maximizing product quality and providing agile response to rapid changes in the global market [3,4]. In order to achieve this operational state, it is inevitable that current production processes must be redesigned, transformed and improved by introducing new technologies, devices and techniques [5]. The new industrial environment provides the backbone for the development of smart, flexible and configurable processes [6,7].

One of the most significant transformation can be observed in the work environment, specifically during human machine collaboration where the physical and virtual worlds merge [8]. Virtual animations and simulations of products and processes, as well as visualizations of raw and computational information, are just some of the key aspects necessary to achieve a Cyber Physical System (CPS) [9]. Adopting visual computing by using AR combined with the availability of appropriate data can improve vertical integration within the factory [10]. AR represents a new form of worker support and also a crucial link between humans and the I4.0 environment as a method of human machine collaboration [11,12]. Equipped with appropriate technological support, AR is able to transform present day workers into the smart workers/operators of the future. These smart workers are becoming one of the key elements of the I4.0 environment as

strategic decision makers and flexible problem-solving operators [13,14]. In that case, AR represents a key link between the factory's web database and smart workers by presenting the right information in the right place [15]. The challenge is to develop AR applications that can lead to shorter production times, cost reductions and quality improvements [16]. Process control using AR can be based on BCI (Brain Computer Interfaces) technology. BCI technology enables direct contact between the brain and an external device and, based on the generated signals, it is possible to control the process and influence various objects in space, including, for example, the movement of a mobile robot in different manners [17].

AR applications show the potential to assist in solving problems such as limited availability of information to workers, insufficient training of workers, the gap between practical application and planned solution and poor communication between actors in an industrial environment [18]. Moreover, AR can potentially simplify a worker's tasks and optimize their decisions by introducing real-time virtual information into their environment. Regardless of the level of digitalization and automation in the industrial environment, they will continue to be key decision makers in the foreseeable future.

AR can also play a significant role in improving occupational safety conditions in industrial environments, as workers' injuries are mainly associated with inadequate training, insufficient work experience and monotony at work [19]. AR can also be useful in areas of the product life cycle outside the design and production phases. In particular, it provides marketing opportunities by transforming the customer experience in pre-sales [20]. AR can also improve the after-sales experience by providing the user with AR manuals, repair instructions or communication from after-sales sales professionals, etc. Furthermore, the widespread use of AR in educational environments [21–24] prepares users for future use in industrial environments.

This paper focuses on the use of AR in industrial applications and its significance and impact on I4.0. This study is organized as follows: Section 2 explores the basic concept of I4.0 and provides a brief overview of AR, a type of digital reality that has been evolving rapidly in the last decade. Section 3 describes the adopted research methodology. Section 4 provides an overview of the most important results obtained during this extensive research. Section 5 suggests steps for companies on their path to implementing AR and focuses on several different areas for future research and development. The paper ends with Section 6 which presents some concluding remarks.

2. Related Work

The term industrial revolution represents a concept that essentially changes our society and economy [25]. The fourth industrial revolution (I4.0) envisages the implementation of production systems based on the use of techniques that connect virtual and real worlds and completely transforms the entire industrial environment [26]. In such conditions, smart factories are systems in which information processing systems monitor physical processes, creates a virtual copy of the physical world and executes decentralized decisions based on self-organization mechanisms [27]. Each entity from the physical world has its digital twin in the digital world and so the entire production system can be simulated. These systems are characterized by context awareness, which allows people and machines to perform their tasks in an optimal manner [12].

AR is a rapidly evolving technology for creating a digital reality in which the user's physical environment is complemented with additional digital content, such as text messages, images, 3D virtual objects, videos, etc., in the user's field of vision [28–30]. In some cases, the sensation can also be experienced by touch, hearing and smell [31]. AR applications have already been developed for various social and business sectors such as education [32], tourism [33] and medicine [34]. Unlike virtual reality, augmented reality keeps the user in the real world and provides additional visual information.

This technology is already used in many industrial environments to help address product lifecycle challenges, including planning, design, ergonomics assessment, maintenance, management and training [35]. In addition, the application of AR technology

significantly contributes to increasing flexibility and productivity, avoiding recurrence of errors, increasing the health and safety of workers and thus facilitating the optimization of production processes [36].

A typical AR application consists of three layers, as shown in Figure 1 [37]. The lower layer represents the real and material world. In the middle layer, digital information that is relevant and useful is added to the real world. Combining these two layers creates a third augmented world in which users are given access to digital content. AR applications combine real and virtual objects and provide real-time interaction between users and the augmented world and the geometric alignment of virtual and real objects [38].
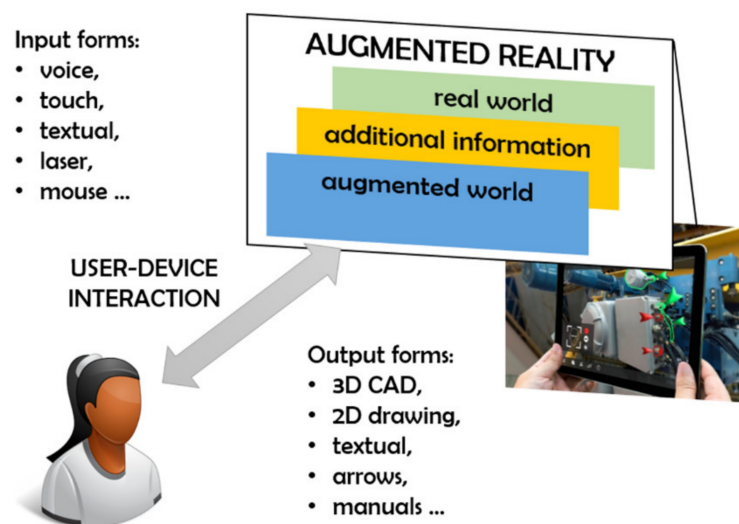

Figure 1. Interaction between user and AR device [37].

During the design and implementation of AR applications, developers must pay attention to the following [39]:

- Provide the user with all the necessary information, but keep it as simple as possible;
- Place the information in the right position;
- Do not restrict the user in performing his tasks;
- Equip the environment, not the user;
- Strive for intuitive natural interaction;
- Design for personalized feedback;
- Enable users to control speed;
- Add motivating quantified-self information.

One of the most important things, not only in the field of AR but in any human machine collaboration, is the interaction between users and the devices [39]. It must be easy and simple, otherwise the users will not be able to perform their tasks on time and the number of errors can also increase. The role of the device is not to slow down the user, but to help him/her complete the task.

AR can be experienced by using wearable and non-wearable devices [40] depending on whether the performer needs more flexibility and a free hand. Some of the smart glasses available come with touch-sensitive fields on the side and so users can communicate that manner. Furthermore, voice control in this case can be very useful because it helps free the user's hands to be completely while performing the task. A new method of hand tracking is presented in [41] where the interaction with a virtual AR object is realized manually. In the case of tablets, smartphones and touch screens and other smart devices, users find it easier to get used to the device and the AR application because people in the present days are familiar with smart devices. For a projector or AR with a computer, the best solution is to introduce a mouse or keyboard.

Depending on the type of AR application being developed, the user can be shown additional online information that enriches the real world and allows the company's employees to work more efficiently. Information may consist in giving step-by-step instructions; displaying customized user instructions; marking places to download parts; displaying text descriptions; navigating users through the warehouse; displaying assembly steps with 3D virtual objects; displaying the final assembly; giving audio instructions; displaying messages if an error occurs or warnings if the user performs incorrect actions; providing sensor values, machine or tool data, etc. Moreover, the ability of users to enter data into the system can be valuable. For example, it can be useful in diagnostic procedures or maintenance tasks. Designers and engineers can work on joint projects from almost any location around the world and execute changes to product components or processes in real time while simultaneously rendering the changes visible to all members of the team. In the case of difficulties with the installation or repair of the machine, additional information can be obtained via AR devices in real time or other independent experts and colleagues can join in [40]. When the task is completed, it can be automatically verified or in some cases notes can be entered that become visible to all users on different devices.

3. Methodology

The space in which AR applications are developed has exploded in recent years. The same situation is observed with respect to AR applications that facilitate the application of I4.0 concepts in an industrial environment. The great variety of applications not only renders it difficult but also requires a lot of time to find the best solution when choosing and applying the application in an industrial environment. In order to address this issue, this article provides an overview:

1. Areas in which most of the work have been conducted so far;
2. Devices in which most of the tests in the field of AR have been conducted so far;
3. Implemented tracking methods;
4. Roadmap for implementation of AR in companies;
5. An overview of future research areas that might be of interest for experimentation.

The presented results and identified advantages and disadvantages should serve as assistance and encourage companies to start the development and implementation of solutions in this area, as well as to overcome teething troubles in the application of AR in their business. The research methodology adopted in this paper is based on three consecutive steps (Figure 2).
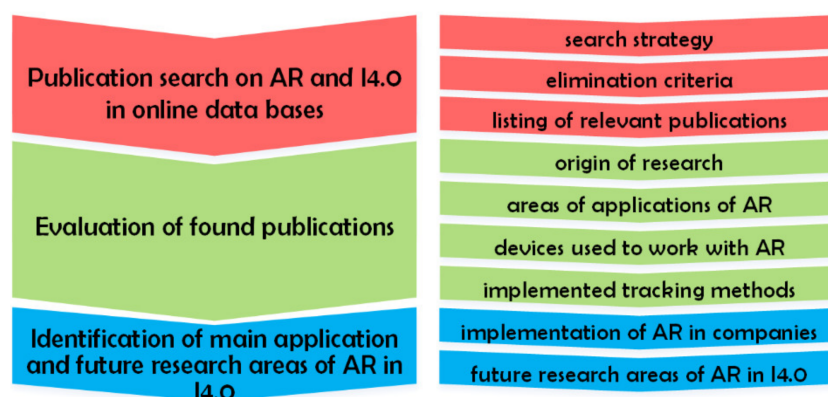

Figure 2. Research methodology.

The first step involves a comprehensive search of publications. The research was conducted in the field of AR applications and their implementation in industrial environments presents the current trends in this field of technology. The terms "augmented reality", "AR", "Industry 4.0" and "I4.0 sequences" are searched on Google Scholar, Science Direct and the web in general. These terms are searched in the title, keywords or abstract. Only

papers written in English describing specific AR applications developed and applied in an industrial environment are included regardless of the year of publication. Review articles, irrelevant studies (on the research question), non-academic publications (commercial literature and posters with reports) and duplicate studies are excluded.

This was followed by an evaluation of the publications found. A detailed analysis of the publications was performed according to different criteria in order to gain insight into AR applications that support the application of I4.0 concepts in industrial environments. This step provides an overview of current trends, advantages and limitations of existing AR applications in industrial environments. Finally, the process of implementing AR applications in companies is presented in the third step and possible future research areas in the development of AR applications that can further facilitate and improve the usability and adoption of I4.0 concepts in industrial environments are also identified.

4. Results

During the first step of the research, publications on AR and I4.0 in online databases were searched. A large number of papers have been collected and categorized and the most important data from them are presented later in this manuscript.

A total of 201 manuscripts were collected, which contain the searched strings in their titles, keywords or abstracts. The collected papers are divided into four groups (Figure 3):

1. There are 19 papers referring to the application of AR in educational processes;
2. Out of the total number of manuscripts, 115 are related to the implementation of AR in I4.0 applications;
3. Out of the total number of manuscripts, 45 describes AR in general or user guidelines for implementing AR solutions in companies;
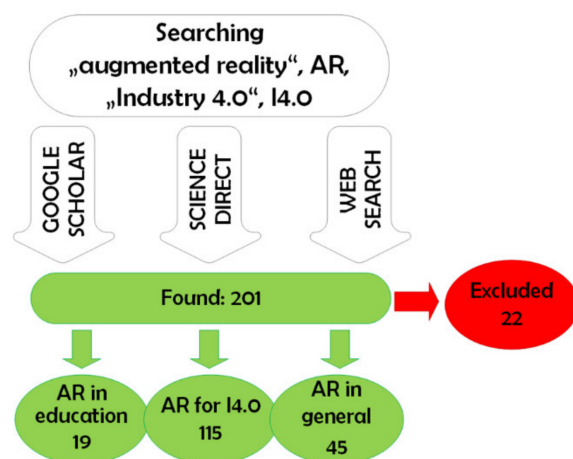4. The remaining 22 papers are excluded due to irrelevance.

Figure 3. Search results for AR and I4.0 publications in online databases.

For further analysis within this paper, only a group of papers describing the implementation of AR applications in an industrial environment is relevant (AR for I4.0). This group of relevant publications was analyzed based on the following criteria:

1. Origin of the studies;
2. Areas of applications in which AR have been applied or tested;
3. Types of devices used to work with developed AR applications;
4. Tracking methods implemented in the AR applications.

4.1. Origin of Research

Industrial applications of AR are a well-discussed topic around the world. Comparing the affiliations of the researchers listed in the relevant publications, 60% of the publications come from Europe. Almost 19% of papers come from Asian institutions, 12% from North

America, 5% from Oceania and about 3% of published papers come from South and Central America, while only about 1% come from the African continent. Since the concept of I4.0 originates from Europe, i.e., Germany and this term is used more in the papers of European universities and research institutes than anywhere else; this can be seen in Figure 4.
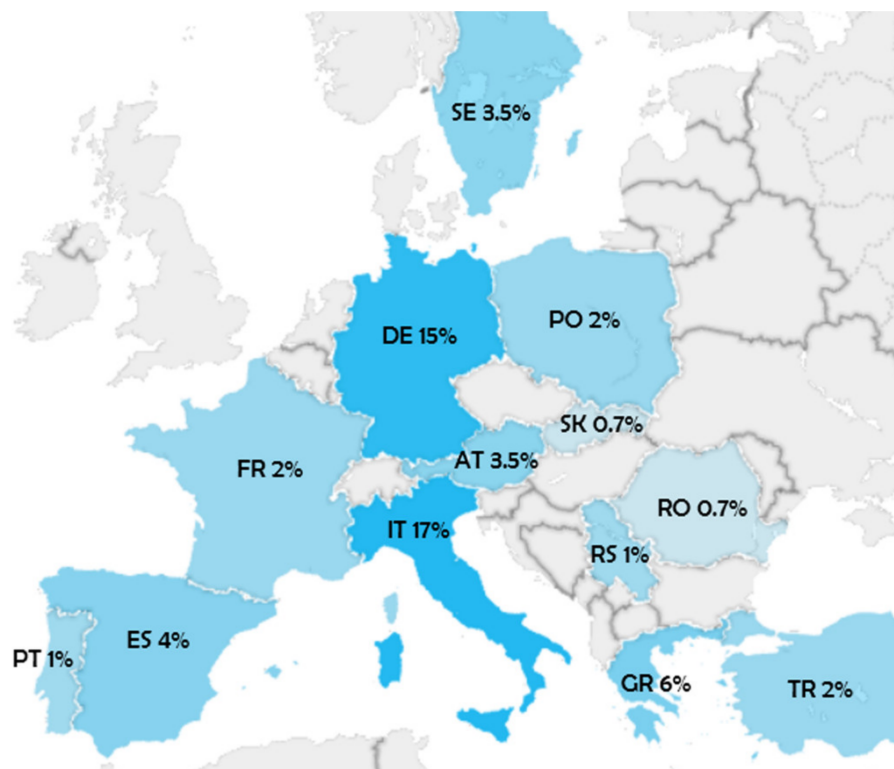

Figure 4. European countries from which relevant publications come.

4.2. Areas of Applications of AR

Currently, the development of new technologies has led to the application of AR applications in various areas of the industry. A detailed analysis of the relevant publications provides insight into the primary purpose of AR in industrial environments. Developed AR applications have found implementation in six main areas: maintenance, assembly tasks, human robot collaboration, manufacturing, training and logistics (Figure 5). Nearly 13% of the selected publications refer to application in more than one category.
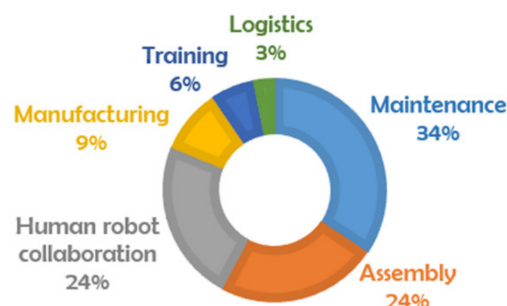
Figure 5. Areas of AR application.

Maintenance. One-third (34%) of the analyzed papers describe the use of AR in industrial maintenance and repair activities. In this type of application, task technicians are pre-equipped with information, instruction sequences or user manuals on their smart devices [41–51]. Another method for performing maintenance activities is to obtain instructions from a remote expert [52–54]. Moreover, some of the AR applications have been

developed to support diagnosis and to document the repairs made [55–58]. Maintenance processes can benefit from these technologies, with consequent advances in maintenance and production execution [59]. A typical and illustrative application for maintenance planning by using machine monitoring and AR monitoring is described in [41]. Developed AR mobile applications can visually see the health of the machine, schedule maintenance and support remote maintenance via AR.

Assembly. The second most common area (24%) of industrial tasks in which AR applications are applied is assembly [35,50,60–74]. In order to reduce assembly time and improve the quality of the assembly process, employees can, in most cases, be provided with some of the following information: the order of connecting the parts; visual help of the position of the next element; technique of connecting the parts. An interesting AR application for mounting a spindle motor on a CNC carving machine is presented in [75]. This smart instruction system with AR support and deep learning-based tools detection is designed to improve worker achievement through assistive instructions. Utilizing this application reduces the completion time and the number of errors compared to manual assembly.

Human robot collaboration. AR applications (24% of them) can also be used for human robot collaboration. These applications are not only implemented in cases where humans are serving industrial robots but also for programming or trajectory defining as well; this results in the avoidance of collisions [76–91]. One of the significant advantages in this area is related to the safety of employees and equipment because these applications can show operators the location of unsafe areas [92].

Manufacturing. The current manufacturing era is characterized by high demands on industrial performance, flexibility and agile response to customer requirements and the principles of sustainable production. AR has been identified as one of the key technologies important for the transformation from machine dominant manufacturing to digital manufacturing. Almost 10% of developed AR applications are directly related to the realization of smart manufacturing. Some of the benefits of the AR systems have been already proven, including safety [19], the increased precision [93,94] and reduced assembly time with AR [95,96].

Since manufacturing is a complex field that consists of product design, material specifications, machining, quality control, etc., all published papers related to manufacturing are classified in the manufacturing area. AR technology can increase product quality, working quality and productivity. AR applications can assist operators in performing quality control tasks. For example, an approach to online quality assessment of polished surfaces is described in [97]. Here, AR technology is used to project a 3D map of quality data, collected during the inspection, directly onto the correlated surface of the real component. With the support of the Industry 4.0 concept, traditional quality is shifting to a discipline in which products are combined with data or so called Quality 4.0.

Training. Nearly 6% of AR applications have been developed for employee training in industry, mainly for maintenance and assembly tasks, thus avoiding the repetition of errors and further facilitating the optimization of the production cycle [48,50,67,98]. AR has been shown to seriously improve human performance [47,99]. It can be observed that the time required to complete tasks can be reduced with these training applications [68]. AR applications intended for training provide flexible "in-house" training support, which turned out to be especially valuable in COVID-19 living and business conditions. Recent experiences with the pandemic have encouraged humanity towards flexibility, adapting to a new work environment and adopting new tools and technologies. However, further efforts are required to share knowledge by using AR and the long-term benefits of using AR technology [100].

Logistics. AR can also find its application in logistics (3%), for example, for order-picking tasks [101–103]. In the field of manufacturing, AR can be applied for prototype designing [104,105].

In addition to the above listed areas, there are examples of the application of AR in the aerospace industry, as well as in many other practices, such as tourism, food and

beverage industry, fashion and beauty industry and others. Furthermore, the use of AR in architecture and construction is increasing [106,107]. Another large and rapidly expanding area of application of AR is medicine, where AR offers a new approach to treatment and education.

Almost 13% of papers relate to applications in more than one area. Some interesting examples of mixed categories are given below. An example of an AR-based order picking system is presented in [108]. With the help of AR device, navigation in the warehouse and global visual instructions are enabled, with shortened object identification and superior picking performance in terms of accuracy, speed and usability. The outstanding application of AR in the ship assembly training process is described in [109]. The user is provided with an animation and text instructions necessary for step-by-step assembly. Furthermore, the user can see the related documentation and perform the scaling and moving of the 3D model within the developed application.

4.3. Devices Used to Work with AR

The real physical world can be augmented using two methods and several different devices as is shown in Figure 6. The first method is to equip an environment that can be carried out in two different methods. Projectors and holograms can be used for spatial AR where information can be projected onto 3D objects or screens. Large touch screens and tablets are used for computer-based AR. The second method involves equipping users with various smart devices. In the case of hand-held devices (HHD), there exists the possibility of using smartphones or tablets, while smart glasses are used in the case of head mounted displays (HMD). Almost two-thirds, 61%, of the analyzed papers show the implementation of AR by equipping the user.
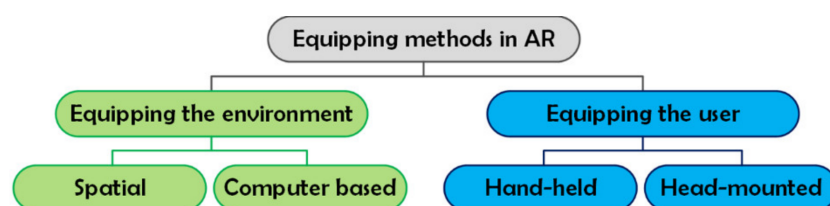

Figure 6. Methods of AR application.

Processing and display of AR applications are performed on various visualization devices (Figure 7). Augmented reality smart glasses (ARSG) are among the most commonly used wearable devices for supporting operators in the shop-floor, with a share of 35%. The main advantage of ARSG is that in cases of industrial tasks, such as maintenance, repair or installation or assembly, workers can perform tasks hands-free while viewing in real-time [34,35,41,45,57,60,66,69,72,93,97,100].
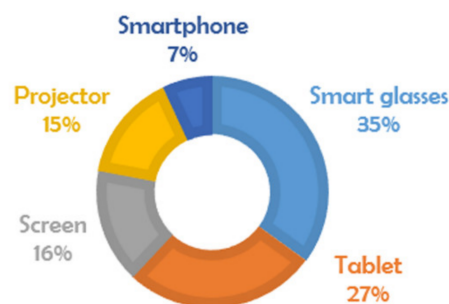

Figure 7. Visualization devices for the application of AR.

According to the analysis of publications, the second most commonly used device to support AR in the industrial environment is the tablet (27%). Using tablets, AR can be administered by two methods, either as a computer based application or as a handheld

application. In the case of computer based applications, tablets are placed in a fixed position [67,104]. On the other hand, in handheld applications the user must carry the device so his ability to perform the task is limited [40,43,47–49,52,55,71,75].

Similar to fixed tablets, large touch screen devices (16%) can also be used to apply AR computer based applications [60,62,79,80,84–87,90,91,110]. These devices can be placed in the workplace by utilizing a camera that monitors the real world or as a part of the remote equipment used by experts.

The use of projectors (15%) as a device for visualization of AR applications was also observed in the analyzed literature [28,45,47,63,69,70,81]. Additional task information can be projected on the big screen or on objects that are part of the task. Finally, smartphones (7%) are also used, but due to their relatively small size they are not utilized a large number of cases [52,57,77,88,110].

Each of these devices has certain advantages and disadvantages. The main purpose of these devices is to help the user in performing the task and to improve his safety. In some cases, the use of smart glasses is optimal. In this case, the user's hands remain free and they possess all the necessary information in front of their eyes. There are wide ranges of ARSG available on the market today [111]. However, some technological improvements are still required in this field in order to extend the battery life and expand the field of view, increase the resolution and reduce the weight of the ARSG.

On the other hand, the price of handheld devices (tablet and smartphone) is still relatively lower compared to smart glasses, but in the case that they are not used in computer applications they should be worn in the hands. Their smaller size is certainly an advantage due to their weight, while the main disadvantage is the amount of information that can be displayed.

Computer based and projector based AR applications are stationary, connected to the work environment and difficult to make universal. Their advantage is that it is possible to easily utilize one device in different places by simply spreading the codes for them.

4.4. Implemented Tracking Methods

In order to put the right information in the right place within the AR application, it is necessary for the device to know where it is in relation to its surroundings. For this purpose, several tracking methods have been developed that enable the identification of objects. However, all of them can be divided into two large groups: tracking with or without markers. Most of the analyzed manuscripts (66%) use markers in their applications. These markers are located on objects in the work environment and when the device recognizes them, it displays information to the user assigned to the marker. Similarly, in an industrial environment it is possible to recognize 3D objects (16%). In this case, these objects are often predefined in the system. Furthermore, various other methods are used (18%), which are based on location (GPS data and digital compass), context recognition, computer vision, spatial environment recognition, etc. [112].

An example of a marker-based AR application is described in [113]. With the help of QR markers, the AR module calculates its relative position and orientation and aligns the three dimensions of the virtual objects on the corresponding ones. Object recognition as a tracking method in AR applications is widely used. However, it must be more precise and become faster and, therefore, more reliable, especially with objects that do not possess recognizable texture such as screws, nuts, etc. (characteristic objects in an industrial environment). An innovative approach to how to achieve this is presented in [114].

5. Discussion

AR application development involves a very complex approach. Developers need to be familiar with the task for which they are developing an AR application for and the same goes for users. It is very important that the user is shown the right amount of information at the appropriate time.

AR provides easier and more natural interaction compared to other systems with traditional audio or video communication [54]. Almost all participants in the assessment process [28] of those who performed assembly tasks find it easy to understand the instructions. Most of them noticed increased efficiency with the use of AR. The application of AR can reduce the time required to locate objects and reduce head and neck movements during their performance [46]. The time savings depend on the complexity of the tasks and the quality of the developed AR application. In some cases, assembly tasks can save almost 30% of time [68]. A large number of users expressed confidence in their assessment of the selection and installation of parts during assembly compared to standard user manuals [62]. Furthermore, the number of errors are halved. With the help of AR, operators worked noticeably faster than in the case of printed instructions and about 4% faster in selecting tasks [115]. Using an AR application can also provide a reduction in time and required maintenance costs [52]. According to [116], maintenance time was reduced by an average of 43%. In the case of robotic tasks, after only a few minutes, users felt good with respect to the human robot collaboration using AR. What is very important is that users do not feel limited by the AR system [91]. A significant improvement in precision was observed during manual precision welding using AR compared to non-AR assistance [93].

5.1. Implementation of AR in Companies

The issue of application of AR technology in different segments of the industry has been addressed in many papers. In particular, useful instructions for the implementation of AR in manufacturing companies are given in [48,111]. In addition to research in the field of application relative to AR applications in the industrial environment, which are currently more related to solving technical problems, it is necessary to intensify research with respect to the impression of users, ergonomics and usability of applications. A good starting point in this case could be the innovative procedure for selecting AR maintenance technology, which is user-oriented, proposed by [117].

Nevertheless, according to [118]: Every company requires an implementation plan that introduces the application of AR into its business, while simultaneously expanding its capacity for further development and use. Based on the literature and personal experiences of the authors, the process of applying AR applications in companies can be realized through five steps:

1. Define the goal for the AR application.

Many different tasks and subtasks can be performed or improved using AR technology, but may require different levels of technology and complexity. For example, in order to view assignments or examples from a workbook using AR [113], you only need to install the appropriate AR application on your smartphone. However, specialized head mounted displays or smart glasses are likely to be required to enhance maintenance or assembly tasks, along with appropriate software with dynamic 3D models of the environment.

2. Create your own digital content.

The AR application consists of software, hardware and digital content presented in an innovative manner. Software and hardware can be easily purchased, but digital content, as the core of the application, is a unique asset of the company and should be created within the company. In order for an object to be presented in an AR application, it needs to be digitized. This can be achieved by customizing existing 3D models of products and/or machines and devices or by creating new ones using 3D modelling or 2D or 3D scanning. In any case, it is strategically wise to make a list of existing digital assets in 3D and other representations in addition to all useful assets of the company. However, the transforming procedures (assembly instructions, machine repair guidelines, design procedures, etc.) into digital content suitable for AR application are complex and usually requires a team that consists of company technology experts and AR experts.

3. Define the location of the AR device and interconnecting object.

Different technologies can be used to determine the position of the AR device and the interconnecting object. Three types are used:

- GPS positioning; belongs to the group of so-called unregistered AR experience and is limited by the accuracy of the GPS system;
- Marker based; use QR codes, bar codes, logos or a specially designed symbols. Markers should be placed at visible points in the environment and the AR user should know where to point his AR device;
- Machine vision is the most powerful approach in environment recognition and it allows the use of AR in an unstructured environment. Tt requires high quality software and hardware, but in some conditions (low lighting, etc.) it is still unable to recognize the object.

4. Define the required equipment.

For the simplest AR applications, smart devices such as smartphones and tablets are quite sufficient. Most AR applications for manufacturing and assembly require universal HMD that can free the user's hands. There are many such devices available on the market. High-value AR applications, especially in the automotive, aircraft and pharmaceutical industries, use dedicated and very expensive AR HMDs. It is strongly recommended that companies use a multi-platform approach that allows AR experiences to be distributed across multiple platforms.

5. Define the required type of software approach.

There are two common approaches to software development: standalone software that loads onto the device and can run without an Internet connection and, second, access to AR content hosted in the cloud. The first approach is reliable and solid with a high-resolution experience but it is not easy to change. The second approach requires an internet connection but can be easily upgraded across multiple devices. The ability to publish content is now essential when large amounts of information and frequent content changes are required.

5.2. Future Research Areas of AR Applications in I4.0

AR technology is developing intensively, especially in the industrial environment. In the continuation of the chapter, three research areas within smart manufacturing are identified, which according to previous analyses are the most promising for further research: recognition and position of objects; eye and voice control; the control of industrial systems by using AR.

1. Recognition and position of objects.

One of the areas of AR that provides a wide area for research is the localization of the device and object recognition in the working environment. The most important goal is to achieve accurate localization. Global positioning system (GPS) is a good solution for outdoor localization but in the case of indoor environments GPS can hardly be used due to reduced signal strength. Different technologies can be used for indoor positioning, depending on accuracy, cost and scalability. Most methods change from passively receiving information to actively seeking information. For AR applications Wireless Local Area Networks (WLAN), sensor networks, vision-based positioning, RFID, etc., are widely used.

As already mentioned, the recognition of objects in the environment is usually performed with markers. In addition to markers, predefined 3D object recognition, contextual recognition and spatial recognition using computer vision are also utilized. Using markers is the simplest and seemingly most reliable method. However, devices must be directed at them in order to display associated information. What if the markers are hidden, damaged, or unintentionally displaced? Until they are replaced, the AR application cannot be used.

Since each of these technologies has advantages and disadvantages, many researchers are working to improve the algorithms of these methods and are developing hybrid methods based on a combination of the available technologies [119]. This area provides

huge potential for further development. In the near future, by using cyber physical systems the location of each machine or device will be known in an industrial environment. By creating a digital twin of the entire factory in terms of interactive 3D models and by using these models, the recognition and position of objects can be improved.

2.   Eye and voice control.

Based on a review of the literature, it has been observed that there exists a small number of AR applications that include voice commands. An even smaller number of AR applications exist and are based on eye commands. Eye and voice commands are useful because they save time and free the user's hands to perform the task. Due to the nature of the industrial environment, in which a lot of noise is present, it is still difficult to enable the proper functioning of these applications but this opens up avenues for future research.

3.   Control of industrial systems through AR

The biggest challenges and opportunities for research lie in the control of industrial systems with the help of AR. The I4.0 concept implies the decentralization of industrial systems, where each subsystem has a control unit for itself that communicates with other devices at the factory level. This fact opens the possibility of developing AR applications that will be able to individually control parts of industrial systems, subsystems or even actuators. The main advantage of such a system is the acceleration of maintenance procedures in industrial systems. In cases of intervention, smart workers do not have to go through the user interface, their menus and submenus but can access individual actuators or machine subsystems and manage them directly by using the AR application. Such an application can also represent a link between real systems and their digital twins such that parameters from the AR application are transferred to the cloud, simulated via digital twins and applied to real systems if valid.

6. Conclusions

Over the years, the development of mobile technologies, smartphones, fast processors, cameras and displays and other smart devices has led to AR appearing as the cutting-edge technology not only in the industrial environment but also in everyday life, medicine, education, entertainment, etc.

The given literature review complements previous AR surveys, with the aim of gaining insight into the different areas in which AR has found its application within the I4.0 environment. Identified AR applications detected the most common areas of applications in industrial environments in which AR are implemented, as well as the most commonly used devices and tracking methods. The area in which the application of AR is currently the most developed is certainly maintenance, followed by assembly, human robot collaboration, manufacturing, training and logistics.

The main steps of implementation of AR in companies are also given, which should include broader requirements, among which are non-technological ones such as user impression, ergonomics and the usability of applications.

AR has been an attractive concept since the beginning of its development and will remain so since there is much room for further research and improvement. The following future research areas have been singled out as the most promising: object recognition and position; eye and voice control; the control of industrial systems via AR. These areas allow the combination of existing technologies and the exploitation of their best characteristics in order to obtain the highest achievements and thus improve the digital industrial environment.

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