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PERCEPTIVE REVIEW OF AUGMENTED REALITY APPLICATIONS AND THEIR OUTLOOKS IN THE FORGING INDUSTRY

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Abstract

Perceptive review of augmented reality applications in the forging industry is the primary goal of the paper. The differences between the Virtual (VR) and Augmented (AR) realities are highlighted first. Examples of the AR technology's various industrial applications are then presented, which is followed by the evaluation of capabilities of the approaches in the forging industry. The two practical case study solutions were implemented, and their operational capabilities under industrial conditions were tested. Examples of obtained results are presented within the paper.

Key words: Augmented reality, Virtual reality, Forging, Industry 4.0

1. INTRODUCTION

The forging industry is a branch of the metallurgical industry that uses large, heavy machinery, where in most cases, the maintenance and repair operations are very demanding. Such equipment is built to meet very demanding load-carrying capacity for many years of consecutive work and require regular maintenance operation, which have to be performed by specially trained engineers. However, due to the constructional requirements of the, e.g., forging presses, such maintenance engineers' training is challenging and often not intuitive as many components are hidden without direct access. Similar difficulties apply to the training process of forgers that operates the machinery on a daily basis. The effective training operation is time-consuming and often requires interruption of current production, which generates unnecessary costs for the company. Therefore, much effort is put in the forging industry to reduce training operation costs for both maintenance engineers or forgers. Recent progress in the Industry 4.0 concept provides valuable options in this regard in the form of Augmented (AR) (De Pace et al., 2020) Virtual (VR) (Crespo et al., 2015), or Mixed (MR) (Dai et al., 2021) realities that can be directly incorporated into the industrial practice. The former one is more and more often used in various areas. The industries in which augmented reality is already used on a daily basis include, among others: architecture (Davila et al., 2020), medicine (Kumar et al., 2020; Cen et al., 2020), and more often, the broadly understood manufacturing and processing industry (Palmariniet al., 2018). In production environments, AR applications are found in many stages of production, from product design, through manufacturing, to distribution (Firu et al., 2021). Augmented reality was also used as a support within the production lines in such concerns as BMW (Aziz et al., 2019) or Volkswagen (2020).

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The concept of applying the AR in the training and maintenance in the forging industry could look into the machine's interior and identify an effective way to provide required treatment faster and more efficiently, without interruption of the production cycle. These topic are perused in the current work.

First, the state-of-of-the art and examples of applications of various VR and AR approaches are presented. A review of the most commonly used implementation solutions is then highlighted and finally followed by practical case studies realized within the forging industry. Directions for further development in this area are also presented at the end of the paper.

2. VIRTUAL REALITY

Virtual reality is an element of the so-called artificial reality that is being developed with the use of specialized information technologies. The approach is based on the multimedia mapping operations of objects, space, and events into the virtually generated environment. Such a representation replicates elements of the real world or creates a completely fictional environment (Guo et al., 2020). The elements of the real world include various simulations of events taking place in everyday life. A very good example of the use of VR technology as a simulation of the real world is health and safety training (Chang & Lai, 2021). On the other hand, the fictional world is most often used in the gaming industry, where the logic, mechanics, and rules of physics can significantly differ from the real world's rules.

The current VR technology development allows delivering to the user, mainly the image and acoustic elements. However, it should be mentioned that VR technology does not only relates to image and sound; it also includes the sensations of taste, smell or touch as the key aspect of VR technology is the interaction of the user with objects that are in the virtual world.

Visual effects are perceived through the sense of sight, and the environment is represented through the use of various types of screens. The image can be presented on both wide, large areas and miniature displays. Large area screens include screens located, among others, in cinemas, while small screens are those build into the specialized goggles (figure 1a) or screens of a mobile device supporting virtual reality technology that can be located into external goggle devices (figure 1b). The later solutions are particularly interesting from the point of view of their application in an industrial environment. However, to deliver a reliable 3D representation of the environment, several technologies including 3D graphics algorithms, texturing operations, light tracking systems, and description of basic physics laws, have to be combined to produce the final outcome (figure 2).

Sound is another standard element that is often used in the world of virtual reality. Surround sound technology is used for the best experience. Typically, modern VR devices have built-in speakers, thanks to which the user can hear sounds around him. Less advanced devices, e.g., mobile devices, use the built-in loudspeaker. Unfortunately, such a solution does not allow the user to experience the localization of sound. However, as already pointed out, visual and sound effects are not the only options in the VR world. Equipment manufacturers develope devices that allow experiencing everything that is in the virtual space. An example of such a solution is the iSmell Personal Scent Synthesizer technology (Harel et al., 2003). Thanks to this device in the form of a dedicated face mask, the virtual world experience is extended to smell senses. In this case a more commercial project titled FeelReal should be mentioned, where even the smell of metal can be incorporated into the VR (Flavián et al., 2021). An essential aspect of FeelReal technology is the fact that it acts as an overlay that can be adapted to the most popular VR devices.

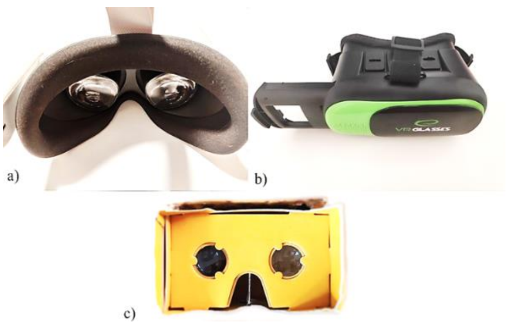


Fig. 1. *Examples of a) dedicated goggles with build-in screens, b) plastic, and c) paper googles without build-in screens designed for mobile devices.*

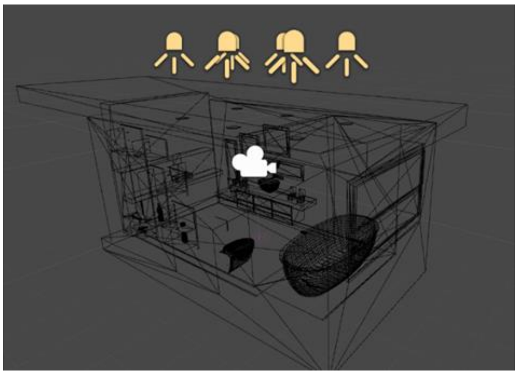


***Fig. 2.** Developed 3D model of compartment space.*

The initial models of the virtual world limited the interaction with the environment. However, with the development of technology and computing power, software producers added the possibility of full interaction with various components of the virtual world using standard input/output (I/O) devices. Initially, in order to interact with the environment, computer mouse, keyboards, gamepads, steering wheels, touchpads, and touch screens were used (Chen & Or, 2017). Currently, the technology is developing to such a degree that manufacturers produce more futuristic solutions, such as: dedicated seats, special suits, gloves, motion sensors or simulation cabins (Firu et al., 2021) what again creates extensive application possibilities in the metal forming industry.

As mentioned, one of the most accessible VR equipment are lenticular goggles that do not have built-in matrices but only lenses (Figure 1b,c). It is one of the easiest ways to obtain the required effect because it does not require a specialized computer that will be able to reproduce the virtual world. In this case, an additional device is placed in the goggles, usually, it is a phone with Android or IOS. However, to obtain a smooth animation effect in the virtual world, more advanced googles with built-in matrices connected to an external device are required (figure 1a). Most often, these are computers with very high computing power or recently popular game consoles. In this case, the goggles are directly connected to the device and display the image on the matrices inside the goggles.

Most of the available goggle systems are also equipped with controllers (figure 3) that detect the user's displacement or interaction with the virtual environment (Ameur et al., 2020).

Lenticular goggles, most of the time, have a simple controller that allows the user to interact with the environment in a basic way, e.g., selecting an element on the stage with a pointer. In this case, the movement capability is operated by the application itself, which reads information from the device and moves or rotates the user in the selected direction, allowing to move across the virtual world, as seen in figure 4.

More advanced goggle systems have an additional external tracking solution in the form of motion sensors. In this case, a crucial element is the appropriate arrangement of the sensors so that they have good visibility of the space around the user. These sensors can identify the user's position; however, they do not respond to user gestures. Therefore, a Leap Motion sensor was developed to overcome this limitation (Beattie et al., 2015). This type of device is attached to the VR goggles and directly to the workstation. The sensor uses a camera and specialized algorithms to detect the hand's structure, displacement, and rotation. Thanks to this solution, the user receives full freedom of hand movement (figure 5a). Thus, the sensor provides the ability to interact with the environment in a very natural way. This is especially beneficial from the point of view of the mentioned forging industry and training purposes.

***Fig. 3.** Examples of different types of a) simple remote controller, b) oculus rift and c) oculus quest 2 controllers.*

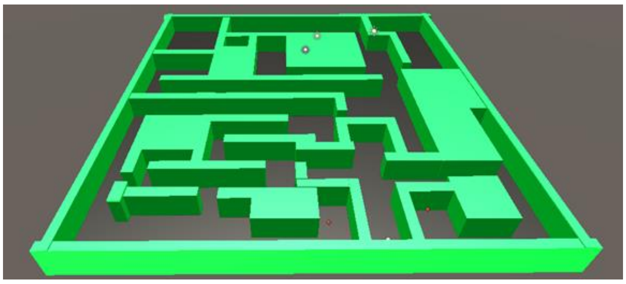


Fig. 4. *Virtual reality building layout.*

a)

b)

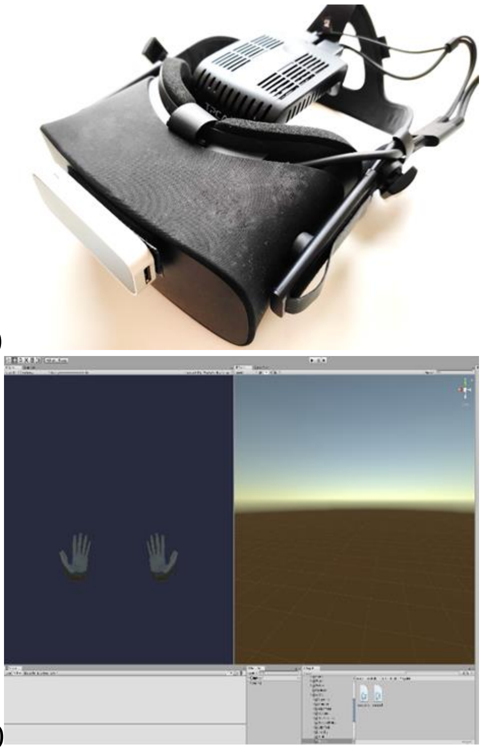


Fig. 5. *a) Leap Motion sensor attached to VR goggles, b) the model of hands detected by the Leap Motion.*

The Microsoft Kinect offers a similar solution, however, the equipment cannot be easily incorporated into the VR goggles.

AUGMENTED REALITY

Augmented reality is a variation of the virtual reality. However, unlike VR, which thoroughly introduces the user to a synthetic environment, AR is a system that overlays computer-generated information in real-time over data from the real user environment (Doshi et al., 2017). Usually, for this purpose, an image obtained from the available cameras is used, on which 3D objects are digitally superimposed, extending the real world with additional information (Regenbrecht et al., 2005).

In this case, to determine the user device's position in relation to the real world, the so-called markers - images, QR codes, inscriptions etc. are used by the AR software (Rohacz et al., 2020). After recognizing the marker, the AR system displays 3D objects on the screen in an appropriate, predefined spatial relation. A practical example of the interaction between the code and the 3D model in the developed system for children therapy support is shown in figure 6.

The most frequently used AR device types include Head Mounted Display (HMD), which is a device worn directly on the head (figure 7)

The optical display is mounted in front of one or both eyes in this case. Variation of the HMD is an Optical Head Mounted Display, where an image is projected onto a transparent plane so that the user sees both the projected image and the surroundings at the same time. One of the main advantages of the HMD is that the hands are unoccupied and free to do the required operations under, e.g., production. An alternative to this solution is Handheld Devices (HHD), mainly smartphones or tablets. AR applications are available for the most popular operating systems of mobile devices, i.e., Android and iOS, and can be developed within a dedicated implementation platform.

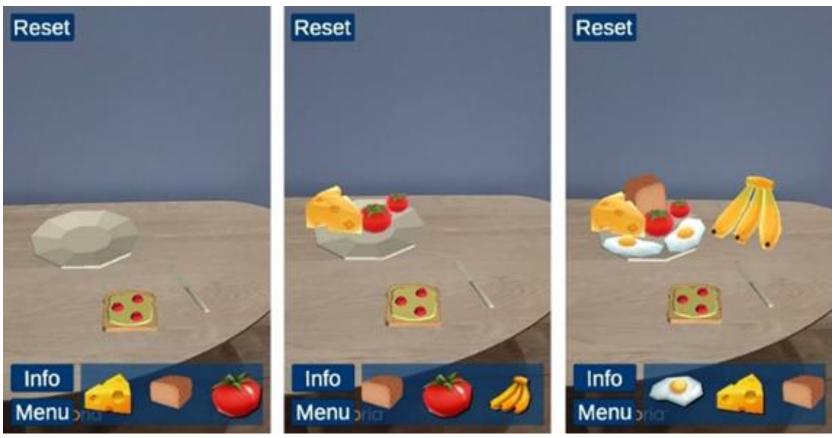


Fig. 6. *Virtual models generated on top of the real table based on the QR code.*

Fig. 7. Vusix glasses for the AR application.

3. IMPLEMENTATION PLATFORMS FOR AR

Several implementation platforms are worth considering when an AR application is under development: ARCore, ARKit, Vuforia, Wikitude, XZIMG, View AR, WayRay, and Spark AR Studio (Blaga et al., 2021). Creating an application that uses augmented reality without the use of a dedicated framework would be extremely laborious and time-consuming. The most commonly used solutions are:

- ARKit - platform provided by Apple company for creating augmented reality applications for iPhone and iPad devices. ARKit allows you to capture people's movements and pass their gestures to virtual objects. It has mechanisms for face detection and the use of multiple cameras simultaneously.
- ARCore - platform provided by the Google company. This technology is based on three main concepts: motion tracking, understanding of the environment, and estimating light intensity. Adequately connected, they allow devices to track their position during movement and build their own understanding of the real world.
- Vuforia – platform developed by the PTC company. Vuforia provides API in many programming languages, including C ++, Java, Objective-C ++, and .NET through add-ons to Unity - an environment for creating three-dimensional and two-dimensional computer games and visualizations. Thanks to the extensive API, Vuforia supports both native iOS, Android, or UWP applications.

The ARCore and ARKit put more emphasis on consumer/entertainment applications, while Vuforia is focused on industrial solutions. For that reason, it was selected in the current work as a tool for AR solutions in forging industry applications.

4. PRACTICAL APPLICATIONS IN THE INDUSTRY

The first practical application of AR in the industry can be dated to the early 1990s with the project for assembling electric wire packages at Boeing (Caudell & Barfield, 2001). Current applications of augmented reality include: supporting operations directly at the production line, remote assistance of experts, assistance in maintenance and technical inspections, quality assurance, or assistance in training and learning how to operate facilities and machines. Among the mentioned applications of AR particularly valuable are the ones related to the selection of appropriate parts during the assembly process, e.g., in the automotive industry (Gong et al., 2003). Similar solutions can also be found in the aerospace industry. AIRBUS Military developed the MOON project (asseMbly Oriented authOring augmeNted reality) in 2010 (Serván et al., 2012). It was applied to supervision of the setting up process of electrical installations in the Airbus A400M aircraft. Using a tablet device with installed software, the operator was able to see the entire electrical installation in the form of colored lines superimposed on the image from the camera. Quality assurance (QA), which are activities that must be taken to ensure that the quality of the final product meets customer requirements, is another common application of the AR. One of the well-known companies supplying the automotive industry - Magna, with the help of Holo-Light - developed an application for HoloLens aimed at QA process (Vorraber et al., 2020). It allows the operator to see directly in front of his eyes which part of the car is under investigation and then check whether the object has defects and moves to the next part. With such a solution, it is possible to document the entire process without additional equipment and take photos of defective parts. Finally, maintenance activities are also supported by the AR. A review in (Palmariniet al., 2018) showed that out of the 30 discussed articles, 52% of AR applications in maintenance were related to repair, inspection, and diagnostics of systems. General Motors in Australia proposed an alternative solution to the AR to support electric resistance spot welding [18]. In this case, the use of HHD and HMD devices was not practical. Therefore, a SAR (Spatial Augmented Reality) based on a projector integrated with the production station was used. SAR is a type of AR in which virtual images are projected directly onto physical objects. With the approach, the standard deviation related to the location of the weld dropped by 52%. The Audi company also decided to use AR for quality control. The company decided to implement a system that displays information to employees, e.g., dimensions of components or appropriate operations sequence that needs to be performed during testing. This approach ensured that no important element could be omitted.

As presented, applications of AR approaches in the industry become more and more frequent. However, applications in the forging industry are still rare, therefore this topic is addressed below.

5. CASE STUDIES IN THE FORGING INDUSTRY

The mobile application dedicated to maintenance in the forging industry was implemented as a case study within the Vuforia platform and Unity software as an IDE (Integrated Developer Environment). The selected platform and IDE provided the ability to run the application on a computer without using an Android emulator. The Blender tool was used to process 3D models of the forging press, while the FreeCAD was used to convert parts of the model between different formats. The application was tested on different mobile devices such as smartphones and tablets to investigate its universality. The primary goal was to develop a visualization of the press model to reveal the subsequent constructional components, often not visible in the real press (figure 8).

An Extended Tracking approach was used to allow the required flexibility in the visualization of the press components. The algorithm enables the marker to be tracked and objects displayed even after the marker is lost from the camera's field of view. It is especially useful when displaying large objects that do not fit entirely on the screen of the device, such as the forging press. The disadvantage of the approach is the requirement for more computing power after losing the marker from the camera's field of view. The main concept of the approach assumed the possibility of flexible disassembly of particular press components. Therefore, the developed functionally allows by touching the screen of the device to introduce a change in the transparency of several parts of the model. Therefore, the display of internal components and the display of the part name is possible (figure 9).

In order to assess the possibility of using the application in the production environment, a set of tests was carried out. The effect of changing the lighting and marker position on the quality of tracking and visualization of subsequent objects was evaluated. The tracking quality was checked with the low and full lighting available on the production floor, where the forging press was located. The marker was placed on the press body, and it was checked how the visualization behaves when the lightning conditions are reduced. The study showed that even with low lighting conditions - as long as the marker is clearly visible by the camera - the application detects the marker at a speed comparable to full lighting. It was also verified how the location of the marker affects the quality and speed of the visualization. Three marker positions were selected, as presented in figure 10.

Among all the tested marker positions, the tracking was at the best level for the marker on the press's lower body. For this setting, the tracking was easily maintained even up to the marker's total loss from the camera's field of view. The model remained in its initial position even at a 90° angle to the marker. For this variant, the model's visualization was closest to the actual press (figure 11a). For the marker placed on the top of the press, despite its position in the center of the object, there were artifacts consisting in shaking of the model visualization. These can be caused by the background in the form of yellow and black stripes. The maximum angle at which the model was systematically kept in the correct position for the best-case scenario was approx. 50°. The placement of the marker behind the press (figure 11b) caused problems with marker detection and good tracking quality.

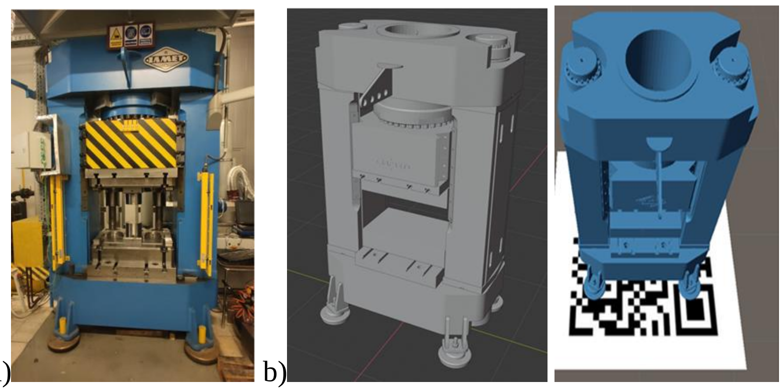
a)  b)

Fig. 8. Comparison of the a) forging press with its b) virtual model generated based on the QR code.

Fig. 9. Comparison of the a) full model and b) partially disassembled model of the forging press.

As presented, the developed solution can be applied in a real forging environment to support the press maintenance operation and guide the engineer to the appropriate location of subsequent components. At the same time, similar technology can be applied to the training of the press operator. In this case, during the designing of the AR application for training, it should be ensured that the model reflects real situations very accurately so that the training prepares for the actual work, as seen in figure 12.

In the current work, the two AR training sessions were developed - for initiating the press and for turning off the press. Both algorithms are linear and assume only one correct order for pressing the control panel buttons. Developed scripts have lists of the subsequent instructions displayed on the screen and lists with references to the voice recordings in which these instructions are stored for audio effects. The developed AR press panel and its superposition onto the real panel are shown in figure 13.

With the intuitive combination of the visual and voice directions, the inexperienced operator can easily practice the press's operation in a safe environment prior to the forging. Both presented AR application approaches are directly related to the Industry 4.0 concept, which the forging industry has to adapt to remain competitive in fast-changing markets.

Fig. 10. Investigated locations of the QR marker on visualization results.

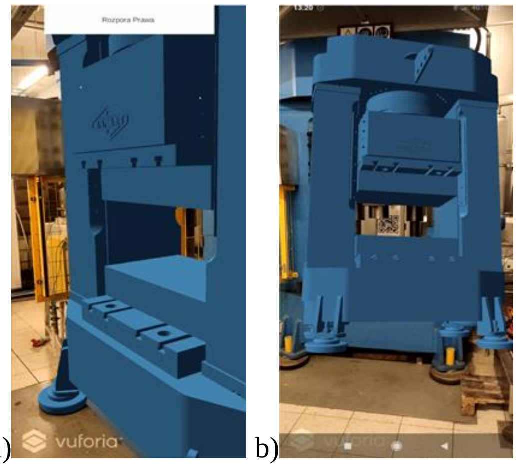
a)  b)

Fig. 11. Position of the visualization from a sharp angle in the case of the marker located in the front of the press (a) an) behind the press (b).

Fig. 12. AR training module developed for the appropriate initiation and termination of the forging press.

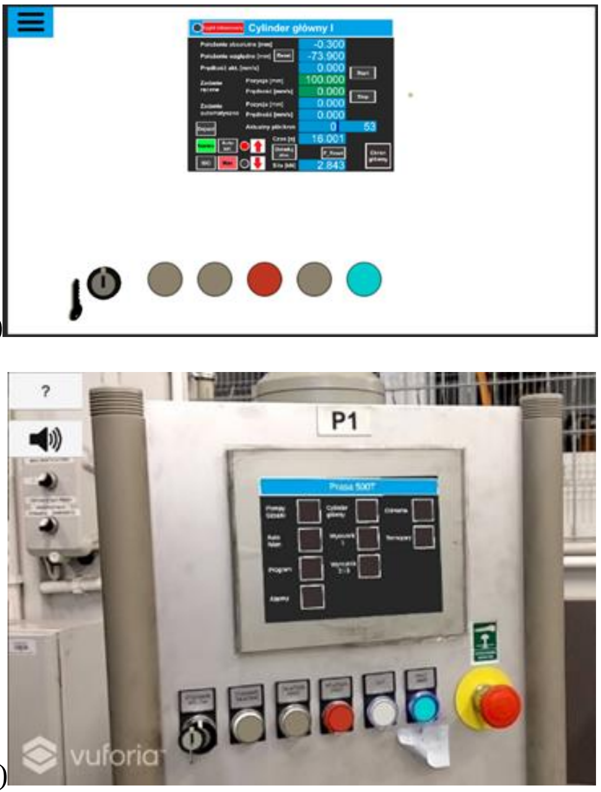
a) b)


***Fig. 13.** a) Implemented visualization of the control panel, b) superposition of the control panel in the AR environment.*

6. CONCLUSIONS

As presented, many industries already use augmented reality on a regular basis to improve their functioning and increase market competitiveness. The use of AR in the industry primarily contributes to increasing QA, shortening the amount of time necessary to perform assembly activities, and improving employees' qualifications through training. It was presented within the current work that the forging industry could implement augmented reality technologies in various fields. The effective visualization of even large press components is possible under various lighting conditions and from various angles. Both the maintenance as well as training applications have been shown. However, it should also be mentioned that the main requirement for successful AR applications is the availability of appropriate documentation and CAD models. To use the entire spectrum of options available within the AR environment, the forging equipment should be able to create a network within the Internet of Things (IoT) concept.

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PRZEGLĄD WYBRANYCH ZASTOSOWAŃ ROZSZERZONEJ RZECZYWISTOŚCI I PERSPEKTYWY ICH WYKORZYSTANIA W BRANŻY KUŹNICZEJ

Streszczenie

W pracy przedstawiono przegląd wybranych zastosowań technologii rozszerzonej rzeczywistości ze szczególnym uwzględnieniem przemysłu kuźniczego. W pierwszej kolejności omówiono różnice pomiędzy technologią rzeczywistości wirtualnej (VR, ang. Virtual Reality) i rozszerzonej (AR, ang. Augmented Reality). Następnie przedstawiono przykłady zastosowań przemysłowych technologii AR. W kolejnym etapie badań opracowano i zaimplementowano dwa rozwiązania testowe wykorzystujące AR dedykowane dla kuźni i określano możliwości ich wykorzystania w warunkach przemysłowych.

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