Augmented and Virtual Reality Tools in Training Mining Engineers

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Abstract

The transition to smart mining has significantly increased the requirements for training modern mining engineers, this necessitating digitalization of this process. Based on scientific research, virtual and augmented reality technology are the most effective and safe. The article presents methods for using virtual and augmented reality technology in training mining engineers. The methods are successfully implemented in laboratories of Kryvyi Rih National University (Ukraine) and have been proven effective during distance learning in the context of the COVID-19 pandemic and the russian military aggression against Ukraine. Nevertheless, further scientific research is needed to introduce modern digital technologies into mining engineers' training at universities in order to form a competitive and competent specialist.

Keywords: *mining engineer training, Augmented Reality (AR), Virtual Reality (VR), digital transformation, distance education, COVID-19 pandemic, russian military aggression against Ukraine*

1. Introduction

Recently, there has been an increase in the number of projects for the introduction of augmented (AR) and virtual reality (VR) technology, which is actively used in many different areas of human life, from industry to education.

Since both AR and VR are key components of the Industry 4.0 concept (Fig. 1), companies around the world are investing heavily in their development. For example, Google and Microsoft, which initially focused their products on the consumer market, have now provided for both industrial and educational use of their technology. Industry 4.0, which is made up of cyberphysical systems, the Internet of Things and complex networks that combine industrial production with the latest information and communication technologies, involves creation of smart factories, such as network and automated ones [16].

In recent years, there has been a transition from traditional to smart mining, which has greatly improved mining engineers' capabilities to identify hazards and make further decisions to ensure industrial safety [7; 24; 25; 26; 30; 32; 39].

The latest technologies in mining are expanding the boundaries of practical training of future mining engineers. Thanks to these technologies, the learning process can provide an advanced simulation of the production environment that humans perceive almost as real.

AR and VR technology is being used to solve a variety of problems in training mining engineers, from designing new industrial lines and final products to supporting personnel training in repairs. The technology applied to training can change the role of the human factor by reducing the risks associated with improper operation of equipment while working at hazardous facilities.

Collaboration between universities and VR/AR manufacturers contributes to solving problems of forming competences of future mining engineers (Fig. 2).

The main advantage of using AR/VR in training mining engineers is the fact that the technology allow teaching in AR/VR environments close to the real one, through simulating virtual scenarios [1]. Clearly, the introduction of AR/VR as training technology requires new teaching methods that take into account future engineers' level of training and the changing role of educators [9].

2. Literature review

AR/VR technology is being actively introduced into the mining industry. Many enterprises are already applying it to increasing productivity and improving occupational safety. Therefore, the introduction of the technology into the process of training mining engineers is the need of the hour.

Australia, the United Kingdom and the United States are leaders in using the VR learning environment for mining simulation, reconstruction and accident investigation, and industrial safety. The UK has a long history of developing and using virtual reality technology for mine safety training. VR products such as SafeVR and Vroom are well known for training truck drivers at open pits [28].

Universities in Australia are actively introducing VR technology into the training of mining engineers:

– the University of Queensland is involved in research to develop VR training applications with rig models, Instron UCS rock testing models and ventilation models [18];

– the University of New South Wales is implementing iCinema, a VR environment with 18 modules, to improve teach-

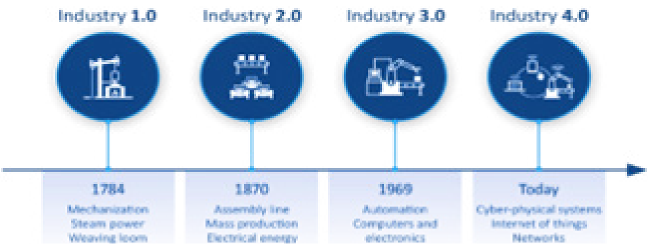

Fig. 1. The Four Industrial Revolutions [16]
Rys. 1. Cztery rewolucje przemysłowe [16]

Fig. 2. Advantages of collaboration between universities and VR/AR manufacturers
Rys. 2. Korzyści ze współpracy uczelni z producentami VR/AR

ing and learning activities in mining [12]. iCinema-based training allows students to recognize difficult work situations and receive training in a safe environment. The technology enables students to interact with the VR program that responds to movements in space and incorporates production situations (Fig. 3).

Scientists at the U.S. National Institute for Occupational Safety and Health have investigated how the mining industry can effectively use gamification and VR to learn how to escape fires. The Spokane Research Laboratory has developed fire evacuation training software for a mine safety training course (Fig. 4). The study notes that VR-based training significantly improves students' skills in determining proper evacuation routes in a possible emergency [23].

The expertise of educational institutions and mining companies in China includes VR technology applied to teaching safety regulations in rescue operations. Scientists [19; 20] have developed a cloud-based VR system for training mining engineers. This system includes VR hardware, a projected panoramic display system, a VR headset, a monitor, a tablet and other devices (Fig. 5).

In the context of the COVID-19 pandemic and the russian aggression against Ukraine, lecturers from the Physics Department of Kryvyi Rih National University have developed an AR-based manual for laboratory work in order to provide distance learning for future mining engineers [3; 29; 37; 40]. Future engineers use their smartphones to recognize AR markers, and the actual laboratory installation and its use are displayed on the screen (Fig. 6).

To summarize the national and international experience, we can say that in the process of training mining engineers, many courses, training laboratories, and research centers for mining research using AR/VR technology have been created at universities to improve mining engineers' training, prepare them for employment, and reduce training costs.

3. AR/VR apps analysis

The latest AR/VR technologies for simulating mining production processes expand the boundaries of practical mining training. In the educational process, it is important to ensure an advanced simulation of the production environment, perceived by students as reality. Professional AR/VR-based training of future engineers allows students to participate in production processes of a mining enterprise and be engaged in their future professional activities.

The VR/AR development in mining is based on automation of technological processes in the context of digital transformation of modern society. A significant effect of VR/AR technology applied to practical training of engineers is achieved through forming professional competencies in handling mining equipment.

3.1. Experience of using VR in the training process of mining engineers

Mobile communications, the Internet of Things, artificial intelligence, and cloud computing provide the information infrastructure needed for smart mining. Thanks to these modern technologies, next-generation VR systems for under-

Fig. 3. iCinema at the University of New South Wales [12]
Rys. 3. iCinema na Uniwersytecie Nowej Południowej Walii [12]

Fig. 4. The VR application for trainees to view a simulated underground mine [23]
Rys. 4. Aplikacja VR dla stażystów do oglądania symulowanej kopalni podziemnej [23]

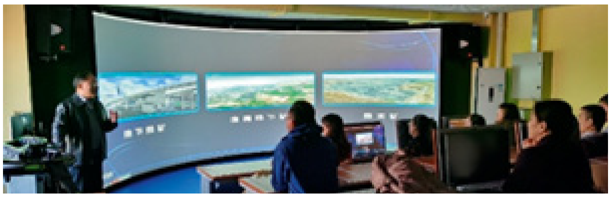

Fig. 5. The VR Learning and Experiment Laboratory of the University of Mining and Technology in China [20]
Rys. 5. Laboratorium uczenia się i eksperymentowania VR Uniwersytetu Górniczo-Technologicznego w Chinach [20]

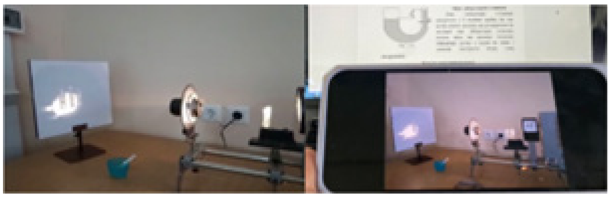

Fig. 6. Visualization for the laboratory work instruction
Rys. 6. Wizualizacja instrukcji pracy laboratorium

ground mining are being created to improve professional adaptation and occupational safety processes of future mining engineers [5; 10; 14; 22; 33; 36].

Scientist [6] studies the application of training with VR tools and concludes that students using VR applications learn four times faster than those learning in a classroom. The training was carried out using VR simulators (Fig. 7) to train operators and simulators for maintenance, which are key virtual reality training programs for the mining industry. These systems can monitor the training process and provide feedback to students. Gamification is a feature of VR training, which allows learning activities to be repeated until the desired level of competence and productivity is achieved.

Maptek, in collaboration with LlamaZOO MineLife, has developed VR digital tools to visualize production processes at mining companies in Canada, Australia, and South Africa. With the help of LlamaZOO MineLife, a digital model of an underground mine has been created, which can be used with a VR headset or a computer to explore the site (Fig. 8). This technology can be used for educational purposes for professional training and retraining of mining engineers. The use of digital models of mines makes the process of training mining engineers closer to real-life working conditions and safer [34].

First Quantum Minerals has installed Cybermine 5 Full-Mission simulators from ThoroughTec at its underground mine to train mining equipment operators. Simulation booths (Fig. 9) are copies of real mining equipment, with tools operating as they would in real mine transport. Simulators allow operators to test and practice the skills needed in an emergency (brake failure, fire, etc.). Notably, the two simulators can interact with each other to train teamwork in real production situations [8].

Thus, VR is an important component of smart mining, but there are a number of problems with introducing these technologies into the process of training mining engineers. They are expensive and there are no methods to assess their effectiveness. The technologies also require prior training for instructors and are complicated to adapt to different production conditions in different regions.

3.2. Experience of using AR in the training process of mining engineers

In the mining industry, AR technology is fast to develop, thus contributing to the evolution of training methods and tools for future professionals. When using AR, digital content is superimposed on the real-life production environment,

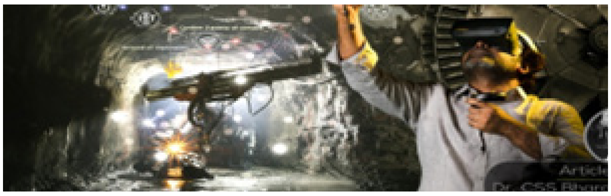

Fig. 7. Virtual Reality is a Game Changer for the Mining Industry [6]
Rys. 7. Rzeczywistość wirtualna zmienia zasady gry w przemyśle wydobywczym [6]

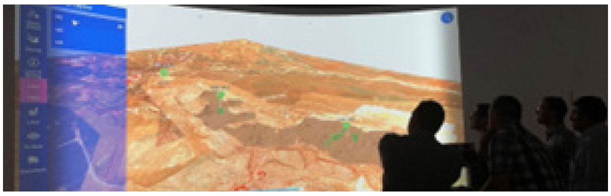

Fig. 8. Using VR to monitor the performance of mining machines in real-time [34]
Rys. 8. Wykorzystanie VR do monitorowania pracy maszyn górniczych w czasie rzeczywistym [34]

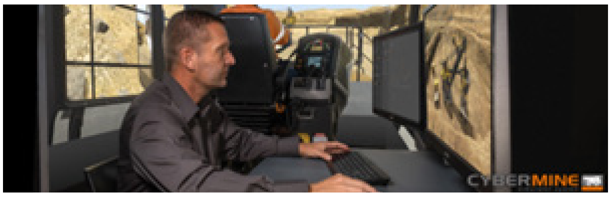

Fig. 9. The simulated mining cab [8]
Rys. 9. Symulowana kabina górnicza [8]

Fig. 10. Hands-Free AR with Visual Instructions [27]
Rys. 10. Hands-Free AR z instrukcjami wizualnymi [27]

bringing the training process as close to production conditions as possible. The advantage of the technology is that it is not expensive. A smartphone is all that is needed.

AR simulators enable preparing future mining engineers to work on the production floor without having to leave for the industrial facility. AR can be used to create conditions for the front-line mining experts to participate in remote consulting of future mining engineers.

Developer [13] create an AR platform to simulate unmanned mining in underground mines, revealing good results and stable operation. It has been noted that such production has a number of advantages, namely high efficiency, safety and low cost.

RealWear has developed an ergonomic device (Fig. 10) that fits under a helmet and does not interfere with the use of goggles in an industrial environment. The device helps workers to access documents (instructions, drawings, etc.), speeds up interactions with other employees, and facilitates navigation on the production floor [27].

DAQRI has developed an AR headset (fig. 11) for engineers and technicians, that can be used to repair, maintain and inspect industrial equipment. While working at the enterprise, instructions are displayed on the screen to direct the employee. In addition, the worker can remotely connect to a mentor or an expert to perform the task [38].

Plutomen designs and develops the innovative AR technology (Fig. 12) aimed at improving production processes, training mining engineers, and eliminating space and time constraints for communication between employees and experts. This technology allows experts who are located far from technical equipment to observe a production situation by means of employees' AR glasses and remotely give them advice on equipment diagnosis, repair, and control [17].

VSight develops applications based on AR technology (Fig. 13) to provide real-time remote assistance to operators in equipment maintenance and repair, drilling, as well as in training future specialists [21].

SensPlus Buddy AR tools (Fig. 14) provide smartphone communication for remote support of technicians at industrial facilities. Information is exchanged by sending images and text, this greatly improving efficiency of equipment maintenance and reducing the number of errors [29].

The TOMRA Visual Assist AR technology (Fig. 15) has three types of support: telephone and email support, real-time monitoring features, and remote login to the customer system by a TOMRA service engineer [11].

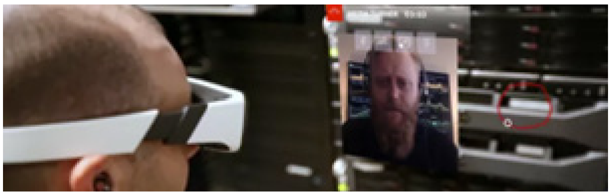

Fig. 11. The hard AR helmet of DAQRI [38]
Rys. 11. Twardy hełm AR firmy DAQRI [38]

Fig. 12. AR and VR in Mining Industry [17]
Rys. 12. AR i VR w górnictwie [17]

Fig. 13. Industrial Remote Service Platform Powered by AR [21]
Rys. 13. Przemysłowa Platforma Usług Zdalnych obsługiwana przez AR [21]

Fig. 14. Communication support service SensPlus Buddy [29]
Rys. 14. Usługa wsparcia komunikacji SensPlus Buddy [29]

Consequently, the use of AR technology allows for advanced operational readiness and improves the overall efficiency of the mining engineers training process. However, further research is needed to spur more innovative applications of virtual and augmented reality-based learning. It is effective because AR-based training can fully immerse future mining engineers in the production environment, allowing them to perform production tasks on simulators and receive advice from remote experts. Practice-oriented training has a significant impact on the formation of professional competences needed to work in production.

4. Methods of using AR/VR technologies in training mining engineers

Formation of professional competences, aimed at closing the gap between university education and real-life production, are key factors in training mining engineers.

Lecturers of Kryvyi Rih National University developed training materials using AR technology when training master's degree students in Specialty 184 Mining (Shaft Sinking and Drifting). The use of such materials is effective for independent work of students during distance learning, especially in the context of the COVID-19 pandemic and the russian aggression against Ukraine.

We offer several methods for making AR-based training materials for training mining engineers that contribute to modernization and digitalization of mining education.

1. The videos with digital training materials relevant to the topic of your class are freely available online, such as the following resources:

- https://www.imaker.ca/portfolio;
- https://www.herrenknecht.com/en/products/productdetail/gripper-tbm/;
- https://www.youtube.com/@HerrenknechtAG.

We offer as an example a video from Herrenknecht AG (Fig. 16).

2. Various AR applications can be used to visualize training material, such as:

- applications for creating AR (https://arize.io; https://www.augment.com);
- free applications for creating QR code for (https://goqr.me; https://www.qrstuff.com) (fig. 17).

3. Using the selected applications, you can create a QR code or and AR object.

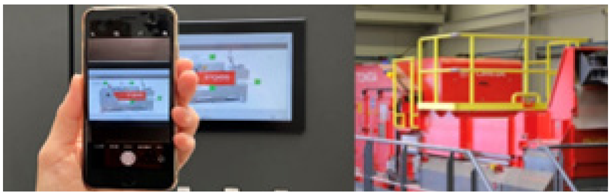

Fig. 15. AR tool for remote assistance TOMRA Visual Assist [11]
Rys. 15. Narzędzie AR do zdalnej pomocy TOMRA Visual Assist [11]

Fig. 16. Shaft Boring Machine for Shaft Enlargement
Rys. 16. Wytaczarka wałkowa do powiększania wału

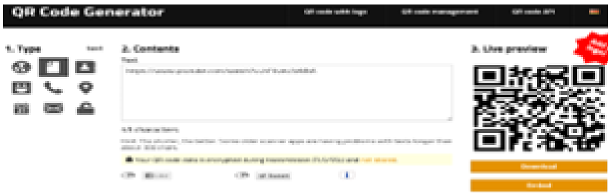

Fig. 17. Application for creating QR code (https://goqr.me)
Rys. 17. Aplikacja do tworzenia kodu QR (https://goqr.me)

Fig. 18. The QR code with a link to the video https://www.youtube.com/watch?v=hF6veu3zMbA
Rys. 18. Kod QR z linkiem do filmu https://www.youtube.com/watch?v=hF6veu3zMbA

When preparing training materials, we use applications for creating a QR code (https://goqr.me) and receive it with a link to our video (Fig. 18).

4. A QR code is added to the instruction for a laboratory work on mining with a link to training.

While performing a laboratory work, students must perform the following sequence of actions: 1) open the Camera application on the smartphone; 2) point the camera at the AR marker or the QR code and scan it; 3) a training video appears on the screen (Fig. 19).

This method of presenting the material has proven to be very effective in distance learning in the context of the COVID-19 pandemic and the russian aggression against Ukraine [40]. Thus, when teaching the subject Blasting Safety, lecturers use QR codes to visualize training materials. Students simply scan the QR code (Fig. 20) and view different types of explosions. It is essential to note that students remain in a safe place and receive all the information.

It should be noted that the use of AR for performing laboratory works by future mining engineers is an effective tool to motivate students to study and develop their research competences. Students can better understand abstract theoretical models of production processes through AR visualization.

Thus, after analyzing the available materials, we can conclude that the introduction of AR/VR technology into the training of Ukrainian mining engineers is a promising direction for further research. Prospects for further research include (Fig. 21):

5. Conclusions

Analysis of the data on the problem of training mining engineers reveals that the international experience with the use of AR/VR technology in mining is positive and shows a developing trend.

AR/VR technology, as a smart mining tool, is an innovative method of training mining engineers to control production processes. The technology is particularly effective for visualization of employee locations, safety monitoring, and handling of mining equipment. It should be noted that AR/VR technology is appropriate for building health-saving competences at safety training courses of mining enterprises aimed at preventing emergencies. An advantage of the AR/VR technology in the process of training mining engineers is the ability to visually present future production processes.

Fig. 19. Visualization of training videos to perform laboratory works
Rys. 19. Wizualizacja filmów szkoleniowych do wykonywania prac laboratoryjnych

The impact of stemming in blast outcomes | The longest visible shocktube blast burning front | Longest Heave Non electronic Blast (Shocktube) | Longest Surface Mining Explosives Delays

Fig. 20. Types of explosions
Rys. 20. Rodzaje wybuchów

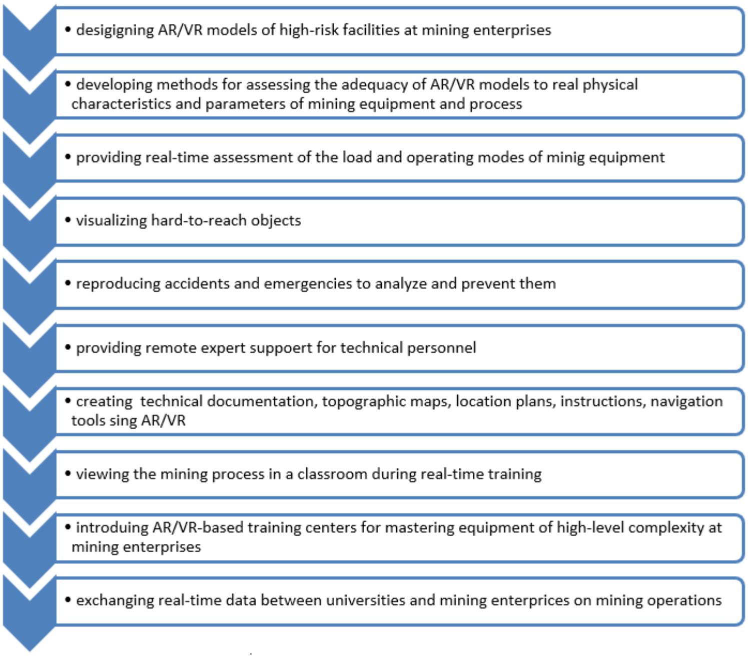

Fig. 21. Promising research areas of the implementation of the AR/VR technology in training mining engineers in Ukraine
Rys. 21. Perspektywiczne obszary badawcze zastosowania technologii AR/VR w szkoleniu inżynierów górnictwa na Ukrainie

The methods of using AR/VR technology in the training of mining engineers described in this paper have allowed University teachers to easily and effectively implement the technology in the educational process during distance learning in the context of the COVID-19 pandemic and the russian aggression in Ukraine. AR/VR-based teaching materials contribute to modernization of the process of training competitive specialists in the mining industry.

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Narzędzia rozszerzonej i wirtualnej rzeczywistości w szkoleniu inżynierów górnictway

Przejście na inteligentne wydobycie znacznie zwiększyło wymagania dotyczące szkolenia nowoczesnych inżynierów górnictwa, co wymaga cyfryzacji tego procesu. Bazując na badaniach naukowych, technologia wirtualnej i rozszerzonej rzeczywistości jest najskuteczniejsza i najbezpieczniejsza. W artykule przedstawiono metody wykorzystania technologii wirtualnej i rozszerzonej rzeczywistości w szkoleniu inżynierów górnictwa. Metody są z powodzeniem wdrażane w laboratoriach Krzyworoskiego Uniwersytetu Narodowego (Ukraina) i okazały się skuteczne podczas nauczania na odległość w kontekście pandemii COVID-19 i rosyjskiej agresji militarnej na Ukrainę. Niemniej jednak potrzebne są dalsze badania naukowe, aby wprowadzić nowoczesne technologie cyfrowe do kształcenia inżynierów górnictwa na uczelniach w celu ukształtowania konkurencyjnego i kompetentnego specjalisty

Słowa kluczowe: *szkolenie inżynierów górnictwa, rzeczywistość rozszerzona (AR), Rzeczywistość wirtualna (VR), transformacja cyfrowa, edukacja na odległość, pandemia COVID-19, rosyjska agresja militarna przeciwko Ukrainie*