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ANALYZING INTEGRATION OF IMMERSIVE TECHNOLOGIES IN AVIATION EDUCATION

Ján JEVČÁK*, Martin KELEMEN, Anton KORNIIENKO, Kristína OZDINCOVÁ
Technical University of Kosice, 04121, Rampova 7, Kosice, Slovak republic
**Corresponding author.* E-mail: jan.jevcak@student.tuke.sk

Abstract. As technology advances at a rapid pace, immersive tools such as Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) are increasingly being adopted in higher education, especially within universities. These technologies offer innovative approaches to enhance and digitize learning environments, opening up new avenues for enriched educational experiences and improved training methodologies. This paper investigates the integration of VR, AR, and MR in aviation education at the university level, evaluating their effectiveness, advantages, and limitations. It explores both the strengths and challenges associated with these technologies in relation to educational objectives, assessing their suitability for aviation training. Furthermore, the study examines emerging trends, particularly the synergy between artificial intelligence (AI) and immersive tools, underscoring the importance of continuous innovation and collaboration to maximize their potential. Through a comprehensive analysis of current practices and future directions, this paper sheds light on the transformative impact of VR, AR, and MR in aviation education. The conclusion reaffirms recent trends and positive outcomes of these technologies while also addressing cost implications for future developments.

Keywords: virtual reality, VR, augmented reality, AR, mixed reality, MR, simulator, education, aviation,

1. INTRODUCTION

Technologies that modify the environment around us and digitalize it or create new purely digital ones are rapidly evolving and finding use in various institutions where they can be most useful. It is in the university environment that we are seeing the rise of virtual, adapted and mixed reality. The manufacturers and developers of these systems, together with their users, are promising results that could not be achieved with previous methods, in a shorter time and with less financial burden. In order to find out whether this is really the case, it is necessary to look at the development of these technologies in the university environment, to map out all the positive and negative aspects as well as to evaluate whether these technologies are fit for purpose, what path they are taking and what the latest trends in this field are.

2. LITERATURE

Virtual reality (VR) [11] is a technology that uses a combination of hardware and software to simulate realistic and immersive environments. It involves three technical elements - tracking, rendering and display - that are flawlessly executed to deliver a rich VR experience. An immersive VR system uses a variety of interactive devices, such as head-mounted displays and data gloves, that seal the viewer's vision, hearing, and other senses, and use interactive devices to command and control the virtual environment, so that the viewer truly becomes a participant in the VR system, creating a sense of being immersed and fully engaged in the virtual world or reality.

In virtual reality, the most important component and piece technology is a headset or goggles whose role is to display the digital world but also to collect data and information about the user's head movement and then send it to the software for evaluation. More advanced glasses have a higher resolution display unit, a higher field of view, a higher number of sensors that are more sensitive to even the smallest changes in position, or tracking the movement of the eyes and the behavior of the eye itself when interacting with the display unit.

Figure 1 Virtual reality headset and simulator used in pilot training

Another element that is extremely important is the means or medium used to control and interact with virtual reality. This means depends on the use case and the environment. The most common is a game controller, a mouse with a keyboard. In flight simulations it is a joystick and pedals, cockpit simulator as we can see in Figure 1. Virtual reality headset and simulator used in pilot training. The choice is important as it helps in maintaining realism, thus providing a more authentic experience.

Augmented reality (AR) [12] is a technology that complements the real world by layering computer-generated information on top of it. It uses a combination of hardware and software to create 3D images and objects that allow users to interact with both the physical and digital world. There are many kinds of augmented reality for example:

- **Marker-based AR** - relies on pre-defined tags or patterns, such as QR codes or images, to trigger the display of AR content. When the device's camera recognizes these tags, it overlays digital content on top of them. This type of AR is often used in advertising, educational materials and interactive experiences.
- **Markerless AR** - does not require predefined tags. Instead, it uses GPS, compass, and other sensors to determine the user's location and orientation, and overlays digital content onto the real-world environment accordingly. The most widely used examples of tagless AR are navigation applications.
- **Recognition-based AR** - uses computer vision algorithms to recognize and track objects or features in the user's environment. It can superimpose digital content on recognized objects, such as faces, products, or landmarks, to enhance interactions and provide additional information. Snapchat filters and AR shopping apps use recognition-based AR.

Superposition-based AR - overlays digital content onto the user's view of the real world, enhancing or modifying their perception of the environment. This type of AR is commonly used in wearable AR devices such as smart glasses or headsets, where virtual objects are seamlessly integrated into the user's field of view.

Figure 2 AR car navigation

Also, the implementation is dependent on the use cases. In certain cases, the user can get by with a smartphone that has all the software but also the hardware to run augmented reality, also programmatically it is possible to compensate for technical shortcomings while still getting an acceptable result.

Mixed reality (MR) is a technology that combines elements of augmented reality (AR) and virtual reality (VR), allowing users to interact in real time with both digital and physical objects in a merged or "mixed" environment. In MR, virtual objects are not simply overlaid on the real world as in AR, nor are users fully immersed in the virtual environment as in VR. Instead, MR seamlessly integrates virtual content with the user's physical environment, creating a hybrid environment in which digital and physical elements coexist and interact. MR achieves this by using advanced sensors, cameras and spatial mapping technology to understand and interact with the user's environment in real time. This enables the precise placement and anchoring of virtual objects to specific locations or surfaces in the real world, enabling realistic interactions and experiences.

One of the key features of MR is its ability to provide spatial awareness and depth perception, allowing users to move and interact with virtual objects as if they were real. This immersive and interactive nature makes MR ideal for applications such as gaming, design visualization, training simulations, and remote collaboration.

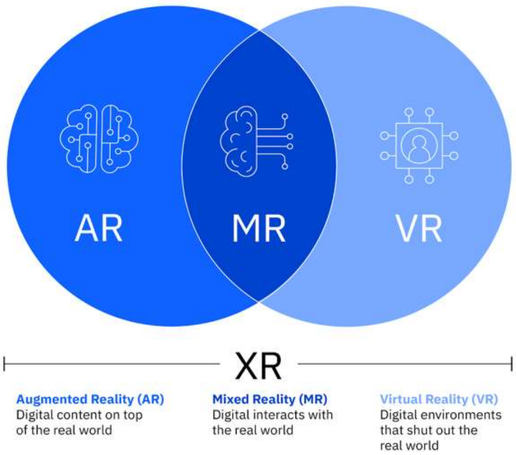

Figure 3 Intersection of different realities (Source: IBM)

An example of an MR device that combines see-through displays with spatial mapping technology to create immersive mixed reality is the Apple Vision Pro. This device allows users to interact with holographic objects and digital content that overlap with the physical environment, blurring the line between the digital and physical worlds.

The system of computer processing of simulations and the implementation of the exact phenomena studied at the Faculty of Aeronautics is controlled by a computer system that uses the above mentioned elements. Simulators from the company "VRgineers" are used in the theoretical training and practical flying skills training of civil and military pilots. Their simulation software system provides several types of flight plans for different flight modes and it is possible to monitor whether the exact conditions of a given flight have been observed. "VRgineers" use different types of software when creating their comprehensive solution for the purpose of providing the best possible virtual experience providing the best possible situational awareness. These are specifically:

- **Prepar3D -** flight simulator developed by Lockheed Martin, based on Microsoft Flight Simulator engine. It is designed for personal and professional pilots, whether for fun, training or research. It offers realistic flight, weather and landscape modelling and is widely used in military and commercial flight training. Its accuracy and realistic effects have made it very popular among flying enthusiasts and aviation professionals.
- **DCS (Digital Combat Simulator World)** - is a military flight simulator developed by Eagle Dynamics. It features detailed modeling of military aircraft and environments, making it a favorite for serious flight sim enthusiasts and pilots.

The development of the environment as well as the redistribution of individual flight parameters is directly redistributed by the instructor's workplace, where the instructor also becomes the guarantor of compliance with the conditions and controls the activities of the phenomena entering the overall simulation through the processing of the simulation mode forming a complex picture of the air situation. Another tool for training practical skills in pilots is the simulator equipment based on Microsoft Flight Simulator and Xplane 11. Microsoft Flight Simulator is a realistic flight simulator that allows you to fly over any location in the world using satellite data and current weather conditions. It allows graphics and performance settings where graphics and performance can be optimized. Night flying and live atmosphere provide opportunities to test your piloting skills with night flying and real-time simulated weather. Flight planning provides options to create your own flight plan to any location on the planet.

Figure 4 Simulator in use during class session

Virtual reality (VR) offers substantial educational potential by allowing students to develop skills in a risk-free environment. VR simulations are particularly valuable for teaching emergency skills and can reveal critical obstacles to consider in real-life scenarios. This technology enhances students' abilities in simulations by closely replicating real environments, which significantly boosts both their knowledge and practical skills [14]. Additionally, VR brings a fresh, innovative approach to learning, fostering greater participation and encouraging critical thinking. By immersing students in realistic scenarios, VR holds their interest and makes learning more engaging and enjoyable, ultimately improving their understanding of the material. VR also proves especially beneficial during situations like pandemics, as it enables students to experience a classroom-like atmosphere remotely. Furthermore, VR's efficient use of time and resources makes learning both more effective and cost-efficient, creating a high level of interest and satisfaction among students [13]. Other big advantages that these technologies bring are:

- **Engaging and Motivating [4]** - VR, AR and MR technologies are revolutionizing education by providing immersive and engaging experiences that fuel students' curiosity and enthusiasm for learning. Research consistently shows that these technologies increase student motivation and interest in the subject matter. By transporting students into virtual worlds and offering interactive learning experiences, VR, AR and MR foster a sense of excitement and adventure that makes learning enjoyable and engaging. These technologies motivate students to explore new concepts, acquire skills, and actively participate in learning, ultimately preparing them for real-world applications of knowledge.

- **Work Environment and Situations [4]** - Supplement aviation education by offering students realistic situations and insights that go beyond traditional learning methods. These technologies simulate cockpit environments, historical landmarks, and flight scenarios, providing hands-on learning opportunities that are both engaging and educational. By leveraging VR, AR, and MR, educators can enhance students' understanding of complex aviation concepts, improve their decision-making skills, and promote inclusivity by adapting to different learning needs. These innovative tools prepare students for real-world challenges in the aviation industry while fueling their curiosity and passion for flying.

- **Safety [5]** - Virtual simulations provide a safe environment for students to practice and hone skills without the risk of injury or damage to equipment. This is especially important in aviation education where hands-on training can be dangerous and costly.

Naturally, in addition to practical training, research in the field of crew performance and aviation safety for these systems includes the study of the safety of approach and landing procedures for aircraft at airports without powerful ground-based radio navigation equipment, as well as the investigation of the psychophysiological stresses on pilots during different phases of flight using various flight data display methods. In addition, the research addresses the psychophysiological load on pilots during different phases of flight using different self-regulation techniques and navigation procedures during different phases of flight, modelled using a Geographical Information System (GIS) for integrated processing of Global Navigation Satellite System (GNSS) measurements, thus further enhancing crew performance and aviation safety. Simulation training has already proven its worth, especially in a military context. Research suggests that pilots who initially trained on simulators required less in-flight training time to reach a satisfactory level of proficiency. Simulators serve as an effective substitute for the costly and limited resources, as well as the dangerous situations that occur in military operations. This frees up important facilities, such as runways, that may be unavailable due to operational requirements and facilitates safe training for critical operations such as flight and air traffic control. In addition, simulation training offers immediate feedback, enabling faster and more accurate learning by allowing learners to self-correct errors before their consequences become widespread. The same can be said for training and learning using simulators based on reality editing [1]. These systems have many advantages and positive aspects that make them rapidly expanding and finding application. Simulation training with the help of simulation means together with VR,AR has of course its problems and shortcomings, the most frequent of which are:

- **Technical requirements and compatibility [3] -** The technical solutions on which these technologies operate are often not perfect and contain many programming errors that spoil the impression and often even make the system dysfunctional. Also the hardware on which the whole solution runs is expensive and also prone to corruption. In the event of a failure where components need to be replaced, this is a significant financial loss that not every institution can afford,

- **Health drawbacks [3]** - In particular, prolonged use of VR headsets can lead to discomfort, eyestrain and nausea in some users. Educators and staff who use these devices must consider the potential health and safety risks associated with immersive technologies and take appropriate measures to mitigate them.

These shortcomings need to be addressed as soon as possible so that the systems can spread further and attract more users.

3. CONSIDERATIONS OF INTEGRATIONS

The introduction of state-of-the-art technologies such as Virtual Reality (VR), Augmented Reality (AR) and Mixed Reality (MR) into educational facilities, especially in the specialised field of aviation, requires careful consideration of various factors. As these immersive technologies continue to evolve and expand their capabilities, educators and institutions must navigate a complex environment full of opportunities and challenges. Training and support using virtual reality (VR), augmented reality (AR) and mixed reality (MR) opens up new possibilities in staff and educator training and development. These technologies can be used to train your employees in a variety of areas such as workplace safety, equipment operation, soft skills, project management, and more [9]. These training sessions can be more effective and fun than traditional methods, leading to better retention and application of learned skills in practice. The benefits this brings are for example [7][8]:

- **Interactive Simulation Environments -** VR and MR can provide an interactive and realistic simulation environment where staff and educators can practice different scenarios and skills without the need to access real equipment or locations.
- **Demonstrations and visualizations -** AR can be used to demonstrate and visualize complex concepts and processes directly in a real-world environment, allowing staff and educators to better understand and retain the curriculum.
- **Personalised training programmes -** VR and MR can enable the creation of personalised training programmes that are tailored to the individual needs and preferences of staff and educators.
- **Remote Learning** - With VR and MR, staff and educators can effectively train remotely, regardless of their geographic location, enabling flexible and efficient learning.
- **Decision support -** VR and MR can be used to simulate different work situations and problem scenarios, allowing staff and educators to train their decision-making skills and improve their performance.

These technologies offer many opportunities for training and support for staff and educators and can lead to improved performance and efficiency[10]. Virtual Reality (VR) has revolutionised the field of flight training. With advances in technology, more and more instructors and pilots are choosing to use this tool to provide a more realistic and effective immersion experience in the aviation environment. Virtual reality can be used as:

- **Flight Simulations -** VR allows pilots and future pilots to simulate a variety of situations such as takeoffs, landings, emergencies and different weather conditions. These simulations are much safer and cheaper than traditional simulators.
- **Airborne training -** Pilots can use VR for training on board specific types of aircraft. They can practice instrument control, communication with the control centre and various manoeuvres.

- **Environment and Cockpit -** VR allows future pilots to explore the interior environment of the aircraft cabin. They can familiarize themselves with the layout of the instruments, control panels and seats.
- **Emergencies -** VR simulations of emergencies such as fire on board, engine failure or loss of orientation allow pilots to train fast and accurate responses.
- **Virtual tours of airports -** VR can be used for virtual tours of airports where pilots can see the layout of runways, terminals navigation points.

Overall, virtual reality allows pilots to get more hands-on experiential training and improve their skills before real flying. Collaboration in the field of virtual reality (VR) with industry partners in Slovakia can bring interesting opportunities and innovations. In this context, it is possible to collaborate with industrial partners and research institutions in the following ways. Cross-border cooperation programmes (Interreg): the European Union supports cross-border cooperation through project funding. Interreg programmes are one of the key instruments to address common challenges in areas such as health, environment, research, education, transport and sustainable energy. These programmes make it possible to finance activities that will lead to increased cooperation between regions sharing a common inter-state border. Development cooperation (SlovakAid): the Ministry of Foreign and European Affairs of the Slovak Republic provides official development assistance under the SlovakAid logo. The cooperation is based on a long-term strategic partnership and is characterised by a higher volume of funding. A development cooperation strategy is drawn up for each of the programme countries, specifying the objectives, priorities and modalities of bilateral development cooperation. The use of virtual reality in research is increasingly widespread and offers many opportunities for innovation and discovery. In the Czech Republic, there are institutions engaged in research and development in the field of VR. One of them is the Research Institute for Entrepreneurship and Innovation (VUPI), which deals with the use of VR in education and teaching. Collaboration with such institutions can bring new insights and opportunities for research in virtual reality.

4. FUTURE OF APLICABILITY

The future of virtual reality (VR), augmented reality (AR) and mixed reality (MR) holds great promise as these technologies continue to evolve and intersect with advances in artificial intelligence (AI). AI has the potential to greatly expand the capabilities and impact of VR, AR, and MR by enabling intelligent interactions, personalization, and automation. In VR, AI-powered algorithms can increase immersion by dynamically adapting virtual environments based on user behavior, preferences, and real-time feedback. This personalization can lead to more engaging and personalized learning experiences

Figure 5 Hardware responsible for running VR simulator

in education, including flight training scenarios tailored to individual learning styles and proficiency levels. Similarly, in AR and MR, AI algorithms can augment real-world environments with contextually relevant information, predictive analytics, and intelligent assistance. For example, AI-based object recognition and natural language processing can enable AR applications to provide real-time guidance and support for complex tasks such as aircraft maintenance or navigation. In addition, AI-based analytics and predictive modeling can optimize training simulations in MR environments, improving the efficiency of skill acquisition and decision making. However, as AI is increasingly integrated into VR, AR, and MR technologies, ethical issues around data privacy, bias, and algorithm transparency need to be carefully addressed to ensure responsible and fair deployment. Overall, the synergy between AI and immersive technologies has the potential to revolutionize education, training, and human-computer interaction and shape the future of more than just aviation education. By deploying and continuously implementing AI in simulators, the algorithm will incrementally improve as the amount of data provided to the system for learning and improvement increases. The same is true for student learning where the system monitors for periodic errors and can adjust the conditions in a way that encourages the student to avoid and prevent these errors early. The advantages of using AI are clear and speak in favour of its use, but they also bring some limitations. The problem arises with the necessary computing power used to function. Current VR systems already need a lot of power, especially on the graphics side, which is handled by the GPU. In the case of sophisticated AI systems, existing hardware solutions will need to be upgraded to at least meet the minimum requirements.

5. CONCLUSION

The implementation of VR, AR and MR technologies has undoubtedly increased the effectiveness of future training of pilots [6] and support personnel while minimising the associated risks. Students are now working with state-of-the-art tools, which promotes increased motivation to learn and adapt to new concepts [7]. In addition, university staff benefit from access to the latest technology, which enriches their work experience and allows them to stay on the cutting edge of their field. Looking to the future, artificial intelligence and virtual reality emerge as dominant trends, synergistically combining their strengths to propel aviation education into the future. As current systems used in universities and training institutions must evolve to take full advantage of these trends, continuous innovation becomes a necessity. It is essential to recognise the constant need for research and development and to ensure that pilot training programmes remain adaptive and responsive to new technological advances. In addition, fostering collaboration between academia, industry partners and technology developers is key to promoting innovation and maximising the potential of these transformative technologies in aviation education. Therefore, it is incumbent upon stakeholders to invest in the future of aviation education, embrace technological innovation, and cultivate a culture of forward thinking and collaboration as we move forward

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