2.4. USING VIRTUAL REALITY IN COMPUTER SCIENCE LESSONS ON THE EXAMPLE OF DRONE CONTROL EMULATORS

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Virtual and augmented reality technologies are increasingly being used in the educational environment, opening up new opportunities to improve the learning process and enhance the quality of knowledge acquisition. Their introduction is primarily aimed at creating conditions in which students are not limited to theoretical material but can learn knowledge through active practical activities, which is extremely important for modern education. Virtual and augmented reality provide immersion in a learning situation by simulating real-world conditions, which greatly facilitates the understanding of complex topics and helps to develop professional skills.

The successful implementation of such technologies requires coordinated action by all participants in the educational process. Students are the main consumers of educational services, who, as members of the digital generation, are accustomed to the constant presence of technology in their everyday lives. For them, the integration of modern digital tools into learning is not only attractive, but also quite expected. They want to see innovative solutions in the educational environment that meet the challenges of the times.

At the same time, teachers play an extremely important role as they are the leaders of innovation in the learning process. The effective use of virtual and augmented reality requires them to have appropriate methodological training and a willingness to change teaching approaches. It is teachers who have the necessary experience and understanding of the specifics of perceiving educational material, which allows them to reasonably determine the feasibility of using interactive technologies at certain stages of learning. Their active participation in the implementation of digital educational tools is the key to the effectiveness and efficiency of educational changes.

It is also necessary to take into account the position of educational institutions that play a key role in expanding the use of virtual and augmented reality in education. They should not only implement these technologies at the experimental level, but also integrate them into curricula at the systemic level. It is important to create the conditions for the widespread use of such solutions, in particular through the purchase of the necessary equipment, the development of training courses and staff training. In order to achieve high quality education, it is important not only to ensure access to the latest technologies, but also to effectively integrate them into the learning process, making them an integral part of educational practice.

Particular attention should be paid to the role of hardware, software and technology solution providers. They shape the market for educational technologies, determining the direction of their development. Innovative devices, software products, and interactive platforms they create directly affect the effectiveness of virtual and augmented reality in the educational process. Specialised events, the development of new products, and the improvement of existing solutions help to expand the possibilities of digital learning.

However, the most important aspect of implementing these technologies is not the devices or software products themselves, but their role as tools to improve the learning process. The main purpose of using virtual and augmented reality is not only to introduce innovations, but also to increase students' knowledge, facilitate the learning of complex topics and promote their professional development. The educational process is dynamic and constantly changing, so the integration of the latest technologies should be aimed at creating conditions for high-quality and effective learning that meets the current challenges and requirements of society.

The relevance of the study is due to the rapid development and integration of virtual reality (VR) and unmanned aerial vehicles (drones) technologies into various spheres of life, including education. Modern students expect to use the latest technologies in the learning process. At the same time, the study of computer science requires practice-oriented approaches, and drone control is becoming an increasingly popular skill. The relevance of the study lies in the need to find effective, safe, and cost-effective methods of teaching drone control. The use of VR emulators can solve the problems of the cost of real equipment, the risk of damage, and space limitations, providing a realistic environment for practicing piloting skills and understanding the principles of UAV operation as part of school computer science lessons.

An analysis of scientific sources shows a high level of interest in the introduction of augmented reality in the educational process, which is confirmed by numerous studies both in Ukraine and abroad. In particular, the work of Lucena-Anton et al. (Lucena-Anton, Fernandez-Lopez, Pacheco-Serrano, Garcia-Munoz, & Moral-Munoz, 2022) confirms that the use of augmented reality technologies activates students' cognitive activity, creating an exciting, playful and comfortable learning environment. Such technologies help to establish effective interaction between students, encouraging them to solve problems together, conduct reasoned discussions and develop critical thinking. Students note that augmented reality is an effective tool for learning, particularly in pedagogical disciplines, as well as for modelling and resolving conflict situations.

Similar results are presented in the works of Singh et al. (Singh, Kaur, & Gulzar, 2024), where it is noted that augmented reality allows for an organic combination of digital content with the real world, which greatly facilitates the understanding of complex concepts. In addition, these technologies provide teachers with the opportunity to diversify teaching methods, increasing student engagement and motivation to actively participate in learning. Scientists note that the use of augmented reality helps to build confidence in one's own knowledge, a positive attitude to the educational process, and an increase in the overall level of satisfaction with learning. The integration of augmented reality into the teaching of natural and technical subjects, such as physics, mathematics, biology, and history, is particularly effective, where visualisation plays a key role in learning.

Ukrainian scientists also recognise the prospects of using augmented reality in education, although the number of domestic studies in this area is still inferior to international ones. In particular, S. Lytvynova, O. Burov, and S. Semerikov (2021) emphasise that the flexibility of this technology allows it to be used both for individual learning and in group work, which contributes to the personalisation of the educational process in accordance with the needs of individual students. Augmented reality can be successfully applied at all levels of education, which is evidence of its universal nature.

Scientists note the particular value of AR technologies in distance learning, as they provide access to educational material regardless of the location of students. The systematic implementation of augmented reality contributes to the development of digital literacy and the formation of key professional skills required in the modern digital society. Integrating AR into educational materials not only expands the content of educational content but also increases its didactic effectiveness. This is especially important when studying complex scientific concepts, historical processes, or natural phenomena, as it promotes deeper learning.

A study (Semerikov, Lytvynova, & Mintii, 2020) on the domestic experience of introducing augmented reality into the educational process confirms its significant potential for increasing motivation to learn, developing cognitive abilities and learning in the format of interactive interaction. The study analysed modern AR/VR platforms, in particular, the feasibility of using Unity, Visual Studio, Google VR, and Vuforia tools for educational purposes. Particular attention is paid to the development of an optional course dedicated to virtual and augmented reality. This course aims to familiarise students with both the theoretical foundations of AR and the practical skills of creating innovative educational products.

The curriculum covers a wide range of topics, from building user interfaces to setting up geo-positioning systems and creating educational materials using platforms such as Vuforia. Feedback from participants showed a high level of interest in augmented reality technologies, their desire to continue their studies in this area, and confidence that the knowledge they acquired would be useful in their future professional activities.

Among the suggestions for improving the course, the most frequently mentioned was the need to increase the amount of practical training, which would allow students to better master the material through real-life projects. The expediency of integrating the course with STEM disciplines was also emphasised, which would provide a link between theoretical knowledge and engineering and scientific practices.

According to L. Tarangul and S. Romaniuk (2022), augmented reality is becoming particularly important in the field of information technology. Unlike virtual reality (VR), which completely immerses the user in an artificial environment, augmented reality (AR) combines the real world with digital objects, creating a new level of interactive educational experience. This approach contributes to the formation of a personalised interaction between the student and the learning content that corresponds to the individual style of knowledge acquisition.

The researchers point out that the lack of need for specialised laboratories makes learning with AR applications mobile and accessible anywhere with a smartphone or tablet. Modern mobile devices have sufficient technical characteristics to support

AR applications. There is a wide range of platforms on the market, including Vuforia, ARToolKit, Kudan and other libraries that provide tools for creating educational AR solutions, combining various multimedia elements and supporting work on most popular devices.

In addition, as shown in other studies, augmented reality technology can be an effective tool for modelling various practical actions and techniques. This opens up the possibility of practicing professional skills in a safe and controlled learning environment.

The purpose of this paper is to study the theoretical foundations and practical aspects of using virtual reality, in particular drone control emulators, as a teaching tool in computer science lessons, as well as to justify the feasibility of their implementation in the educational process.

Virtual reality is a modern trend in the use of computer technology that allows the user to immerse themselves in an artificially created world that exists only in the memory of a machine. However, true VR is not just a 3D image or 360-degree video, but a complex system that simulates reality through full sensory immersion. Just a few years ago, such systems were only part of experimental laboratories, such as NASA Ames, where the first immersive environments with primitive vector graphics were demonstrated in 1987. However, even then, they conveyed the key principle of VR - the feeling of being in another world, regardless of photorealism.

In general, the term “virtual reality” refers to an interactive technology that gives the user a sense of real presence in a simulated space. This is achieved not only through visual effects, but also through the synchronisation of movements, spatial sound and tactile feedback. For example, early systems such as the Placeholder project (1993) used wing movements to move as a virtual crow, and in the Osmose installation (1995), participants controlled the environment with their breath. Such solutions emphasise that VR is primarily about action, not passive observation.

The main hardware element of a VR system is a high-performance personal computer, but specialised devices play a key role. Modern VR helmets, such as the Oculus Rift or HTC Vive, do not just display stereo images - they provide binocular vision (stereopsis), where each eye sees slightly different frames, simulating depth perception. In addition, gyroscopes and accelerometers track even micro-movements of the head, and spatial sound adapts to the user’s position. For example, if a virtual sound source is on the left, when you turn your head to the right, its volume and timbre automatically change to maintain the illusion of localisation.

Tactile devices, such as touch gloves or suits, expand the boundaries of interaction. The Placeholder project used prototypes of trackers for both hands, as the one-armed Dataglove limited the feeling of full embodiment. Today, technologies such as haptic feedback allow you to feel the "touch" of virtual objects, such as resistance when you press a button or vibration when you hit it. Even systems that simulate temperature or pressure are being developed, although this is still an experimental area.

The prospects for VR go far beyond gaming. In medicine, virtual environments help train surgeons or treat phobias through immersive therapy. In education, students can "visit" historical events or study molecules in 3D space. Engineers use VR to design complex structures, and in the future, virtual offices may completely replace physical workplaces. For example, Microsoft Hololens technology (developed by graduates of the Art Centre College of Design) shows how AR/VR hybrids can integrate digital objects into the real world for collaborative work.

The most revolutionary may be neural interfaces that allow you to control VR without physical devices. Experiments with BCI (Brain-Computer Interface) have already demonstrated the ability to move in virtual space with the power of thought. This opens the door for people with disabilities, as well as for fundamentally new forms of art and communication.

Virtual reality is not just an "extended screen" but a new medium that redefines the concept of presence. From the primitive vector worlds of the 1980s to modern multi-sensory systems, VR continues to evolve, combining technology, neuroscience and creative design. And while today we wear helmets, in the future VR may become an extension of our consciousness.

Virtual reality (VR) is becoming a powerful tool in modern education, transforming traditional teaching methods and opening up new opportunities for students and teachers. One of the key benefits of VR is its ability to provide visualisation and interactivity, making learning more engaging and effective. Through virtual simulations, students can explore complex concepts such as cell structure, cosmic phenomena, or historical events in detail in three dimensions, which greatly improves their understanding of the material. For example, instead of passively reading about the solar system, students can "visit" it with a VR helmet, making learning more vivid and memorable.

In addition, VR helps to increase students' focus and engagement, as the virtual environment minimises external distractions. This allows learners to be fully immersed in the learning process, actively interacting with the content. For example, apps such as Google Expeditions allow you to take virtual tours of museums or historical sites, and Labster allows you to conduct complex laboratory experiments without the need to use real equipment.

An important advantage of VR is also safety, as virtual simulations allow you to model dangerous or expensive situations without any risk. Students can conduct chemical reactions with hazardous substances, practice flying an aircraft, or even find themselves in conditions that cannot be recreated in the classroom, such as the middle of a volcano or on Mars. This not only keeps them healthy, but also pushes the boundaries of the learning experience.

Studies show that VR improves memorisation and understanding of material through the effect of "learning by doing". When learners become participants in events or experiments, the information is better absorbed and retained in the memory for longer. This is especially useful for learning complex topics such as molecular biology, physics, or history, where abstract concepts can be visualised and "felt" in practice.

VR also opens up access to unique learning opportunities that would otherwise be unattainable. Students from anywhere in the world can visit famous museums, take part in virtual archaeological excavations, or observe rare animals in their natural environment. This is especially true for schools with limited resources, where organising real-life excursions or experiments is often difficult.

In addition, VR allows you to adapt learning to the individual needs of students, including children with special educational needs. For example, students with autism can practice social skills in a controlled virtual environment, and children with disabilities can "visit" places that would otherwise be inaccessible to them.

The interactivity and gaming elements of VR also increase student motivation, making learning a fun experience. Apps such as Minecraft Education or HistoryMaker VR allow students not only to observe but also to actively participate in the creation of content that develops creativity and critical thinking.

However, to fully implement VR in education, a number of challenges need to be overcome, such as the high cost of equipment, the need for teacher training, and the development of high-quality educational content. Nevertheless, Ukrainian schools are already taking the first steps in this direction by testing VR technologies in classrooms and libraries.

Virtual reality significantly expands the boundaries of traditional education, making learning more interactive, safe, and accessible. It not only improves the quality of learning, but also prepares students for life in the digital world, where technology

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plays a key role. The future of education will undoubtedly be closely linked to VR, and it is worth investing in its development now to provide students with the most advanced learning opportunities.

Table 1.

Advantages and opportunities of VR in education

Advantage	Specific opportunity	Example
Visualisation	3D visualisation of complex concepts and processes	Learning anatomy through 3D organ models, travelling through the solar system
Interactivity	Direct interaction with learning content	Virtual experiments in Labster, «touching» historical artefacts in digital museums
Safety	Modelling dangerous or expensive situations	Chemical experiments with toxic substances, evacuation training
Memorisation	The effect of «learning by doing»	Simulation of historical events as a participant, VR excursions to ancient civilisations
Accessibility	Overcoming geographical and physical limitations	Visiting the Louvre or the Great Barrier Reef without leaving the classroom
Individualisation	Adaptation of content to the student's level	Personalised simulations for children with special needs
Motivation	Gamification of learning	Mastering the material through the InMind 2 game (modelling emotions)
Practical skills	Training of professional actions without risks	Virtual medical operations, pilot training
Creativity	Ability to create your own virtual projects	Designing 3D models in Tinkercad VR, creating virtual exhibitions
Interdisciplinarity	Integration of knowledge from different subjects	The Volcano project (geography + chemistry + physics) in the VR environment

Drones are not only entertaining, but also become a powerful tool for studying various disciplines, from science to art. They help broaden students' horizons, motivate them to learn and make lessons more interactive. The use of modern technology in the educational process has long been a necessity, as young people live in a world where technology is developing at a rapid pace, and education must adapt to these changes.

One of the main advantages of drones at school is their ability to demonstrate complex concepts. For example, in physics classes, the laws of aerodynamics, gravity, and flight control principles can be taught. Students have the opportunity not only to observe the processes, but also to experiment by changing flight parameters and analysing their impact. This approach makes the learning process more engaging and helps students better understand how physical laws work in real life. In addition, the use of drones in the educational process can help to increase students' interest in technical sciences and motivate them to pursue further studies in engineering and aviation.

Geography and biology also benefit from the use of drones. Students can explore landscapes, analyse environmental features, and even conduct nature observations. Drones can be used for mapping, studying rivers, forests, and other ecosystems. For example, as part of environmental projects, students can assess the state of the environment and identify pollution problems. This helps to develop ecological thinking and a responsible attitude towards nature. Many modern environmental problems require detailed analysis and monitoring, and drones can become an indispensable tool in this process.

Computer science classes get another interesting opportunity - drone programming. By learning the basics of coding, students can learn how to create algorithms for automatic flight control. This not only develops logical thinking, but also introduces them to real-world technologies used in robotics, artificial intelligence and aviation. Thanks to such tasks, children acquire practical skills that can become the basis for a future career in the IT field. Programming drones helps to understand the basic principles of artificial intelligence and automated systems, which is extremely important in today's digital world.

Even the humanities can be made more interesting with drones. For example, history classes can conduct virtual tours of historical sites using aerial footage. Literature or art classes can also include creative assignments involving video projects or artistic imagery using drones. For example, students can create documentary videos about places of interest in their region or experiment with cinematic techniques. This allows them to combine technology with creativity, developing both analytical and creative thinking.

In addition to academic disciplines, drones promote teamwork and critical thinking. Collaborative projects, where students work together to plan tasks and analyse results, help strengthen collaboration and problem-solving skills. This is especially important in today's world, where teamwork is a key skill. In addition, the use of drones can develop leadership skills, as students have to take responsibility for certain aspects of a project when working in teams. In many fields of activity, the ability to work in a group, coordinate the efforts of different people, and solve problems together is now valued.

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However, introducing drones into the school process requires some preparation. Appropriate guidelines for teachers, curricula, and safety rules need to be developed. The use of drones requires adequate space, and schools should be able to organise flights without risking students. The cost of such devices should also be taken into account, although with the development of technology, prices for basic models are becoming more affordable. To overcome financial barriers, you can use grant programmes or cooperate with local companies that are interested in developing STEM education.

Attracting additional resources and partners can help to speed up the introduction of drones into the educational process.

In summary, drones open up great prospects for education. They make learning fun, promote the development of technical and creative skills, and allow you to apply the knowledge gained in practice. Thanks to , with the right approach, their use in schools can become not just an interesting addition, but an important element of modern education. Further improvements in technology and teaching methods will only expand the possibilities of using drones in the learning process, contributing to an interactive and dynamic educational environment. As technology continues to evolve, drones can play an even greater role in educating future generations, building the skills needed for a successful career in the modern world.

An unmanned aerial vehicle is lifted by the rotation of propellers, which generate lift. One of the most common types of drones is a quadcopter.

A quadcopter is an aircraft equipped with four engines with propellers attached to their shafts. Their rotation generates lift, which allows the drone to take off.

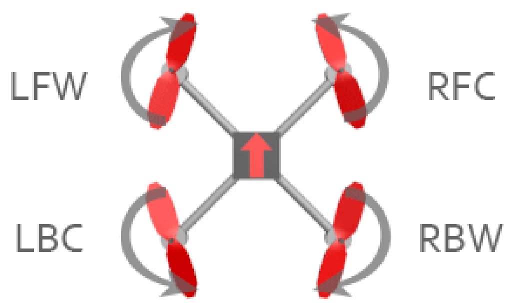

Fig.1 Direction of rotation of the screws and location of the motors.

The quadcopter is controlled by changing the power of the motors. To move forward or backward, the speed of the front and rear propellers changes. For example, to move forward, the power of the rear motors increases, and the front motors slow down, which also causes a slight tilt of the drone.

Turning works on a similar principle. When tilting to the left, the right motors rotate faster and the left motors rotate slower. To turn around, it is enough to change the speed of the diagonally spinning propellers.

Modern quadcopters are equipped with additional sensors and detectors, such as a barometer, GPS, or cameras for obstacle detection. This allows you to program the flight depending on the surrounding conditions.

The presence of sensors and special obstacle detection sensors significantly helps both beginners and experienced pilots avoid accidents. You won't find such sensors on budget models, but their presence in expensive equipment is more than justified. Depending on the settings and number of these sensors, the drone can either fly around an obstacle or stop at a safe distance from it.

Quadcopters usually support at least two flight modes: manual and autopilot.

Manual mode - in this mode, the control of the quadcopter is completely dependent on the operator, none of the internal systems stabilise or control the quadcopter. This is the most difficult mode, recommended for experienced users.

Stable Flight Mode/Space Orientation Mode - this mode uses an accelerometer to help stabilise the quadcopter. This mode is suitable for most beginners who are just starting to learn the basics of flying a quadcopter.

Altitude Hold Mode - In this mode, the quadcopter automatically maintains a set altitude using a barometer or other sensors. This simplifies control and allows the operator to focus more on the direction of flight rather than altitude control. The mode is useful for aerial photography and flying in difficult conditions.

Stabilisation with GPS - quadcopters with built-in GPS can use this mode. It is designed to capture high-quality videos and photos, as it allows you to keep the quadcopter in place. With the help of GPS, you can also perform autopiloting, holding the altitude and direction of flight.

As for how they can be controlled, there are a variety of ways to do so, allowing them to be used in a variety of areas - from entertainment and amateur filming to military and scientific purposes.

One option is to use a remote control that works on radio frequencies or WI-FI. The remote control is convenient via for real-time operational control, but it has a limited range, and in conditions of radio interference, the connection may be lost.

The most advanced control method is a fibre-optic connection. This method is used in professional and military drone models because it provides extremely fast data transmission speeds, minimising signal delay, and allowing the drone to

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respond instantly to changes in control, which is critical for complex flights. Another advantage is that it is not subject to electromagnetic interference and it is almost impossible to intercept data transmitted via fibre optics.

The main disadvantage of fibre optic control is its limited mobility. Since the quadcopter must be physically connected to the operator by a cable, this makes it impossible to use this method for long-distance flights. However, in certain conditions, for example, when exploring dangerous objects or in underground tunnels where radio communication does not work, this method is indispensable.

As for software, it is an important component of unmanned aerial vehicles (UAVs), as it guarantees autonomy, stability and efficient performance of tasks. The most popular drone control platforms include PX4 and ArduPilot (Colomina, & Molina, 2014).

PX4 is an open-source flight software stack that is primarily maintained by the Dronecode Foundation. It is known for its emphasis on accuracy, reliability, and modularity. Among the main features of PX4 is its modular architecture, which allows users to customise and extend the stack's functionality. Developers can create and integrate their own modules, sensors, or control algorithms, making it highly adaptable to different platforms and drone use cases.

The PX4 also provides advanced autopilot functionality, including support for multiple flight modes, obstacle avoidance, and even GPS-free navigation. These features make the PX4 an ideal choice for professional applications such as surveying, mapping, or search and rescue.

The PX4 is widely used in the commercial drone industry and is trusted by leading manufacturers. Its stability and accuracy have made it a popular choice for companies that need reliable software for their drones. The drone APIs allow you to write code to control and integrate with PX4-based vehicles without needing to thoroughly understand the vehicle and flight stack details or think about critical safety behaviours. In particular, our work has considered two of them in more detail.

ArduPilot, in turn, is another open source flight software stack that focuses on versatility and strong community support. It has been in development since 2007, and during this time, a large and active community of users has formed around it.

ArduPilot is compatible with a variety of drone hardware, including fixed wing aircraft, multirotors, and ground vehicles. This versatility makes it a popular choice among hobbyists, researchers, and professionals alike. This software has extensive documentation and is supported by an active online community. Users can find tutorials, guides, forums, and other resources to help them complete their drone projects.

It also includes a user-friendly ground control station (GCS) called Mission Planner. This intuitive interface makes it easy to set up a flight stack and plan missions.

The above programs work using MAVLink (Micro Air Vehicle Link), a protocol developed in 2009 that allows you to send commands to the flight controller firmware. The protocol is distributed under the LGPL licence as a module for the python programming language.

Thanks to this protocol, both programs provide high-level APIs that allow you to autonomously control the drone using the programming language of your choice.

For ArduPilot, the DroneKit package is particularly popular. It’s considered a powerful tool because it allows you to control your drone using simple functions without diving into the specifics of low-level hardware management. The downside is that it is considered somewhat outdated.

In PX4, the main high-level interface for vehicle management is the MAVSDK. It functions similarly to ArduPilot’s DroneKit. And it is better in almost all respects: features, speed, support for programming languages, maintenance, and so on.

It is recommended to use MAVSDK because it is more intuitive, easier to learn, and supported on more operating systems, including less productive hardware.

However, if you already have experience with ROS or can use its out-of-the-box integrations (for example, for computer vision tasks), this option may be preferable. In general, ROS is usually the best choice for applications that require extremely low latency or deeper integration with the PX4 than is possible with MAVLink.

Drone control is a complex process that combines theoretical knowledge, technical aspects, and practical skills. It is based on the integration of hardware components, software, and flight modes that ensure stability, manoeuvrability, and mission accomplishment. It is important not only to understand how they work, but also to be able to adapt their use to specific operating conditions, taking into account weather factors, obstacles and possible external influences.

Each drone consists of several key components. The flight controller is the “brain” of the drone, which processes sensor data and regulates the operation of the engines for stabilisation and navigation. Modern controllers have advanced features such as autonomous navigation, environmental adaptation, and intelligent power management to improve energy efficiency.

Sensors include gyroscopes, accelerometers, barometers, magnetometers, and GPS modules. Gyroscopes and accelerometers help determine the speed and direction of movement, while magnetometers are used to adjust the orientation relative to the Earth’s magnetic field. GPS modules allow to determine coordinates with high accuracy, which is especially important for drones performing mapping or aerial photography tasks.

Motors and propellers generate lift and provide manoeuvrability. They can be either brush or brushless, and each type has its own advantages and disadvantages. Brushless motors, for example, offer greater efficiency and durability, making them ideal for professional drones.

The battery is the power source that determines the flight duration. The capacity and type of battery play an important role in a drone's performance. Lithium-polymer (Li-Po) batteries are the most common due to their high energy density, but they require careful maintenance and proper charging to prevent overheating and failure.

The communication system transmits commands between the drone and a control panel or ground station. It can use Wi-Fi, radio waves, satellite, or fibre optics to ensure a stable connection. Some modern models support a real-time video transmission system that allows operators to better monitor the drone during flight.

The drone is controlled by a remote control equipped with two joysticks. The left joystick adjusts the flight altitude and rotation of the drone, while the right joystick controls horizontal movements. The combination of these movements allows you to perform complex manoeuvres. In addition to traditional controls, some drones support mobile app or gesture control, which makes it easier for beginners to use.

Fig.2 One of the drone control panels

Flight modes. Modern drones have different flight modes. In Manual/Stabilised mode, the operator has full control over the drone without automatic stabilisation. This is the most difficult mode and requires a high level of training.

Altitude Hold mode automatically maintains the altitude, which makes it much easier to control, especially for beginners or when taking aerial photos.

Position Hold mode allows the drone to hold its position using GPS, which is useful when shooting video or working in difficult conditions, such as windy weather.

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Headless Mode allows you to control the drone regardless of its orientation, making it easier for inexperienced users to navigate.

Follow Me mode allows the drone to follow the operator or a selected subject, which is useful for dynamic shots such as cycling, running, or road trips.

The Return to Home mode allows the drone to automatically return to the take-off point, which is especially important in cases of loss of communication or low battery power.

In addition to these basic modes, some drones are equipped with additional features such as automatic obstacle avoidance, flight on predefined routes, and intelligent power management, which increase efficiency and safety.

These modes simplify operation and make flying safer and more efficient, allowing beginners and experienced operators alike to get the most out of their drones.

Drone emulators are special software packages that create a virtual environment for training, testing and debugging unmanned aerial vehicles. They simulate physical flight conditions, including aerodynamics, weather effects, control parameters, and sensor signal processing.

The main components of the emulator include: a physical engine that simulates the laws of physics, such as gravity, air resistance, inertia, and wind effects,

Aerodynamic engine - responsible for simulating drone flight, including changes in altitude, pitch, speed, and stabilisation.

Sensor modelling - simulates the operation of GPS, gyroscopes, accelerometers, barometers, cameras, and lidars.

Application Programming Interface (API) - allows you to interact with the simulation through code in Python, C++ or ROS.

Graphics engine - visualises the environment to ensure realism.

Modern simulators use highly accurate modelling algorithms, such as computational fluid dynamics (CFD) methods, to more realistically reproduce the air movement around the drone.

The advantage of emulators is their safety, as they allow you to learn without the risk of damaging a real drone. They provide flexibility by allowing you to simulate different weather conditions and flight scenarios, allowing you to practice your skills in a wide range of situations. Their scalability allows a large number of variants to be tested at no additional cost, making them an effective tool for research and training. Moreover, they are characterised by accessibility, as they do not require physical resources other than a computer, making them a convenient solution for both beginners and professionals.

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Today, there are many emulators that help to master the skills of drone control. Emulators take into account all the technical characteristics of a winged machine - from engine power, weight, and wind force to the specifics of fuel distribution in the wings, aerodynamic advantages and disadvantages, and stall conditions. The same simulators are used by novice navigators in maritime schools. Controlling a copter in the simulator is quite different from real life experience - instead of a special remote control, a joystick is used. If you use a smartphone or tablet, then control will be limited to a few buttons and tilting the device. In a real flight, drone control requires a completely different level of precision and coordination. Nevertheless, it is still useful to learn basic skills in an emulator, as it helps to avoid costly mistakes. In addition, this approach can be useful in computer science classes, helping students to better understand the principles of drone control, algorithms of their work, and develop programming and technical modelling skills. Switching from a joystick to a remote control will take some time, but it is much safer than trying everything out on real drones and risking damage. The main area of application for drones is teaching photo and video shooting. Shooting from drones opens up new opportunities for creativity, allowing you to get unique angles and shots that are impossible to make with a regular camera. In addition, drones are actively used in journalism, cinema and the advertising industry.

However, their use is not limited to filming. Drones play an important role in agriculture to monitor fields, in rescue operations to search for people, and in construction and inspections of hard-to-reach facilities. Thanks to advances in technology, the scope of drones is constantly expanding, making them an indispensable tool in various industries.

Fig.3 Drone sprayer at work

Having analysed modern emulators in detail, we will compare them based on their key advantages and disadvantages:

Fig.4 Litoff emulator logo

Liftoff by Immersion RC . This game is a leader on the Steam gaming platform in terms of content and the number of active users. It is equipped with a drone editor, pre-configured models, and integration with the Workshop, which provides access to a variety of drones, tracks, and settings created by other users.

The project has a wide range of maps, each of which contains several options for speeding through. A freestyle mode is available that allows you to perform trick manoeuvres with the accrual of points. The game progression system includes the accumulation of experience, opening cases, and unlocking visual customisations.

There is an option to fly in FPV mode for both experienced pilots and beginners. A mode with dynamic objects is also available, but it is implemented as a separate paid add-on.

Realistic control is ensured by extended support for various radio controllers and compatibility with FPV glasses.

Fig.5 Uncrashed emulator logo

Uncrashed: FPV Drone Simulator. This simulator is characterised by a lower content saturation, but it allows you to fully customise it. The peculiarity is that unlike Liftoff, where changing components affects the characteristics of the drone, in this simulator, the user directly changes the control parameters.

The latest update has significantly expanded the functionality, including the addition of a tool for creating custom maps in a convenient editor. This makes the simulator an effective tool for learning the basics of flying.

Users have access to a free map with interactive, moving objects. An important advantage is the variety of locations, including stadiums, abandoned car parks, parks, etc. In addition, the simulator allows you to configure a much wider range of parameters compared to similar applications, including gravity, aerodynamic drag based on air density and pressure, and propeller efficiency depending on gas levels.

Any joystick can be used to control the virtual drone, but the simulator works exclusively on PCs or laptops running the Windows operating system. There is currently no mobile version of the application.

Fig.6 Tryp emulator logo

TRYP FPV. The simulator is characterised by high quality graphics, which requires powerful hardware. For comfortable use on the recommended settings, you need a graphics card of at least RTX 2060, 16 GB of RAM, 26 GB of free disk space, and Windows 11.

The game offers the possibility of joining a specialised community on Discord, where users can discuss ideas and share experiences. Before the start of the race, the system offers to calibrate the joystick by performing simple manipulations at . The drone's characteristics can be adjusted by replacing its components.

At the initial stage, the user has access to four maps: winter mountains, desert, forest, and summer mountain landscapes. During the game, you can observe moving objects, such as climbers, cyclists, and racing cars, as well as practice manoeuvres in a complex landscape, including abandoned construction sites.

The popularity of the simulator is explained by its wide functionality, affordable price and high quality graphics, which ensures realistic visual perception.

For a more detailed analysis, a comparative table showing the main features of different simulators is provided below. This will allow you to assess their differences and determine the best choice according to the individual needs of the user.

Table 2.

Comparison and characteristics of emulators

Name of the simulator	Advantages	Disadvantages
Liftoff	High quality graphics and the ability to customise UAVs. Provides deep immersion in FPV flight. Compatible with FPV goggles and radio transmitters, which increases the realism of control. Relatively low cost. Easy to use, which makes it convenient for beginners.	Insufficiently realistic physics, which makes the simulator more like a video game. Limited applicability for FPV filming and drone racing.
Uncrashed: FPV Drone Simulator	Easy to set up. A large number of tracks and locations, including parks and abandoned car parks. Wide range of physical settings, including propeller efficiency depending on the throttle pressure. High flight realism.	High system requirements that require powerful hardware. Relatively high cost compared to other simulators. No support for Apple devices.
TRYP FPV	High quality graphics. A large selection of dynamic objects that can be observed (cars, motorcycles, bicycles, climbers, runners, etc.). The ability to practice stunts. The most realistic physics among the presented simulators. Affordable price.	High system requirements.

Training in drone control and programming can be carried out both on real devices and in emulators, and from a financial point of view, the use of emulators is much more cost-effective, especially at the initial stages of training. The cost of training with real drones is much higher, as you need to buy the drone itself, with prices ranging from $300 to $1,000 for basic models and from $2,000 to $10,000 for professional ones. Added to this are the costs of repairs, as beginners often make mistakes that lead to damage, and replacing screws can cost $20-50, while camera or body repairs can cost $100 to $500. In addition, additional equipment such as FPV goggles, controllers, batteries, and charging stations can add another $500 to $2,000 to the total cost of training. The limited flight time, which averages 10-30 minutes on a single battery charge, also requires the purchase of additional batteries or charging costs, and flying in special zones may require the rental of sites, which creates additional costs. In comparison, simulator training is much more affordable, as most emulators cost between $20-100, do not require any repair costs, additional equipment, and allow for unlimited attempts without risk of damage, making them a cost-effective training solution for both beginners and professionals.

Drone racing is the latest form of eSports that has emerged on the border of virtual reality and aeromodelling, which is a small quadcopter racing competition on a specially equipped track. The track at the Kyiv Palace of Children and Youth is marked with ribbons and chips. The track is looped, the start coincides with the finish, there are specially set up obstacles, is equipped with devices for timing and systems for broadcasting the video stream of participants to a large screen.

Ukraine hosts various drone racing competitions for children and young people. One of the centres of such competitions is the Kyiv Palace of Children and Youth, which regularly organises aerial robotics tournaments. In particular, in 2023, the Palace Cube Drone Racing competition was held, where participants demonstrated their ingenuity and skill in flying drones. Such events help to promote drone racing and engage young people in technical creativity.

An exciting drone flying competition was held in Zhytomyr. It was attended by 40 schoolchildren from 17 educational institutions of the city. The youngest participant was only 10 years old, and the oldest was 17. The competition was held in three categories:

Simulator operation - a virtual race where participants demonstrated their drone control skills in a digital environment.

Overcoming obstacles - a challenging trajectory that had to be completed using real drones.

Labyrinth - participants competed on the simplest quadcopters, overcoming difficult routes.

The organisers of the competition prepared an impressive prize fund. The winners of the individual championship received drone control panels worth about UAH 6 thousand. The competition was also supported by sponsors and the Education Department of Zhytomyr City Council.

The winners received remote controls for their drones, and the best participants were invited to continue their education in specialised clubs.

Participation in such competitions allows students to better understand the principles of aerodynamics, the structure and functioning of unmanned aerial vehicles. This contributes to the development of engineering thinking and technical literacy, which are important components of modern education. For example, in Zhytomyr, there is a robotics club called RoboticsZT, where children learn to pilot drones, starting with simple models and moving on to more complex FPV drones.

Conclusions . Based on the study, it can be argued that virtual reality (VR) opens up significant prospects for modernising the educational process, providing a high level of immersion, interactivity and visibility. This contributes to a better understanding of complex topics and increases student motivation. In this context, drones are emerging as a relevant interdisciplinary tool that combines knowledge of physics, computer science, geography and other fields. However, their direct implementation in school practice is associated with financial and security challenges. Drone control emulators, as a specific VR application, effectively overcome these obstacles by providing a safe, accessible, and cost-effective environment for learning piloting skills, studying the principles of UAV operation, and simulating various flight conditions without the risk of damage to real equipment.

The use of VR emulators such as Liftoff, Uncrashed, or TRYP FPV in computer science classes not only teaches the basics of drone control, but also develops important competencies: spatial thinking, problem-solving skills, understanding of software and hardware interaction, the basics of algorithmisation, and even programming through appropriate APIs (e.g. MAVSDK). The availability of various simulators allows you to choose the best tool depending on your learning objectives and technical capabilities. The practice of holding drone racing competitions confirms the high motivational potential of this area. Thus, the integration of VR drone control emulators is an appropriate and effective step to modernise computer science lessons, making learning more practice-oriented and preparing students to interact with advanced technologies.

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