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INFORMATION AND SOFTWARE OF VIRTUAL REALITY TRAINING APPLICATION «NATURAL GAS DRYER PLANT»

ІНФОРМАЦІЙНЕ ТА ПРОГРАМНЕ ЗАБЕЗПЕЧЕННЯ НАВЧАЛЬНОГО ДОДАТКУ ВІРТУАЛЬНОЇ РЕАЛЬНОСТІ «УСТАНОВКА ОСУШКИ ПРИРОДНОГО ГАЗУ»

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Abstract. *Traditional training methods for natural gas dehydration plant operators have several limitations. Theoretical training may need to provide more insight into real-world working conditions, while practical training can be dangerous or require significant financial investment. Virtual reality (VR) technology offers a potential solution to this challenge by enabling the replication of the natural gas dehydration plant experience in a safe, immersive digital environment. This research project has developed a software application that simulates the operation of a natural gas dehydration plant using VR technology. The article describes the world background and possible alternatives for the project's hardware and software implementation. Finally, the virtual environment was created using the Unity game engine, which incorporates Open VR and VRTK plugins to enable user interaction and navigation. The application allows users to explore the plant freely, interact with equipment and tools, perform standard operating procedures, and respond to emergency scenarios. The project has several scenarios controlled by the tutor that need to be solved by the student. All scenarios involve visual effects to increase immersion. A multi-user mode and voice chat functionality have also been implemented to facilitate collaborative learning. The development of this VR training application addresses the need for practical, hands-on learning in the natural gas industry, where actual equipment can be prohibitively expensive or hazardous. By providing a realistic, interactive virtual environment, the application aims to enhance the skills and understanding of natural gas dehydration plant operators, improving safety and operational efficiency. The application was developed on request and in close cooperation with the Department of Chemical Engineering at Sumy State University. The findings from this research can serve as a basis for further development of VR applications in various industrial and educational domains.*

Анотація. *Традиційні методи навчання операторів установок осушки природного газу мають кілька обмежень. Теоретична підготовка не завжди забезпечує достатнє розуміння реальних умов роботи, тоді як практична підготовка може бути небезпечною або потребувати значних фінансових інвестицій. Технологія віртуальної реальності (VR) пропонує перспективне рішення цієї проблеми, дозволяючи відтворити досвід роботи на установці осушки природного газу у безпечному, захоплюючому цифровому середовищі. Розроблено програмний додаток із застосуванням технології VR, який імітує роботу установки осушки природного газу. У статті обговорюються світовий контекст та потенційні альтернативи апаратно-програмної реалізації проєкту. Після детального аналізу для реалізації проєкту обрано ігровий рушій Unity, та плагіни Open VR та VRTK для забезпечення взаємодії користувача та навігації. Додаток дозволяє користувачам вільно досліджувати станцію, взаємодіяти з обладнанням та інструментами, виконувати стандартні операційні процедури та реагувати на надзвичайні ситуації. Проєкт включає кілька сценаріїв надзвичайних ситуацій, які ініціюються викладачем. Усі сценарії мають візуальні та звукові ефекти для посилення відчуття занурення. Для полегшення спільного навчання також було реалізовано багатокористувацький режим та функціональність голосового чату. Розробка цього навчального додатка VR спрямована на потребу в практико-орієнтованому навчанні у газовій галузі, де використання реального обладнання може бути надзвичайно дорогим або небезпечним. Забезпечуючи реалістичне, інтерактивне віртуальне середовище, додаток має на меті підвищити навички та розуміння операторів установок осушки природного газу. Додаток розроблено на замовлення і в тісній співпраці із кафедрою Хімічної інженерії Сумського державного університету. Результати цього дослідження можуть слугувати основою для подальшого розвитку додатків VR у різних галузях промисловості та освіти.*

Keywords: virtual reality, educational process, simulation, Unity, Open VR, VRTK.
Ключові слова: віртуальна реальність, навчальний процес, симуляція, Unity, Open VR, VRTK.

INTRODUCTION

The informatization and globalization of social processes have given rise to a new virtual space. The global computer Internet network has provided millions of users worldwide with access to a vast array of information resources and services. Modern humanity has integrated mobile applications and virtual reality into their daily lives. Immersive technologies, such as virtual reality (VR) and augmented reality (AR), are increasingly being used in various fields, including design, construction, military technology, advertising, and the entertainment industry. These technologies have also had a significant impact on education, where online classes and virtual reality technologies have become integral to the learning process [1,2]. For example, the course "Accelerate: Accessible Immersive Learning for Art and Design" developed in frame of ACCELERATE (Erasmus+) [3] project. The course teaches to utilises VR technologies to provide tools for demonstrating 3D projections, encouraging distance learners, using interactive whiteboards, organising practical classes, and more.

The use of virtual reality (VR) technologies enables the provision of practical skills in fields where the use of actual equipment is either costly or impossible. For instance, it can be used to train military personnel in the use of large-calibre machine guns to shoot down the Shahid unmanned aerial vehicle (UAV). Another example is training personnel to operate large industrial equipment during emergencies. The aim of this project is to create a VR application for a natural gas drying station, including the development of its virtual space and an interface for user interaction.

LITERATURE ANALYSIS

State of the Art at VR educational applications

Every year, new technologies are becoming accessible to the average user. The availability of equipment, such as the Oculus Rift headset released in 2012, has been a driving force behind this trend. These advancements have revolutionised our perception of video games, which have now moved into 3D space, and have transformed our understanding of the digital world. Virtual reality has become widely available and is now affordable not only for the entertainment industry (such as film, advertising, tourism, and games) but also for businesses (real estate development and sales/leasing, and marketing), government (the military, medicine, and education), and non-government sectors. Therefore, developing VR products and applications is not only a profitable business but also a practical solution to specific problems in certain industries.

VR technologies have been widely used in education and have significant research and innovation potential. The educational sphere currently faces several urgent tasks, with accessibility of education being the most important. Today, students worldwide have the unique opportunity to attend online classes, removing restrictions imposed by geography, time zones, and physical factors. Furthermore, recent global challenges such as the COVID-19 pandemic and the outbreak of a full-scale war have hindered communication, work, and learning for individuals, including those in the educational sector. These events have greatly impacted the development of online education.

According to an article on the tech website Built In [4], the use of virtual reality (VR) in classrooms is expected to increase significantly over the next five years. VR provides students with an engaging and exciting learning experience by transporting them to remote corners of the planet, enabling them to mix volatile chemicals and observe reactions without physical harm, and allowing them to see and interact with virtual worlds. As a result, the role of the teacher shifts from providing content to facilitating learning. Teachers will focus on creating conditions for learning, not on providing ready-made knowledge [5]. When developing VR applications for educational purposes, it is important to consider several key requirements:

- Immersive design.
- Easy to use.
- Significance of the goals being achieved.
- Adaptability to changes in learning goals.
- Measurability of the result [6].

Considering these requirements, we have researched several products in this category. Body VR [7] is a virtual reality educational experience that allows users to explore the human body. Users can travel through the bloodstream to observe how blood cells distribute oxygen throughout the body, study the function of organelles, and observe chemical reactions that occur within the human body (Fig. 1).

Mondly: learn languages in VR [8] is a language learning application that offers 30 different languages. The app provides scenarios that simulate real-life situations, allowing users to practice conversing with others on various topics such as ordering a drink in a cafe, taking a taxi, or booking a hotel room. This application uses virtual characters for deeper immersion in the learning scenario and provide instant feedback on your pronunciation, suggestions that enrich your vocabulary (Fig. 2).

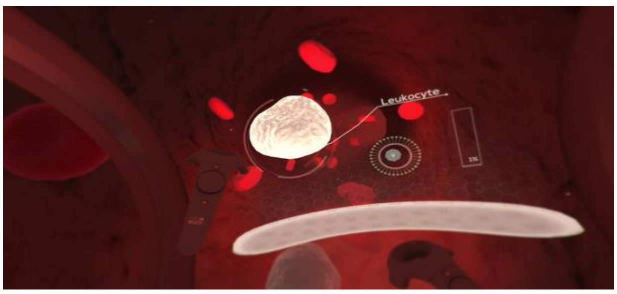

Fig. 1. Body VR application

Fig. 2. Example of learning situation at Mondly: Learn Languages in VR

The Transfr automotive [9] virtual reality simulator offers an interactive car repair course. The simulator creates a realistic environment of a car workshop and includes practical modules aimed at independent learning (Fig. 3). The system covers various aspects of vehicle maintenance, such as general inspection, equipment safety, oil changes, bodywork, painting and tooling.

Fig. 3. Transfr automotive application

Another example of learning how to perform complex technological processes is implemented by the FL Techncs Virtual Reality Training application [10]. The VR training system focuses on detailed simulation and training of various aspects of aircraft maintenance (Fig. 4). The system provides an immersive learning environment and includes virtual replica aircraft on which mechanics can inspect components and perform maintenance and repair procedures. Training covers a wide range of tasks from simple inspections to complex repairs such as opening and servicing an engine, allowing mechanics to practice procedures in a safe and controlled environment.

Fig. 4. FL Techncs Virtual Reality Training application

Hardware platform

The first developments of virtual reality date back to the nineties of the previous century, but the actual "boom" of innovative VR devices has manifested itself in our time. Modern virtual reality glasses and helmets (or their generalized name, VR headsets) provide a high-quality, bright and clear picture, and most importantly, they have become available to everyone. The most common and popular devices are the following.

1. Valve Index is a very progressive and technological model of consumer VR sets. It has a high display resolution and refresh rate. It uses base stations to track the user's position. The controllers have built-in sensors for tracking the position of human fingers, which opens a new level of interaction with the virtual space.

2. HTC Vive is a set that has proven itself over time. Accordingly, it is compatible with various applications and libraries and has gained popularity among users, software developers, and enthusiasts. However, it uses somewhat outdated solutions and technologies.
3. HTC Vive Cosmos is an updated version of the previous helmet. It has a higher resolution and frequency of displays, built-in headphones, and updated controllers. The main advantage is the ability to use a hybrid operation mode, eliminating the need for base stations.
4. Oculus Quest 2 - unlike its predecessors, it is a fully autonomous device, as it has a built-in computer. This fact significantly affects the final cost of the product. All other parameters are average for this class of devices.

After considering the advantages and disadvantages of each product, we chose the Oculus Quest 2 (Fig. 5) as a compromise between price, performance, and quality. The device's complete autonomy was the decisive factor, as it significantly improves the user's mobility, which is essential for high-quality distance learning. Additionally, the headset has a built-in microphone and headphones, enabling voice communication between system users.

Fig. 5. Oculus Quest 2 VR set [11]

To make full use of the technology, you require an accessible area that is at least one and a half meters wide and long, allowing for unrestricted movement. Removing all objects from the surrounding area is also advisable to avoid accidentally hitting them during the training process. Once connected, calibrate the device, and build guard walls to create a virtual user space.

Although our focus is on a standalone device, we must ensure maximum compatibility with all possible VR headsets to reduce the entry threshold for virtual reality training. Therefore, we need to consider the requirements for running our application on helmets that work in tandem with personal computers. The minimum requirements for the HTC Vive [12] are higher than the capabilities of the Oculus Quest 2, so the software developed for it will be compatible with other platforms.

Software Farmwork

There are several solutions available for developing applications using virtual reality technologies. One of the most popular open standards for developing VR/AR applications is OpenXR [13] that implemented by multiple libraries and frameworks. For small development teams, the choice often comes down to two products Unreal Engine and Unity that both can utilize this standard. While primarily game engines, these applications have sufficient capabilities when used correctly. The principles of operation are the same, so other factors should be considered when making a choice. It is important to note that this comparison is not exhaustive and other factors may also be relevant. Unity has several competitive advantages, including the use of the standard C# programming language, a drag and drop interface, and extensive library of ready-made assemblies and plugins (both paid and free) for application development. On the other hand, Unreal Engine offers a visual programming system, a powerful post-processing system and particle simulation, high-quality visual effects, and an advanced animation system.

The key aspects when choosing Unity were the rich library of ready-made models and plugins, as well as the ability to run the application on devices with limited resources.

OBJECT, SUBJECT, AND METHODS OF RESEARCH

To create a realistic environment, it is necessary to develop a model of a gas dehydration station. The station comprises of several cylindrical tanks, a gas treatment column, an elevator for personnel transportation, and barriers to restrict user movement and prevent unplanned exits.

At the primary level, these objects are represented by simple geometric shapes with basic textures, which means that our software product does not require powerful or specific tools. Autodesk 3ds Max is suitable for the task, particularly as it can be licensed for free for educational purpose.

We utilized various ready-made plugins from the Unity library to streamline the development process. The primary plugin on which the foundation of our application is built is OpenVR plugin Unity XR API [14]. This extension addresses compatibility issues between the helmet and our application, tracks the position of the head and controllers, and allows for easy customization of controls. Its primary function is to provide a unified interface for rendering on major virtual reality devices. In addition, we utilize the Virtual Reality Toolkit (VRTK) extension [15], which offers a range of pre-built solutions for creating Unity VR applications, including several standard features such as:

- movement in virtual space;
- interactions such as touching, grasping and using objects;

- interaction with Unity interface elements;
- simulate physics in virtual space;
- 2D and 3D controls like buttons, levers, doors, boxes, etc.

As a result of the systems described above, we can compose the interaction model of the used software in the form of a diagram (Fig. 6).

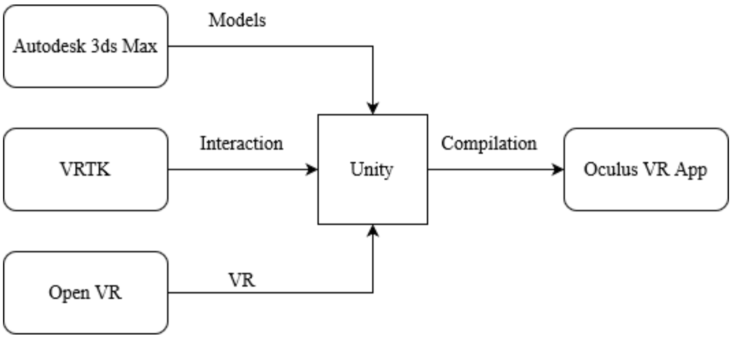

Fig. 6. Model of the interaction of program resources when creating a project

Creating a virtual space

The initial stage involves creating a 3d model of station for the application to operate within. The objective is to accurately represent the plant operator's experience. A model of the technological site of the natural gas dehydration plant was created using images from open sources (Fig. 7). The primary components of the plant include gas storage tanks, a compressor, and gas transmission pipes. When creating the model, we aimed to balance accuracy with free space availability to prevent a feeling of confinement. Model is presented on Fig. 8.

In the second stage, the model was exported to FBX format, which can be imported into Unity. Textures from open libraries were then applied, and several small objects from the Unity Asset Store were added to the interior to enhance realism. Finally, the camera was configured to render the Skybox, which helped to create the feeling that fields and forests were unfolding far beyond the station. In addition, we applied the Ambient Occlusion filter, which adds shadows from objects to the image, smoothing out sharp edges between components and creating a more cohesive picture. We also enabled light colour correction. The result, including the colour correction filters, is shown in Fig. 9.

Fig. 7. References for 3D model

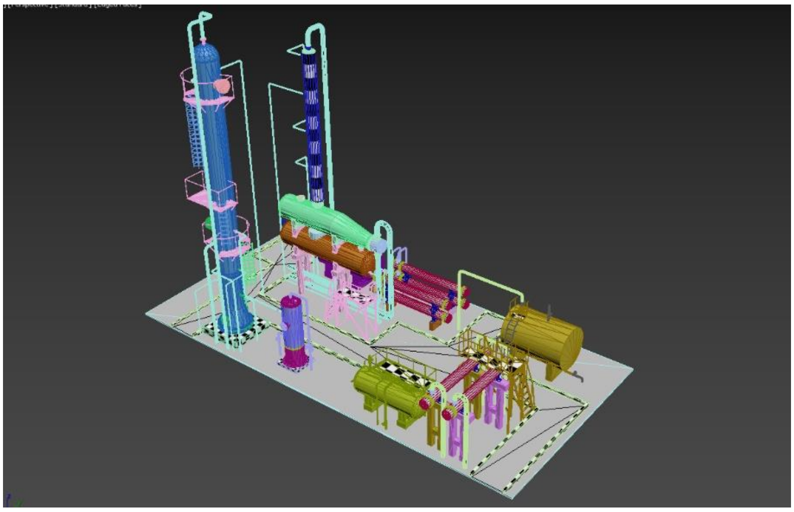

Fig. 8. 3D model for natural gas dryer plant

The image is acceptable, but it lacks dynamism. To bring it to life, we will use a free plugin “Living Birds” [16] to add birds to the scene. As developers, we need to create a bird controller object, configure its appearance and number, and mark the control points (Fig. 10) between which they will fly. Such a system may seem simple and inconspicuous at first glance, but it has a significant impact on the perception of the environment and can create a 'wow' effect.

Fig. 9. Visualization with Skybox and Post Processing

Fig. 10. Living Birds system

To enhance the effectiveness of training with this application, it is essential to demonstrate the processes that occur during natural gas drying inside the station. However, the column where these processes take place is closed and sealed. Opening it would compromise the realism of the scene and create an unrealistic situation. To resolve this contradiction, a special “X-ray” tablet was added that ignores the walls' rendering, allowing the drying process to be visible. To visualise the processes, we utilised Unity tools to work with the particle system and simulate fluid movement. Figure 11 show the outcome of a virtual environment and a tablet that provides extraordinary capabilities.

Fig. 11. “X-ray” tablet view

By using a tablet connected to the controller, the process of natural gas dehydration in the gas treatment column can be observed in detail.

To navigate between different place of station, a standard 'teleportation' method was implemented, taking into account the available surfaces for movement (refer to Fig. 12).

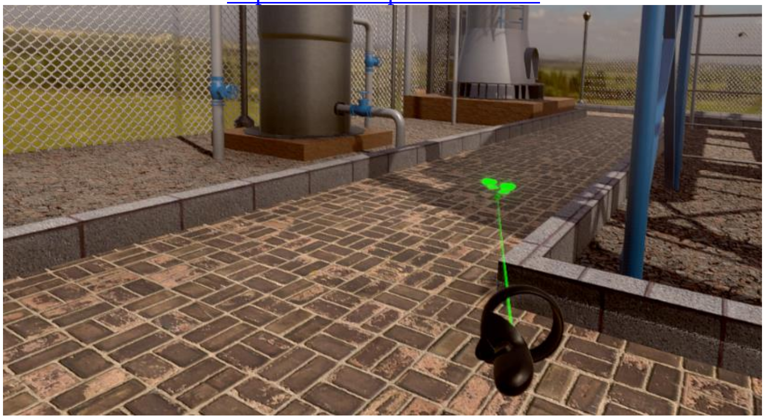

Fig. 12. Moving through VR space

The control room is accessed by a lift. Inside are six valves, implemented using the VRTK library tools, with additional modifications to their signatures and limits. To interact with the valves, the user must use the 'trigger' and rotate the controller around its axis, mimicking the movement of a person operating a real faucet handle.

The purpose of the application is not only to visualise the technological object, but also to simulate an accident scenario, complete with light and sound alarms. Users with administrator rights can start an emergency by pressing a special button. After pressing the button, a timer starts, and the student must move the valves to the correct position to prevent the system from depressurising. An alarm sound is added to immerse the user in a stressful situation. If the station cannot be repaired quickly, the system may depressurise, causing liquid splashes, smoke and sparks (Fig. 13).

Fig. 13. Visualization of an emergency

The application also facilitates corrective interaction and voice communication. It enables the user to practice working with technological equipment in various scenarios.

CONCLUSIONS

Virtual Reality (VR) enables the implementation of new learning scenarios by immersing students in environments that are difficult or expensive to recreate in real life. In response to the Department of Chemical Engineering's request, a VR application was developed to simulate the operation of a natural gas dehydration plant and allow for various accident scenarios. The application supports multiplayer teamwork and voice chat. Further work is needed to expand the library of training scenarios, including those that require teamwork to solve problems. The results obtained during the development of the application served as the basis for other software products.

Список використаних джерел

1. Імерсивні технології в навчанні, розроблені та впроваджені в СумДУ, презентовано на Форумі вищої освіти – Сумський державний університет // Новини СумДУ – Сумський державний університет. 2021. URL: https://news.sumdu.edu.ua/uk/news/11918-imersivni-tekhnologiji-v-navchanni-rozrobleni-ta-vprovadzheni-v-sumdu-prezentovano-na-forumi-vishchoji-osviti.html (дата звернення: 10.04.2024).
2. Liubchak V.O., Zuban Y.O., Artyukhov A.E. Immersive learning technology for ensuring quality education: Ukrainian university case // CTE Work. Proc. CEUR-WS, 2022. Vol. 9. P. 336–354.
3. Accelerate: Accessible Immersive Learning for Art and Design // Examenarium. 2023. URL: https://examenarium.sumdu.edu.ua/promo/program/230 (дата звернення: 10.04.2024).
4. Gossett S. Virtual Reality in Education: Benefits, Uses and Examples // Built IN. 2022. URL: https://builtin.com/articles/virtual-reality-in-education (дата звернення: 10.04.2024).
5. Babich N. How VR education will change how we learn and teach. Adobe XD Ideas // Adobe. 2019. URL: https://xd.adobe.com/ideas/principles/emerging-technology/virtual-reality-will-change-learn-teach/ (дата звернення: 10.04.2024).

6. How virtual reality is changing education // LSU Online. 2022. URL: https://online.lsu.edu/newsroom/articles/how-virtual-reality-changing-education/ (дата звернення: 10.04.2024).
7. The body VR: journey inside a cell // Steam. 2022. URL: https://store.steampowered.com/app/451980/The_Body_VR_Journey_Inside_a_Cell/ (дата звернення: 10.04.2024).
8. Mondly: learn languages in VR // Steam. 2017. URL: https://store.steampowered.com/app/1141930/Mondly_Learn_Languages_in_VR/ (дата звернення: 10.04.2024).
9. Virtual reality automotive mechanic training // Transfr Inc. 2023. URL: https://transfrinc.com/products/automotive/ (дата звернення: 10.04.2024).
10. Case study: virtual reality training at FL techncs // Aircraft IT. 2020. URL: https://www.aircraftit.com/articles/fl-technics-steps-into-the-future-of-training/ (дата звернення: 10.04.2024).
11. Meta Quest 2: immersive all-in-one VR headset // Meta. 2023. URL: https://www.meta.com/quest/products/quest-2/ (дата звернення: 10.04.2024).
12. What are the system requirements? HTC Vive // VIVE. 2023. URL: https://www.vive.com/eu/support/cosmos/category_howto/what-are-the-system-requirements.html (дата звернення: 10.04.2024).
13. OpenXR overview // The Khronos Group Inc. 2024. URL: https://www.khronos.org/api/index_2017/openxr (дата звернення: 10.04.2024).
14. GitHub - ValveSoftware/unity-xr-plugin: OpenVR plugin for Unity's XR API // GitHub. 2020. URL: https://github.com/ValveSoftware/unity-xr-plugin (дата звернення: 10.04.2024).
15. Welcome to VRTK // VRTK. 2023. URL: https://vrtoolkit.readme.io/docs/summary (дата звернення: 10.04.2024).
16. Living birds // Unity Asset Store. 2018. URL: https://assetstore.unity.com/packages/3d/characters/animals/birds/living-birds-15649 (дата звернення: 10.04.2024).

References

1. "Imersyvni tekhnolohii v navchanni, rozrobleni ta vprovadzheni v SumDU, prezentovano na Forumi vyshchoi osvity – Sums′kyy derzhavnyy universytet," Novyny SumDU – Sums′kyy derzhavnyy universytet", 2021. https://news.sumdu.edu.ua/uk/news/11918-imersivni-tekhnologiji-v-navchanni-rozrobleni-ta-vprovadzheni-v-sumdu-prezentovano-na-forumi-vishchoji-osviti.html (accessed Apr. 10, 2024).
2. V. O. Liubchak, Y. O. Zuban, and A. E. Artyukhov, "Immersive learning technology for ensuring quality education: Ukrainian university case," CTE Work. Proc., vol. 9, pp. 336–354, Mar. 2022, doi: 10.55056/cte.124.
3. "Accelerate: Accessible Immersive Learning for Art and Design," Examenarium, 2023. https://examenarium.sumdu.edu.ua/promo/program/230 (accessed Apr. 10, 2024).
4. S. Gossett, "Virtual Reality in Education: Benefits, Uses & Examples," Built In, 2022. https://builtin.com/articles/virtual-reality-in-education (accessed Apr. 10, 2024).
5. N. Babich, "How VR education will change how we learn and teach. Adobe XD Ideas," Adobe, 2019. https://xd.adobe.com/ideas/principles/emerging-technology/virtual-reality-will-change-learn-teach/ (accessed Apr. 10, 2024).
6. "How virtual reality is changing education," LSU Online, 2022. https://online.lsu.edu/newsroom/articles/how-virtual-reality-changing-education/ (accessed Apr. 10, 2024).
7. "The body VR: journey inside a cell," Steam, 2022. https://store.steampowered.com/app/451980/The_Body_VR_Journey_Inside_a_Cell/ (accessed Apr. 10, 2024).
8. "Mondly: learn languages in VR," Steam, 2017. https://store.steampowered.com/app/1141930/Mondly_Learn_Languages_in_VR/ (accessed Apr. 10, 2024).
9. "Virtual reality automotive mechanic training," Transfr Inc, 2023. https://transfrinc.com/products/automotive/ (accessed Apr. 10, 2024).
10. "Case study: virtual reality training at FL techncs," Aircraft IT, 2020. https://www.aircraftit.com/articles/fl-technics-steps-into-the-future-of-training/ (accessed Apr. 10, 2024).
11. "Meta Quest 2: immersive all-in-one VR headset," Meta, 2023. https://www.meta.com/quest/products/quest-2/ (accessed Apr. 10, 2024).
12. "What are the system requirements? HTC Vive," VIVE, 2023. https://www.vive.com/eu/support/cosmos/category_howto/what-are-the-system-requirements.html (accessed Apr. 10, 2024).
13. "OpenXR overview," The Khronos Group Inc, 2024. https://www.khronos.org/api/index_2017/openxr (accessed Apr. 10, 2024).
14. "GitHub - ValveSoftware/unity-xr-plugin: OpenVR plugin for Unity's XR API," GitHub, 2020. https://github.com/ValveSoftware/unity-xr-plugin (accessed Apr. 10, 2024).
15. "Welcome to VRTK," VRTK, 2023. https://vrtoolkit.readme.io/docs/summary (accessed Apr. 10, 2024).
16. "Living birds," Unity Asset Store, 2018. https://assetstore.unity.com/packages/3d/characters/animals/birds/living-birds-15649 (accessed Apr. 10, 2024).