Acta Montanistica Slovaca
ISSN 1335-1788
actamont.tuke.sk

Camera Modes in Multi-user Virtual Reality Applications in Industry 4.0

*Ján LACKO**

Authors' affiliations and addresses:
Pan-European University, Faculty of informatics
Tematínska 10, 851 05 Bratislava, Slovakia
e-mail: jan.lacko@paneurouni.com

***Correspondence:**
Ján Lacko, Pan-european university, Faculty of informatics, Tematínska 10, 851 05 Bratislava Slovakia
e-mail: jan.lacko@paneurouni.com

Funding information:
Grantová agentura academia aurea
GA/6/2021

Acknowledgment:
This work was supported by the grant agency Academia aurea under the project Advanced applications of artificial intelligence and data display in the industrial and medical domain (AAAI) no. GA/6/2021

How to cite this article:
Lacko, J. (2022). Camera Modes in Multi-user Virtual Reality Applications in Industry 4.0. *Acta Montanistica Slovaca,* Volume 27 (2), 281-290.

DOI:
https://doi.org/10.46544/AMS.v27i2.01

Abstract

This paper describes four scenarios of cooperation between a user in virtual reality and a user using interaction through computer peripherals. User cooperation is used in applications for Industry 4.0 in the field of employee training or in the deployment of digital twin companies.
Four scenarios are devoted to the possibility of displaying scenes and the use of avatars in virtual reality using outside in tracked headsets and a user using a monitor display with control via a keyboard and computer mouse. Within the scenarios, we define the VR view, the use of a free camera, the character mode, and the automatic orbit camera, the movement of which depends on the position and orientation of the user in space in virtual reality.
We show the applications of individual scenarios in a case study of user training in the field of mining and production in industrial enterprises.
In the tests, we compared the increase in productivity of employees after training with the use of assisted VR in a multiuser environment.

Keywords

virtual reality, multiuser environment, mining, Industry 4.0, workers training, cooperative virtual reality

Introduction

The use of virtual reality is a relatively common issue in Industry 4.0 today. It is used mainly in the training of employees for new job positions or in operation using a digital twin of the company. Together with augmented reality, virtual reality serves as a tool for mediating remote interaction with individual devices or in obtaining a response to the realized interaction. From the point of view of the competitiveness of industrial enterprises, the introduction of new methods into production and service processes is a necessity. For the needs of industrial enterprises in various domains, the practical possibility of using virtual and augmented reality is shown, especially in the process of training new employees for equipment operators (Roldán et al., 2019), the training aimed at protecting workers' health (Lacko, 2020) or for control and process synchronization using digital twin enterprise (Kuts et al., 2019). Each of the activities contributes to increasing the productivity of employees and ultimately reducing costs. As for many activities, thanks to virtual reality, the industrial environment can be simulated only as a 3D model, and workers can use remote access to the virtual environment.

An important prerequisite for the implementation of these activities is the creation of a specific virtual environment, which arises as a copy of the real environment of the company and the setting up of training processes for staff training (Carretero et al., 2021). For the design, creation, implementation, and evaluation of individual courses implemented in a VR environment, it is necessary to choose an appropriate methodology that supports individual-specific scenarios in different domains of use (Paszkiewicz et al., 2021). Within the domains in the industry, it is possible to use virtual reality to train employees and simulate processes in the domains of the automotive industry (Firu et al., 2021), mining (Barnewold, 2019), (Xie et al., 2018), agriculture (Kumari et al., 2021) or engineering (Górski, 2017).

In terms of creating a virtual environment, it is possible to create a single user environment, where the simulated process for the employee is implemented through a virtual wizard (text description, audio guide or predefined set of instructions), or a multiuser environment is created (Andaluz et al., 2018) in which the user is accompanied by a trainer directly in or outside the virtual reality and is represented in the scene through his avatar.

This paper will focus on using a multiuser environment to train employees in specific Industry 4.0 domains. We explored the possibilities of user cooperation with the trainer, where the user used the means of virtual reality (headset and controllers), and the trainer monitored the user and interacted with him through the computer screen. We explored the possibilities of their mutual interaction, each of which was represented in a virtual environment through a specific avatar. To explore the possibilities of interaction, we proposed 4 modes for camera movement, which represented the trainer in the virtual environment so that it was possible to display the virtual environment on individual devices effectively and minimize the problem of motion sickness (Chattha et al., 2020). As part of the training, we focused on examining the effectiveness of training in the field of mining and industrial production using various camera modes. In the research results, we monitor the degree of streamlining of training in the cooperation of the trainer and the user in virtual reality. During the discussion, we focused on the suitability of individual modes for specific applications and the possibilities of their expansion in the cooperation of several users in virtual reality with the trainer.

Methods

User interaction in virtual reality with a user outside of virtual reality is essential for some training scenarios. Coordinated collaboration in a virtual environment involves users interacting with virtual objects in a scene or interacting with each other through user avatars. In examining user interaction, we focused on ways of interacting with a user who is fully embedded in the virtual world through a headset and using controllers and a user who uses computer monitor displays and standard input devices (computer mouse, keyboard, or joystick) to interact. This way of cooperation in the virtual environment proved to be necessary for training users in virtual reality to operate some devices where the physical presence of a trainer who monitored the user in virtual reality and at the same time monitored his movement and coordination in the real physical environment.

As part of the research, we focused on four different scenarios for displaying the position and orientation of users in a virtual environment and on their mutual cooperation represented by camera modes:

- Motion mirroring
- Free camera
- Character mode
- Automatic orbit camera

Each of the camera modes can be used in specific applications created based on the requirements of the training process.

User avatars. For display purposes, we have created a specific set of user avatars so that it is possible to visualize their position and orientation in a virtual environment and so that it is possible to interact with them. Avatars vary in different scenarios. The virtual reality user avatar that is displayed in the scene to the user outside of virtual reality is represented by the 3D headset model (to obtain the position and orientation of the user's head) and the controller model, which expresses the position of the user's hands. To display the user outside the virtual reality in the virtual environment in the user's scene in the virtual reality, avatars are displayed in the form of a camera, which allows interaction with it as a physical object, respectively. As the user's character, which is for reasons of ergonomics, which we will describe more precisely in the description of the camera mode, realized as a scale model. In general, in all camera modes, the user cannot manipulate the avatar representing the user in virtual reality outside of virtual reality due to the possible loss of orientation in the 3D virtual space by the user, which can lead to motion sickness problems (Patrão et al., 2020). Motion sickness is most often caused by a disproportion in visual perceptions and signals from the user's vestibular system, but the effect may also be caused by other factors (Chattha et al., 2020). Figure 1 shows a user avatar outside of virtual reality in the form of a camera that is manipulable by the user in virtual reality.

Fig. 1. A 3D model of a camera representing a user outside of virtual reality

Virtual environment. To test the proposed methods, it was necessary to create a suitable virtual environment within which it would be possible to test the possible limitations of individual methods. When creating the environment, we focused primarily on meeting the basic requirements - sufficient space, variation of space in terms of distance of individual walls limiting the user's movement, and the ability to manipulate objects in a virtual environment. At the same time, we required the environment to be photorealistic so that the user would not feel immersed in a non-existent environment. Based on the selected requirements, we created two environments, obtained by different methods. The first environment was the environment of an old building obtained by the method of photogrammetry (Fig. 2). The environment provided enough space for the user's movement in virtual reality, and at the same time, it was possible to test the user's camera modes outside the virtual environment in large models. Today, photogrammetrically generated environments are used in combination with virtual and augmented reality in various areas - displaying cultural heritage objects (Dhanda et al., 2019), (Wahyudi et al., 2018), industry (Rudolph & Klinker, 2021) or learning (Janiszewski et al., 2020).

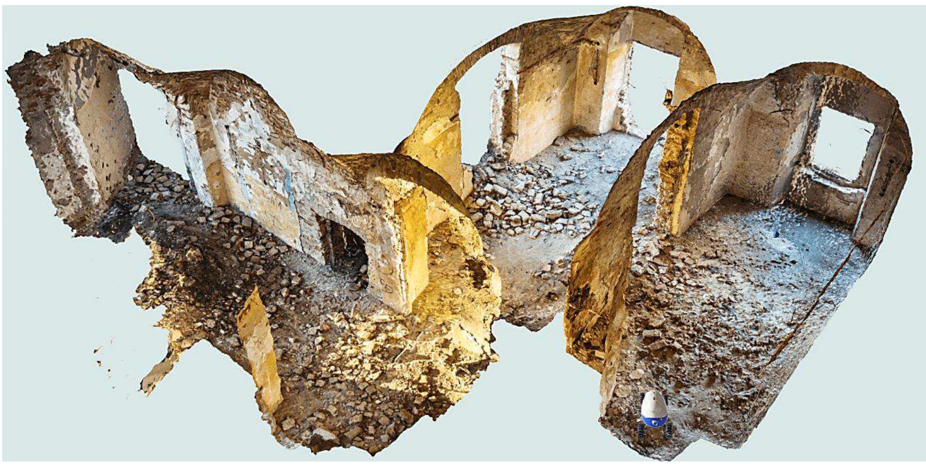

Fig. 2. 3D model of an old building obtained by photogrammetry methods

The second environment was a 3D model of the kitchen (Fig. 3), which was created by box-modeling methods to provide enough objects for interactive manipulation by both users, and at the same time, the space was narrow enough to test possible problems of individual camera modes, especially when using automatic mode orbit camera. When creating a photorealistic environment, we focused on the appropriate placement of reflection probes and reduced the needs of the scene to calculate lighting using static light sources and baked light textures.

Fig. 3. 3D model of a test environment for interactive camera modes created by box-modeling methods

Camera modes. The individual camera modes have been implemented so that they can be used to display the position and orientation of the VR user and non-VR user, interactively manipulate objects in the scene and move the non-VR user in the 3D scene. Each of the four camera modes can be used in different applications, which are based on the requirements for different levels of interactivity in a particular scenario or the possibility of manipulation with 3D objects. Implementation of interaction may vary through various scenarios (Gugenheimer et al., 2017).

Motion mirroring. The easiest way to display a user's view in virtual reality for a user outside of virtual reality is to mirror the movement of the camera on the screen. Simple mirroring of VR screen view is the standard, most direct way to observe VR content in terms of implementation. In most cases, this is the default way of displaying users in VR. In other camera modes, it is possible for the non-virtual reality user to turn on the view mirroring the user's virtual reality position for the non-virtual reality user in the upper right corner of the screen within the graphical user interface (Fig. 4). Motion mirroring reliably, accurately, and efficiently displays where the user is currently in the VR and in which direction he is looking or with which specific object he is interacting, which is the biggest advantage of using this type of camera mode in addition to ease of implementation. Since this type of observation does not provide any kind of interaction with the user in the VR, there was no need to implement interactivity between the VR and the non-VR user. There is no interaction on the part of the VR user either, as the non-VR user does not exist (as an avatar or 3D object) in the virtual world. This way of observing can cause motion sickness for outside viewers. Sharp movements of the user's VR head can easily cause a loss of orientation. One of the most common solutions to the problem of sharp movements is the smoothing of movements and rotation of the virtual camera for non-VR users. In the case of imaging, it is possible to reduce the rotation of the Roll camera (tilting the camera from side to side) for easier viewing. However, these changes apply only to the non-VR user and not to the VR user. The biggest disadvantages of VR view mirroring are the lack of virtual user interactivity in VR and the wider field of view (FOV) observation quality, as they have VR FOV display devices at 110°+ by default, which is not possible with the aspect ratio provided by conventional monitors without image distortion to achieve. This type of display is especially suitable for training where no input interaction between the user and the trainer from outside the VR is required.

Fig. 4. Camera mode for mirroring motion in the upper right corner of the scene within the implemented GUI

Free camera. The free camera allows the non-VR user to move freely around the virtual scene without any restrictions. This camera mode allows the manipulation of objects for the user without a VR headset (Fig.5). Various input devices can be used for the user's movement - keyboard, computer mouse, analog joystick, while the displacement in space can be defined in the individual axes X, Y, Z, and the rotation is defined by quaternions. For testing purposes, we controlled the user's position via an analog joystick, where one controller controls the camera movement and the other controls the camera orientation. The actual implementation of interactions and manipulations with other 3D objects in the scene is relatively undemanding but very effective compared to the following types of camera modes. A free camera for a non-VR user allows interactions with the environment and virtual 3D object models. The method of raycasting is used for interaction, while the beam for manipulating the object is guided by the center of the screen, which is marked by a target. After selecting the object, it is possible to move the 3D model in the direction of the individual axes using the local coordinate system of the camera.

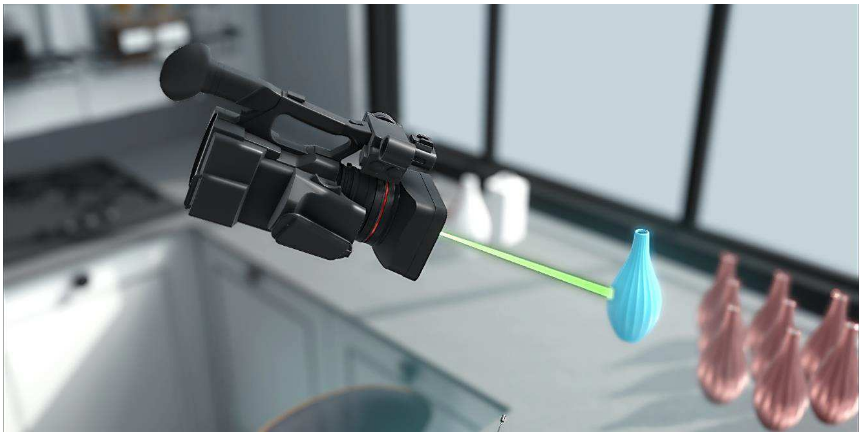

Fig. 5. Interactive selection of a 3D model using ray casting from the direction of the free camera to its center

The user in Virtual Reality can intuitively use his hands and monitored controls to catch, hold and orient the free camera in any direction or point. After grabbing the camera model, the free camera attaches to the user's hand represented by the controller, and as long as the user holds it, it can manipulate it just like any other standard physical 3D model of an object in the scene. While holding the camera in his hand, the watching non-VR user cannot move or rotate the camera. This logic ensures a firm grip in the user's hand in VR. After leaving the user's VR hand, the camera automatically rotates so that it does not roll. This straightens its engagement (Fig. 6). The biggest advantage when choosing a free camera mode is the unambiguous navigation and complete freedom of the camera location, whether for a user in a VR or a non-VR user. Another advantage is the intuitive interaction between users with and without an HMD headset for Virtual Reality. The main goal of this implementation was the complete freedom of movement of the camera and the ease of tracking the user in

Virtual Reality from any vantage point and angle. It allows you to quickly find a good shot of user actions in a virtual environment while also giving a choice of clear interaction with the scene and users in Virtual Reality.

Fig. 6. The direction of rotation of the free camera (roll) after the end of the user interaction in the VR with the camera

Character mode. The character camera allows the non-VR user to move around the virtual scene by navigating the avatar from a third-person perspective (Fig. 7). At the same time, the character's avatar allows physical manipulation of objects for users without a VR headset. The character is controlled similarly to a free camera; it is possible to change its position (shift) and orientation (scaling). Camera mode behaves like a third-person view in a scene. A series of movements using inverse kinematics can be applied to the avatar in this camera mode. The user in VR has the opportunity to grab the character in his hand and manipulate it as a physical object. Physical forces such as gravity and inertia act on the character. The character can be placed in places that are inaccessible during normal handling using a third-person camera. During prototyping, it turned out that the size of the character has a great influence on the intuitiveness of control and ease of navigation in the environment. For the user in VR, the sharp movements of the 180 cm tall figure near the head were unpleasant. For this reason, we scaled the avatar and position to 1/5 of the original height. The reduced size of the character prevents these inconveniences and facilitates control and overall orientation in the scene. Implementing this type of monitoring and interaction allows for a better virtual connection with the user in the VR. The non-VR user is in the scene as well as the VR user. It is possible to cooperate with each other during the interaction. The biggest disadvantage of using the character is the difficulty and speed of navigating the scenes. It does not allow you to move fast enough to more distant parts of the scene. However, the benefits of the character are manifested in the cooperation of multiple users. A user with more mobility for a given challenge can help other users. The character can easily get into very tight spaces and small spaces, and by adding dynamic scaling, the non-VR user can get almost anywhere in the scene. A user with a VR headset would not be able to reach these bottlenecks. Conversely, a character needs help from a user in VR to get to higher places unless the character's jump height is set enough. The user in VR can interact intensively with the avatar of the given camera mode.

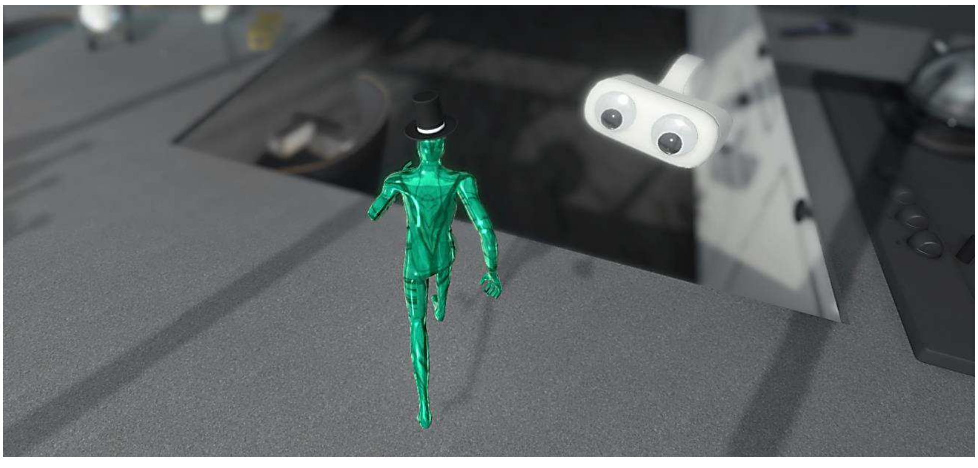

Fig. 7. Avatar of the character camera mode watched by the user in virtual reality

Automatic orbit camera. There are several benefits to choosing such a camera mode. One of them is the automatic smooth tracking of the user in Virtual Reality without any input from the watching viewer. It takes care of the automatic monitoring of the user's position, movement, and actions in the VR. The orbit camera is similar to third-party gaming cameras. The custom implementation allows you to set a large number of camera-related variables. One of the main adjustable values is the distance of the camera in any direction in which the camera will be moved relative to the monitored person or object. Figure 8 shows the set relative distance to the right, which frees up more space for the GUI on the right side of the screen. The user can also adjust the zoom of the camera to the subject. One of the key parts of the implementation of this type of camera is the automatic collision detection, from the pivot position around which the camera rotates to the direction of the current camera position. Collision detection between the camera and the monitored object ensures a clear view of the monitored object. The orbit camera cannot pass through walls or objects in the scene. The nearest collision point with the scene is always calculated as the farthest possible point of the camera from the subject. This ensures a view of the monitored person without any obstacles between the camera and the person. Such interaction with the environment defines the camera in the scene as a physical object existing in the virtual world that respects collisions. The green lines show the relative distance of the camera from the monitored object. The camera does not point directly at the virtual HMD in the scene but is dynamically offset relative to the camera to the right of the headset (Fig. 9). The camera can be controlled with a mouse or an analog joystick. As the user moves, the orbit camera automatically and smoothly orients itself in the direction of the subject. This provides a good view of the main area of user interaction in Virtual Reality. It also ensures a smooth change of orientation and position of the camera during large jumps of the monitored person, for example, when using teleportation as a way of movement in VR. The camera gradually accelerates and decelerates based on the distance from the subject. To increase user comfort in Virtual Reality, the movement of the orbit camera model in the scene is further smoothed. Self-testing has shown that sudden movements of large objects near the head of VR users cause discomfort, and the best way to solve this problem was to smooth out further the sharp movements of the camera model that the VR user sees. The advantages of this camera include ease of use, complete automation of person tracking, and comfortable and smooth tracking for both parties and users in VR and for viewers. However, the biggest disadvantage of this implementation is the lack of interactions between VR and non-VR users compared to a free camera that allows interaction with scene objects.

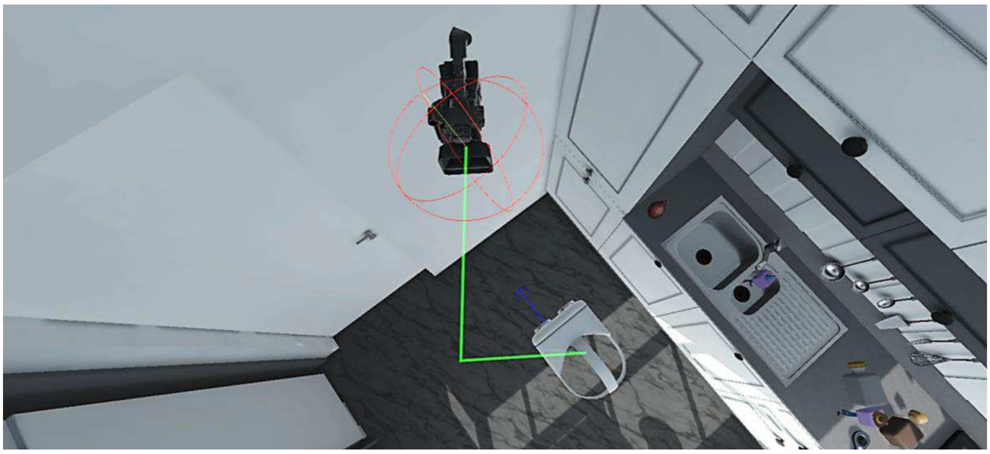

Fig. 8. Scheme of camera offset from the monitored object. The red sphere indicates the collider of the object, and the green lines show the offset of the camera from the user in VR

Fig. 9. View of automatic orbit camera on VR user avatar

Comparison of camera mode properties. In the following overview (Tab 1), we show selected key features of camera modes and their advantages and disadvantages.

Tab. 1. Camera modes properties overview

Key features	Motion mirroring	Free camera	Character mode	Automatic orbit camera
Interaction with objects	No	Yes	Yes	No
Automatic motion in the scene	Yes	No	No	Yes
Interaction with VR users	No	Yes	Yes	No
Automatically computed camera position	Yes	No (only partial roll)	No	Yes
Automatic camera roll correction	Yes	Yes	No	No
Possibility of motion sickness of non-VR user	Yes	Probably No	Probably No	Probably No
Possible avatar scaling	No	No	Yes	No

Results

We used the proposed methods for various camera modes in the training of workers in the field of mining and industrial production. We have designed two scenarios for training purposes. In both cases, staff training was conducted through a trainer who worked as a non-VR user. In the test scenarios, we selected relevant groups and created two comparison groups, where we monitored factors such as the effective use of time for training, the use of resources in the form of real devices or 3D models of these devices, and measuring the ability of users to perform real work based on training in virtual reality or training on real devices in a simulated environment.

Testing scenarios. The first scenario for staff training was focused on operating the Hydraulic Tunneling Drilling Rig for mining staff. Within the scenario, an environment was created simulating the work with the equipment in the tunnel, and the trained worker had to carry out the activities of operating the equipment according to the instructions of the trainer. The staff was completely immersed in virtual reality, and in the first phase of training, the trainer issued only voice instructions and watched the work of the trainee on a computer monitor using the camera mode motion mirroring. In the second phase, the free camera mode was used, through which it was possible to cooperate between the two users, and the trainer could display instructions directly to the trained user in virtual reality. Under this scenario, two groups were created (a total of 10 users, each with 5 employees), with the first group training using virtual reality training scenarios and the second group operating existing equipment outside the actual deployment in the tunnel. For the needs of the second test group, it was necessary to interrupt the actual operation of the facility for two days and to train staff outside the deployment in the tunnel due to the existing safety restrictions.

The second scenario was focused on training workers in an industrial company to operate Metal milling and drilling machines within engineering production. As in the previous scenario, two groups were created for testing purposes (14 employees divided into seven into two groups), while the first group used training in virtual reality using an automatic orbit camera and character camera modes. Within the VR group, the training focused on operating the facility and resolving the crisis situation, which was simulated specifically for the facility. In the first part of the training, the automatic orbit camera mode was used for the trainer, who monitored the user's work in a virtual environment on a computer monitor and issued voice instructions. In the second part, the character mode camera was used, and the trainer could watch the work from any position, and it was possible to interact with the user in virtual reality. The second group carried out training within the regular operation, during which it was necessary to set aside a machine for training new employees, and training of equipment operators was carried out. The crisis situation in the operation of the equipment and the way of reacting to the situation was explained in the real environment only in theory because it was not possible to implement it in operating conditions.

In both scenarios, we measured the suitability of the use of individual camera modes in the simulation of training for users in virtual reality and the suitability of imaging methods for the trainer as a non-VR user.

Effectiveness of use in workers training. Within the results of the training, the use of training methods in virtual reality proved to be more advantageous than the classical approaches for two main reasons. Due to training in virtual reality, it was not necessary to deal with machine downtime or part of the production line, which brought economic benefits to production operations, and in the virtual environment, it was possible to simulate critical and crisis situations for which it is not possible to prepare in case of training on real equipment.

The training showed that both groups of users (VR and non-VR) were able to deliver comparable performance after commissioning, but users who trained in the VR had automated operator crisis management procedures.

For the group that used VR training, we also focused on evaluating the use of individual camera modes from the point of view of VR users and from the point of view of trainers who were non-VR users. The questionnaire survey showed that it was more advantageous for VR users to be able to use modes in which they could interact with a user camera avatar outside the VR (free camera and character mode), as it was easier and more efficient for them to be able to view the user outside the VR a possible problem, resp. when they received instructions from a user outside the VR directly in virtual reality. It was also more efficient to use these interactive camera modes for non-VR users, as it was easier for them to follow the work of the trained user from a perspective they could choose.

Discussion

The presented methods of cooperation between VR and non-VR users have proven to be effective in terms of their use for training workers in different domains of industry 4.0. The presented results show that camera modes that are focused on cooperation are more suitable for training than camera modes that are focused more on observing the user with less interaction in the virtual environment. All four camera modes can be used in the same way for other different applications in other industries or service domains. In terms of implementation, it is possible to extend the existing camera modes with others that will simulate the movement of non-VR users in virtual space through different shapes and appearances of avatars with a differently defined way of moving in the scene (flying, speed-limited movement, ...).

Individual camera modes can be used in cooperative computer games and simulations, where the connection of multiple users in VR or outside the VR. In order to determine the appropriate way of mutual monitoring and interaction, it is necessary to determine what joint activities of individual users should be implemented.

The extension of the principles of camera modes can also be realized by connecting virtual and augmented reality methods. It is not possible to use a virtual reality headset mirroring monitor due to the smaller image width (FOV) compared to the FOV displayed in the headset to control user interaction in virtual reality, for example, in healthcare or patient rehabilitation (Šramka et al., 2020). At the same time, when controlling the patient from the therapist's point of view, it is necessary to choose whether to focus on the patient's movement and the accuracy of the movements he performs or to monitor his interaction in the virtual reality image on the monitor. By involving augmented reality methods using wearable devices (e.g., MS Hololens 2), it is possible to monitor the real movement of the patient and, at the same time, monitor selected parts of the virtual environment by the therapist. The connection between VR and AR methods is realized on the basis of the following principle: The user manipulates objects in virtual reality. The external user uses the augmented reality system by seeing the user and at the same time displaying the objects that the virtual reality user is manipulating through the augmented reality, these being displayed at the same distance from the user as they see in virtual reality.

The biggest challenge when using individual camera modes is the possible extension of the system to a combination of multiple users in the VR and several users outside the VR to share a common virtual space. In this case, it will be necessary to specify in the camera modes motion mirroring and automatic orbit camera to which VR user these cameras will bind and display non-VR users a specific shot. Using the character and free camera modes, it is possible to interact in the scene regardless of the number of users in the VR.

Conclusions

As part of our applied research, we introduced camera modes for cooperation between VR and non-VR users. We have shown that it is possible to use individual methods and modes of the camera in specific cases where it is necessary to interact between users, respectively only observing the ways in which the user interacts in VR in training using the methods in Industry 4.0. We also looked at the effectiveness of the use of training in virtual reality for employees compared to the classic approach while monitoring indicators such as the effectiveness of the training method and the need to shut down equipment or part of the production line. Virtual reality is one of the mainstays of Industry 4.0 in the implementation of digital twins of the companies, and for its applications, it is necessary to work on other camera modes or their combination with augmented reality methods. We would like to thank Kevin Kopasz - a student who worked in the virtual and augmented reality lab at the time, for his help in implementing the methods.

References

Andaluz, V. H., Sánchez, J. S., Sánchez, C. R., Quevedo, W. X., Varela, J., Morales, J. L., & Cuzco, G. (2018, June). Multi-user industrial training and education environment. In *International Conference on Augmented Reality, Virtual Reality and Computer Graphics* (pp. 533-546). Springer, Cham. http://dx.doi.org/10.1007/978-3-319-95282-6_38

Barnewold, L. (2019). Digital technology trends and their implementation in the mining industry. In *Mining Goes Digital* (pp. 9-16). CRC Press. http://dx.doi.org/10.1201/9780429320774-2

Carretero, M. D. P., García, S., Moreno, A., Alcain, N., & Elorza, I. (2021). Methodology to create virtual reality assisted training courses within the Industry 4.0 vision. *Multimedia Tools and Applications*, 80(19), 29699-29717. https://link.springer.com/article/10.1007/s11042-021-11195-2

Dhanda, A., Reina Ortiz, M., Weigert, A., Paladini, A., Min, A., Gyi, M. & Santana Quintero, M. (2019). Recreating cultural heritage environments for VR using photogrammetry. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci*, 42, 305-310. http://dx.doi.org/10.5194/isprs-archives-XLII-2-W9-305-2019

Firu, A. C., Tapîrdea, A. I., Feier, A. I., & Drăghici, G. (2021). Virtual reality in the automotive field in industry 4.0. *Materials Today: Proceedings*, 45, 4177-4182. http://dx.doi.org/10.1016/j.matpr.2020.12.037

Górski, F. (2017). Building virtual reality applications for engineering with knowledge-based approach. *Management and Production Engineering Review*, 8. http://dx.doi.org/10.1515/mper-2017-0037

Gugenheimer, J., Stemasov, E., Frommel, J., & Rukzio, E. (2017, May). Sharevr: Enabling co-located experiences for virtual reality between hmd and non-hmd users. *In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (pp. 4021-4033). http://dx.doi.org/10.1145/3025453.3025683

Chattha, U. A., Janjua, U. I., Anwar, F., Madni, T. M., Cheema, M. F., & Janjua, S. I. (2020). Motion sickness in virtual reality: an empirical evaluation. *IEEE Access*, 8, 130486-130499. http://dx.doi.org/10.1109/ACCESS.2020.3007076

Janiszewski, M., Uotinen, L., Merkel, J., Leveinen, J., & Rinne, M. (2020, June). Virtual Reality learning environments for rock engineering, geology and mining education. *In 54th US Rock Mechanics/Geomechanics Symposium*. OnePetro.

Kumari, S., Raghuram, P., Venkatesh, V. G., & Shi, Y. (2021). Future perspectives on progressive farming with adoption of virtual reality technology for sustainable quality in agriculture. *The TQM Journal*. http://dx.doi.org/10.1108/TQM-06-2021-0191

Kuts, V., Otto, T., Tähemaa, T., & Bondarenko, Y. (2019). Digital twin based synchronised control and simulation of the industrial robotic cell using virtual reality. *Journal of Machine Engineering*, 19. http://dx.doi.org/10.5604/01.3001.0013.0464

Lacko, J. (2020, January). Health safety training for industry in virtual reality. In 2020 *Cybernetics & Informatics (K&I)* (pp. 1-5). IEEE. http://dx.doi.org/10.1109/KI48306.2020.9039854

Paszkiewicz, A., Salach, M., Dymora, P., Bolanowski, M., Budzik, G., & Kubiak, P. (2021). Methodology of Implementing Virtual Reality in Education for Industry 4.0. *Sustainability*, 13(9), 5049. http://dx.doi.org/10.3390/su13095049

Patrão, B., Pedro, S., & Menezes, P. (2020). How to deal with motion sickness in virtual reality. *22o Encontro Português de Computação Gráfica e Interação 2015*. https://doi.org/10.2312/pt.20151201

Roldán, J. J., Crespo, E., Martín-Barrio, A., Peña-Tapia, E., & Barrientos, A. (2019). A training system for Industry 4.0 operators in complex assemblies based on virtual reality and process mining. *Robotics and computer-integrated manufacturing*, 59, 305-316. http://dx.doi.org/10.1016/j.rcim.2019.05.004

Rudolph, L., & Klinker, G. (2021, October). As-built Industrial Scene Reconstruction based on Photogrammetry and Prior-Knowledge for Extended Reality Scenarios. *In 2021 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)* (pp. 480-482). IEEE Computer Society. http://dx.doi.org/10.1109/ISMAR-Adjunct54149.2021.00113

Šramka, M., Lacko, J., Ružický, E., & Mašán, J. (2020). Combined methods of rehabilitation of patients after stroke: virtual reality and traditional approach. *Neuroendocrinology Letters*, 41(3).

Xie, J., Yang, Z., Wang, X., Zeng, Q., Li, J., & Li, B. (2018). A virtual reality collaborative planning simulator and its method for three machines in a fully mechanized coal mining face. *Arabian Journal for Science and Engineering*, 43(9), 4835-4854. http://dx.doi.org/10.1007/s13369-018-3164-8

Wahyudi, A. K., Putra, E. Y., Mambu, J. Y., & Adam, S. I. (2018, August). Combining Photogrammetry and Virtual Reality for Exploration of Otanaha Fortress Heritage of Indonesia. *In 2018 6th International Conference on Cyber and IT Service Management (CITSM)* (pp. 1-6). IEEE. http://dx.doi.org/10.1109/CITSM.2018.8674311