Health Safety Training for Industry in Virtual Reality

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***Abstract*— In this paper we describe the possibilities of using virtual reality methods for training and testing of employees of industrial companies in the field of health and safety at work. We focus on creating scenarios that aim to show correct practices and potential user failures to prevent injuries and economic damage. We show the possibilities of virtual reality in this area in specific scenarios, combining first person and third person view cameras for some scenarios. At the same time, we describe the key parts of the system and evaluate the impact of training in virtual reality compared to training without it. We focus on the key benefits of immersion and emotion induced by virtual reality on the rememberability of security practices.**

Keywords—virtual reality, health safety, training, industry

I. INTRODUCTION

The use of modern imaging technologies, such as augmented reality or virtual reality, is increasingly becoming the standard in industrial solutions. Due to the increased availability of virtual and augmented reality devices, it is possible to carry out different types of training for employees focused on machine and equipment operator training, their maintenance training, or remotely solving current machine problems and repairs in collaboration with specialists outside the plant.

At present, it is quite common to realize training of device operators through virtual reality, where it is possible to simulate individual workflows in controlling the device, or to simulate errors of such devices. Users can get to know the operation of devices relatively simply without having to use real equipment in real factory operation. The possible use of augmented reality is to display the workflows in combination with real devices, or to display the current state of the devices directly on-site [1].

In practice, it is not common to train employees in the field of health protection and safety prevention. These types of simulations require covering a relatively large number of different cases that may occur when operating equipment, but also when moving within the factory's production and non-production areas. As part of traditional practices, occupational safety and health training is provided through video tutorials or lectures by those responsible for compliance with health and safety rules. In our research, we focused on the use of virtual reality for occupational safety and health training in factories. We chose virtual reality technology to provide immersion and interactive real-time feedback. Health safety training can be carried out similarly to simulation of pilot training on flight simulators [2], where various crisis situations can be simulated, and the reactions of trained persons can be monitored so that they can present the consequences of their specific actions. Since it is necessary to simulate complex environments in a specific training room and it is not possible to use the real plant environment. Its digital copy proves inappropriate to use augmented reality methods and devices.

Virtual reality is used in a wide range of training activities in various areas of industry. The most common type of training is the implementation of activities for training the work activities of employees [3][4]. Implementation can be realized across different platforms, not only for virtual but also for augmented reality. These approaches can be evaluated based on both objective and subjective criteria [5]. Many applications are designed specifically for different domains within the industry [6][7].

Virtual reality applications in the field of occupational health and safety are implemented in various domains of industry, especially in the field of mining [8], in the field of construction [9][10][11] or in the field of fire safety [12]. An interesting alternative to using the modeled 3D scene is the possibility to use 360° video-panoramas for training [13]. Research investigating whether virtual reality does in fact improve safety skills and in what areas of learning or skill development this medium is superior is important part of research in this area [14]. It is also very interesting to see if the virtual reality methods are more effective as traditional methods [15].

II. ISSUES

The aim of health and safety training is to minimize the risks that occur in the work of production workers, or in the movement and performance of activities within the internal and external work environment. Within the framework of traditional approaches, these trainings are carried out by professionally qualified persons and in most cases, they are in the form of lectures accompanied by slides or some situations are demonstrated through videos. By using virtual reality, it is possible to demonstrate to the users the possible consequences of their incorrect or correct action in individual activities, and at the same time we have created a platform for testing trained people. Most employees do not meet with virtual reality content routinely, and for many, this technology evokes so-called. "WOW" effect. Then the brain responds to the stimuli obtained more quickly and efficiently, and by combining the information with a positive response, it can be stored in long-term memory. If we expose the user to a situation that creates a positive or negative emotion in the virtual reality, it is possible to assume that the correct procedure of solving the given situation will try to be implemented also in common practice. As part of our research, we focused on designing and implementing a virtual reality system for displaying and evaluating various situations from the normal operating

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practice of the factory. As part of the system design, we put individual scenarios and situations to minimize risks into three basic groups:

- Minimizing risks in the normal course of operations in the operation of machinery and equipment - Simulation of machine failures, simulation of workflows and their evaluation, including incorrect procedures that may endanger the health of an individual or group of workers.
- Minimizing the risks associated with the movement of workers in the production and non-production areas of the factory - simulating the hazards arising from the movement of handling equipment on the premises, overcoming obstacles (stairs, reduced passages…) and using corridors for movement.
- Minimizing risks in emergencies - testing the behavior of workers in the event of fire, explosions, alarms, etc.

From the point of view of the system design, we required that the created 3D environment be photorealistic, not only schematic in order to accurately simulate the lighting conditions, the appearance of individual materials and the possibility of orientation of trained persons in the given areas. The ideal situation is to use a digital copy of the factory so that it is possible to simulate individual activities directly in a "real" environment. In terms of the use of different types of simulations, it is not necessary for all to create a digital copy of the factory, but for example a general environment can also be implemented to simulate a fall from the stairs, and the prevention methods can be repeated in different environments. Testing the system has shown that workers have a much better acceptance of the photorealistic environment and have been able to adapt to it more easily.

On the Figure 1 is a diagram of a system for occupational health and safety training. The system is divided into three basic parts.

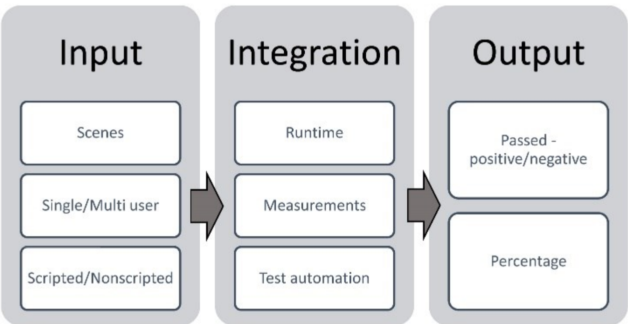

Fig. 1. System diagram.

Within the system inputs it is necessary to determine what type of scene to use for the desired type of training. Scenes are prepared separately for each type of testing. Scenes are indoor by default. There are props in the interiors, some of which can be used and are interactive with colliders, or some serve as triggers for individual events. Some scenes for training various activities can also be implemented as a multi-user (e.g. one user is a forklift driver and other users are pedestrians to carry out the prescribed activities). However, most of the scenarios in our system are single user. Depending on the size of the scene or the space available for user movement, it is possible to choose whether the movement in the scene is to be performed by sensing the position of the headset by external sensors or the movement in the scene is automated by scripts. In automatic movement, the user is required to interact in given sections of the simulation scenario. To prevent motion sickness, we recommend using unscripted sequences to move around the scene.

Within the integration part, the application itself is run based on selected inputs and selection of individual scenes. The system also includes the creation of an automated test that measures the success / failure of each scenario within a scene, for each sequence. By evaluating individual experiments, it is possible to evaluate, in the case of testing, whether the employee is competent in terms of completing training on health and safety at work or it is necessary to repeat the training e.g. also, by performing several simulations.

The output in the section on employee training is information on the consequences of positive or negative actions in terms of health, personnel financial costs and costs for the employer. In the case of the test part, the output is a protocol evaluating the test person's success based on the evaluation of individual scenarios.

III. Procedures

In the research we also focused on the verification of interesting practices, which combined several approaches with respect to methods of simulating specific scenes, simulation for one or more users within the same scene, and to specifying several cases of possible breaches of safety rules when operating machinery and equipment. In the following section we present three specific cases of system utilization.

A. Simulation of stairs

In this specific case, we want to simulate holding the railing when climbing stairs. Simulate climbing stairs in virtual reality in case of tracking rotation and headset translation e.g. external devices is problematic when we have only a flat surface in physical space. If we simulate the movement of stairs in virtual reality and in real space the user would move on a flat surface there would be a disproportion between physical movement and between movement in virtual space, as the virtual camera would move in a different way. This condition could lead to loss of orientation in virtual space or motion sickness. In addition, we want to simulate a situation when a person can get injured by falling off the stairs when not catching the railing. Figure 2 shows a scene to simulate a fall from a stairs.

Fig. 2. 3D Scene for simulation of fall from stairs.

The virtual reality scene was simulated from a first person perspective, with the user's hands being displayed as a virtual 3D model that was tied to the headset controls, and it was possible to display the hand grip by pressing the grip button on the side of the controller. The user's task was to go forward and down the stairs. If the user has caught the railing, this action has been marked as successful and the user has received a message stating what possible injuries, physical and economic consequences he has avoided. If the user did not get caught on the stairs, it was necessary to simulate a fall from the stairs. For the same reasons as mentioned in the article above (preventing motion sickness), it was not possible to simulate a fall from a first-person perspective. For this reason, when moving down the stairs, we added a 3D model of a worker who "dropped" from the first person's perspective and was assigned a ragdoll, which made it possible to simulate a fall in real time (Figure 3).

Fig. 3. Simulation of the fall of worker. 3D model is viewed from side camera in the scene.

After simulating a fall from the stairs, an information window, describing the consequences of the fall, is displayed to the user. The information was placed in the scene area as a window with the text shown in Figure 4.

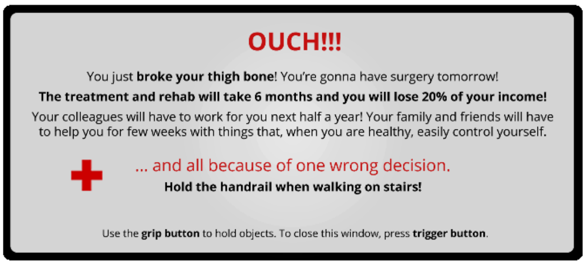

Fig. 4. Information window describing consequences of the fall to the user.

The combination of first-person view and third-person crash simulation has proven to be a surprising element in user testing, but users were able to accept it and were an interesting alternative for them without any problems with possible motion sickness.

In case there is not enough physical space for movement in the virtual space (there is no teleport available for the scene), it is possible to run the scripted movement of the user towards the stairs. Similarly, the time taken by a user to complete a task is measured from the point of view of testing, and the success of the task is also recorded.

B. Simulation of movement in the warehouse hall

In all alternatives, the virtual 3D scene of the warehouse was modeled with racks installed on which pallets of various materials were stored. The virtual space was divided into several sectors within which the movement of pedestrians (workers) was simulated based on predefined routes and forklift movement. Figure 5 shows a plan view of a warehouse hall with pre-scripted routes of movement of workers indicated.

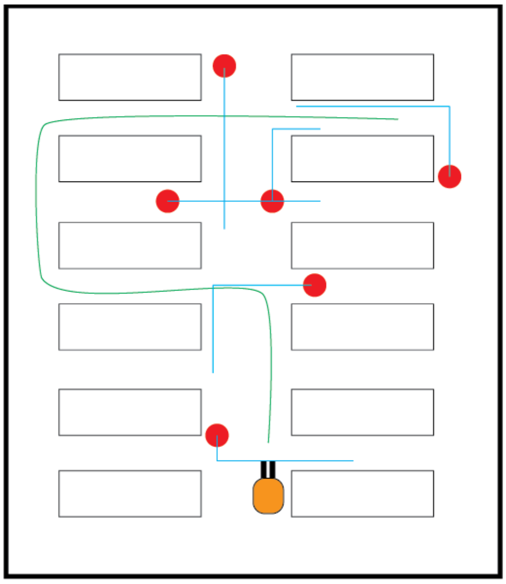

Fig. 5. Floor plan of the scene. Red dots represent the workers with blue motion paths, yellow model represent forklift with green motion path.

There are three basic options for training in this scene.

Option A: Forklift driver.

The user sits on a chair and has a view from a forklift that has a predefined forward, turn and reverse route (to be notified by the system in advance for each action). The user does not have to control the movement of the wheelchair, just to see if there is a person in the path. Holding the button on the remote control moves it to stop the truck. Pedestrians move randomly in the track. The challenge is to avoid all pedestrians. The user must check if the route is free by leaning out of the forklift. When you drive the entire route without an accident, you will be informed of the success of the journey. In the event of a collision with a pedestrian, information about the problem is displayed. The purpose of this alternative is to give the user a view of the forklift driver's position so that the employee has an idea of what the driver sees.

Option B: Forklift driver with control.

The scenario for this alternative is the same as option A, except that the user can control the direction of travel of the forklift and its speed by interacting with the steering wheel and the speed lever. The aim is to avoid accidental bystanders.

Option C: Pedestrian.

In the scenario, the user has the task of walking as a pedestrian through a short route and taking a component off the shelf, avoiding moving forklifts in the scene. If he / she does, he / she will be informed about the route. In the event of a collision with the forklift, information is displayed about the error he has made and its consequences.

C. Simulation of machine operation

When simulating workflows for machinery and equipment, we did not focus directly on workflows that are fair, but on borderline situations that can lead to worker injuries or production threats. For these situations, it is necessary to simulate each production facility separately.

Traditional machine and equipment operator training approaches simulate only a limited number of situations that lead to the successful accomplishment of a given operator task. As part of our approach, we simulated possible problems in operating equipment in the industry leading to injuries. Within the virtual scene, the defined zones within which the worker could move around the device and the operations that could be performed were set. At the same time, the position of the user's hands in the space was monitored, if there were simulated crushing behind the defined safety zones and a notice of the consequences of the user's action was displayed.

All scenarios were implemented in the Unity3D game engine using the HTC VIVE and Oculus Rift headsets with external tracking and using external controllers to simulate the user's hands.

IV. Testing

An important indicator for health safety training is how to memorize information about possible dangers and how long it is stored in the memory of the users. Therefore, when measuring the impact of using our applications on the training process, we have decided to measure just how much information users are able to remember about possible dangerous actions. In the process of remembering, an important factor is the induction of emotion that improves the way the information can be memorized, regardless of whether the emotion is positive or negative. Virtual reality is something new to many users, and immersion itself gives them a positive emotion. In the impact measurement, we created two groups of users. The task of each group was to remember as much of the factual data about the behavior in different simulation scenarios. Group A (37 users) worked in a traditional way without the use of VR only with the videos and presentation of the supervisor, and Group B (32 users) used the VR applications. Subsequently, we created a standardized 20-question test and the users had to answer them correctly. This test was carried out immediately after the end of the lesson, followed by one month. The measurement results are shown in Table 1.

TABLE I. MEASURES OF THE IMPACT OF TRAINING TO MEMORIZING HEALTH AND SAFETY INSTRUCTIONS

Group	% of correct answers immediately	% of correct answers after 1 month
A – without VR	87 %	68%
B – with VR	97%	87%

The results processed in the graph are in Figure 6.

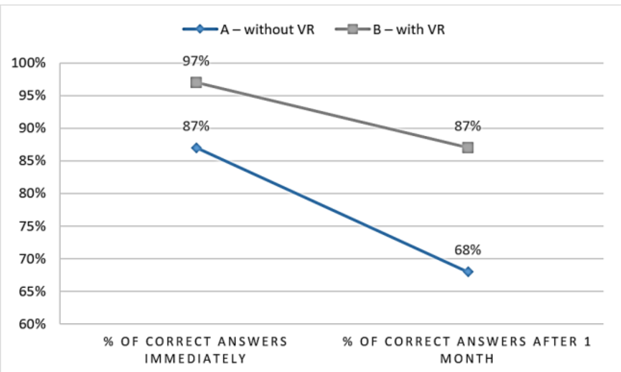

Fig. 6. Graph of the result of the testing.

The results have shown us that the use of virtual reality methods is significant way of submitting information, but it also affects the memorability of the information obtained. On the other hand, the biggest obstacles to technology deployment to industry have shown problems with hardware equipment, but in connection with applications for virtual reality and the problem of motion sickness (manifested in about 12% of the tested persons), despite the fact that user tracking in the area by external sensors.

V. Conclusion

The paper described the use of virtual reality in the training of health and safety workers. During training, environments were created to simulate individual activities to prevent falling down the stairs (the scenario was designed based on a real event), to prevent pedestrian movement in warehouse and production areas with respect to forklift movement. Some scenarios and methods for testing and evaluating tests have been described.

Test results have shown that using virtual reality as a method for simulating occupational health and safety training can make a significant contribution to making training more attractive. The wow effect induced by trained workers in combination with the induced positive emotion causes the effect of long-term storage of information in the user's brain. User immersion in a virtual environment is a key factor in virtual reality training. By tracking the user, it is possible to simulate different scenarios that could not be simulated in real environments because of possible threats to the health of employees.

Key option for the future work is to implement cooperative multi-user scenarios. However, this option requires separate tracking of individual users in real space and their cooperation in the virtual scene. An example would be a movement scene in a virtual warehouse scene where one user controls a forklift and the other is a pedestrian with assigned job sets. After the task is done, you can change the user roles in the scenario. To take advantage of multi-user environments, it is necessary to solve several technological obstacles, such as moving a virtual 3D model in space using only the position of the headset and its controllers and displaying it to other users. Individual controllers are simulated in the virtual scene by the 3D hand model shown in Figure 7.

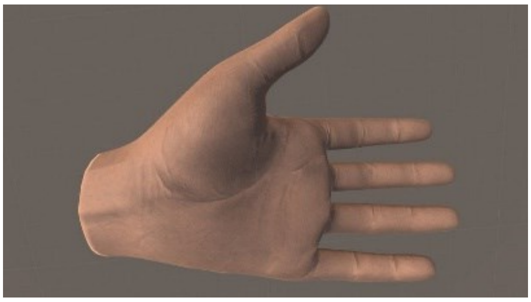

Fig. 7. Rigged 3D hand model used as the controller in the simulation.

For a complex simulation of the user's body movement, it is possible to use additional sensors for sensing the position of joints of the lower limbs with the possibility of using motion capture techniques.

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