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Virtual Reality-based pilot training for underground coal miners

Andrzej Grabowski *, Jarosław Jankowski

Virtual Reality Laboratory, Central Institute for Labour Protection – National Research Institute, Czerniakowska 16, Warsaw 00-701, Poland

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A B S T R A C T

Accidents at works statistics show that mining industry is one of the most dangerous. Therefore there is a need for new solutions, which will improve professional adaptation process and will simultaneously have significant impact on improvement of occupational health and safety situation, especially among the youngest employees. Using the technology of Virtual Reality (VR) allows the acquisition and practice the correct behavior by the miners in a controlled, safe environment. In the paper the results of pilot training with the participation of 21 people employed in the mining industry are presented. Each of the trainees took part in the two simulations, using different motion capture systems: Razer Hydra or vision based system. Head Mounted Displays (HMDs) with different field of view (FoV), wide (110 degrees) and relatively narrow (45 degrees), are also compared. Trainees consider used system useful and feel the positive effects of training even after three months. In almost all cases high immersive VR combined with wide FoV is assessed as the best solution for training. The results of the experiment encouraged owners of training facilities cooperating with polish mines to introduce VR training to basic training for youngest miners.

1. Introduction

One of the most popular fields of Virtual Reality (VR) application is training. Virtual environments (VEs) can effectively simulate various conditions of work and life and, at the same time, successfully support learning processes. Moreover VR supports acquisition and transfer of tacit knowledge (Podgórski, 2010). The use of VR techniques seems to be particularly advantageous in situations where training under actual conditions is related to threats for human health and life. Therefore, training in virtual environment is often used in such areas as medicine, e.g. virtual surgical procedures (Gallagher and Cates, 2004), nuclear power engineering, e.g. limiting the employee's exposure to ionizing radiation or mining. For a review of Virtual Reality as a medium for safety related training in mining see (Tichon and Burgess-Limerick, 2011). Considering learning it is important to identify factors which influences learning effectiveness, like learners' cognitive–affective state (Bakera et al., 2010) or field of view (Ragan et al., 2010).

Virtual Reality techniques are used increasingly frequently in various areas of science, due to the broad range of opportunities offered by such systems. VR systems are useful for treating stress-related disorders (Banosa et al., 2011), analyzing hand postures during grasping different objects (Vatavun et al., 2013), exploring relation between emotion and performance in the context of vehicle driving (Cai and Lin, 2011) or designing a workplace for workers with motion disability (Budziszewski et al., 2011). Virtual environments are also used for synchronous and remote collaborative design (Germani et al., 2012). An important research topic in the field of VR is sense of presence describing the illusion of 'being there' in a mediated environment. The mediated environment can be virtual or real (e.g. in the case of teleoperated mobile robots). The sense of presence is influenced by different factors, like enjoyment (Sylaioua et al., 2010) or personality and individual abilities (Alsina-Jurnetn and Gutierrez-Maldonado, 2010). Usually the sense of presence is measured by proper questionnaire, however resent studies show that analysis of Electroencephalography (EEG) potentials can be useful to assess presence in virtual environments (Kobe and Neuper, 2012).

In our work we are focused on new training solutions using VR technology, because VR applications enhance human abilities and motivation to absorb new knowledge and to modify inefficient and false working procedures (Podgórski, 2010). VR training may also improve workers hazard recognition. Note that failure to perceive a hazard is consistently identified as contributing to injuries and fatalities (Kowalski-Trakofler and Barrett, 2003). Currently we are cooperating with coal mine industry to prepare better training solutions, especially among young workers. Professional adaptation, as a group of activities aiming to prepare rightly a new worker for tough conditions occurring in hard coal mines, is an important

* Corresponding author. Tel.: +48 22 623 46 38.
E-mail address: angra@ciop.pl (A. Grabowski).

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element of safety at work and it impacts on employee's further functioning in a mine plant. In the case of Kompania Weglowa S.A., largest coal mining company in Europe, miners with seniority less than three years constitute of 6% of staff only, but they are injured in 18% of all accidents at work (Pakura, 2011).

Results presented in (Brahm and Singer, 2013) indicates that training is effective in reducing accidents at work and this effect is increased by the level of engagement of the training methods (the influence is weak, however high immersive VR training is not commonly used yet). "A large scale, systematic, evaluation of the outcomes of safety related training via virtual mining environments is required to inform future practice" (Tichon and Burgess-Limerick, 2011), however such study would be extremely expensive because of variety of possible technologies providing different level of immersion (from desktop VR to high immersive virtual environments). Therefore, from point of view of practical application, prior such study we have to know what immersion level is needed for chosen types of training scenarios.

2. Materials and methods

In the paper the results of pilot training with the participation of 21 miners employed in the mining industry are presented. Each of the trainees took part in the two training simulations (in no particular order):

A) using high immersive Virtual Reality (left side of Fig. 1),
B) using moderate immersive virtual reality (right side of Fig. 1).

The average age of miners was 45.7 ($SD = 6.7$) years and average seniority was 22.8 years ($SD = 5.8$). Hence all of them have long experience in mining industry and vast knowledge on working conditions in underground coal mine. It should be noted that all of the trainees have also great expertise in training, because they are also working as heads of training departments (in each mine there is at least one such department). Hence their remarks and opinion are especially useful, because they have expertise in both, mining and training.

Training scenario used for experiment is related to blasting works, which are especially dangerous in underground coal mines because of high methane concentration level. Any deviation from established working procedures risks of explosion and/or fire and as the result the death of many people.

Examples of main actions performed are following:

– initial inspection of the blasting work area,
– removing previous, undetonated explosives,
– measurement methane concentration level,
– adjustment of retaining arches,
– washing the pulverized coal,
– drilling blasting holes,
– preparing explosives,
– measurement of stray currents,
– putting the explosives together with the initiation caps in blastholes and stemming the uncharged collar,
– connection of caps to blasting line,
– checking continuity of blasting line,
– removing all miners from the explosion area,
– provide safety at blasting area,
– detonation of explosives from proper place,
– inspection of the corridor after explosion.

To make results better comparable the virtual environment and training scenario was the same in both above mentioned simulations. The only difference was the hardware (equipment) used to make interaction with virtual environment possible.

In the stage *A* following equipment was used: virtual gloves, vision based tracking system and antenna for wireless image transmission. To investigate the influence of field of view on trainees two different HMDs were used: with low (45 degrees, HMD Sony HMZ-T1) and high (110 degrees, Oculus Rift DK1) FoV. Almost half of the miners (10 persons) were using HMD with high FoV. In this case trainees could freely move in real and virtual environment at the same time, because their position and position of head and hands was calculated in real time using vision system (note that the movement was restricted to the size of a training room, about 5 times 7 m). Therefore to interact with the virtual environment a trainee performs the same movement as in real world, to catch an object a trainee just has to move his hand and clamp fingers.

In the stage *B* following equipment was used: Razer Hydra controller and HMD with relatively low field of view (45 degrees). The HMD was equipped with AHRS device to measure head orientation. Hence, trainee was able to look around in virtual environment. Tracking range of this controller is relatively low, therefore trainee should sit (or stay) as close as possible to the antenna. Note that only movement of head (i.e. change of its orientation) and movement of hands were measured. To navigate in virtual environment joystick was used. The joystick is a part of Hydra controller and is located below right thumb. Analog joystick allows continuous adjustment of avatar's speed. To bend avatar's hand fingers analog button was used. The button is placed below index finger. To grasp virtual object trainee has o move his hand to proper position and push the button. The button was also analog, hence the continuous adjustment of the degree of fingers bending was possible.

At the end of each stage a questionnaire was filled. A part of this was spatial presence questionnaire (Witmer and Singer, 1998), based on MEC-SPQ (Bocking et al., 2004; Vorderer et al., 2004). Such questionnaire is often used to evaluate virtual environments. In order to assess the training a questionnaire based on a

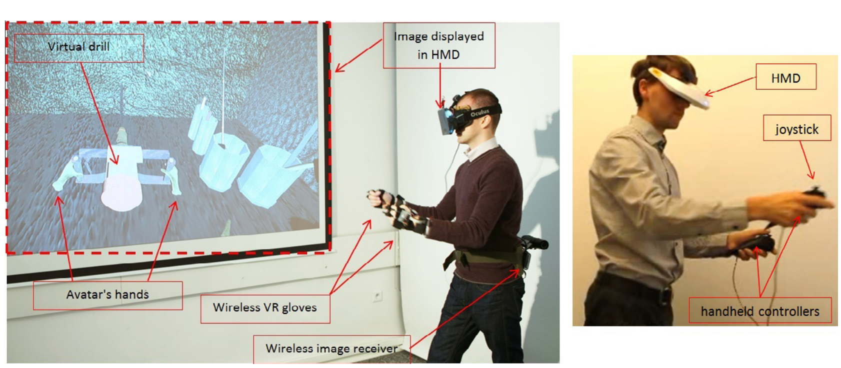

Fig. 1. Scheme of equipment used in highly (left) and moderate (right) immersive virtual environment.