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A new Virtual Reality training system for underground coal mines

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ABSTRACT
Virtual Reality (VR) technology in mining is a new field of research. The successful application of VR to mining is critical to mine safety and production. Based on different input/output devices that are used in the VR system, the current VR mining system can be divided into three types: screen-based general system, projector-based customized system, and Head Mount Display (HMD)-based intuitive system. Based on a VR headset, a smartphone and a Leap Motion, an HMD-based intuitive VR training system was built and tested by 10 students who tried both the HMD-based system and a normal screen-based system to experience the difference between the two systems. The results showed that the HMD-based system can give a better user experience, and is easier to use. In the future, with the employment of more intuitive input devices and improved system software, the VR training system for mines could play a much more important role in mine training.
KEYWORDS: Virtual Reality; training; Head Mounted Display; tracker; immersion; intuitive

1. INTRODUCTION

Virtual Reality (VR) technology is based on computer graphics, and can build a virtual scene, which could be interacted by users through input devices, and seen, heard, touched, even smelt through output devices (Mazuryk and Gervautz, 1996; Burdea and Coiffet, 2003; Zhao, 2009). With a well-designed virtual reality system, people can feel almost like they are in the real world. Burdea and Coiffet (Burdea and Coiffet, 2003) raised the three I's conception – imagination, immersion, and interaction – of VR.

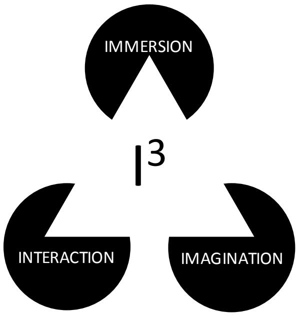

Figure 1: The three I's of virtual reality (Burdea and Coiffet, 2003).

VR is used in many fields, such as military, aerospace, medical, entertainments, etc. After decades of developments, a lot of theoretical and practical experiences have been suggested. Stone (2012) raised some basic rules and principles for developing serious games of military; Burdea and Coiffet (2003) and Stone (2012) discussed the importance of considering the factors of users. Others (Bertram and Moskaliuk et al., 2015) have studied the effectiveness evaluation of VR training systems. Though VR has been studied for several decades, there are still many things need to be studied in the future, especially with the rapid development of the input and output devices in recent years. Nowadays, there are many kinds of Head Mounted Display (HMD) devices on the market, such as the separated devices – Oculus Rift, HTC Vive, etc., or the VR headset plus smartphone solutions.

In many mining countries such as Australia, the U.S., Canada, South Africa, the U.K., and China, many researchers in the past two decades have been studying the possibility of using virtual reality (VR) as a tool for operator's training (Bukowski and Sequin, 1997; Squelch, 2001; Kizil, 2003; Foster and Burton, 2004; Tichon and Burgess-Limerick, 2011). Dozens of prototypes have been developed and some of them have become popular products (ThoroughTec, 2010; CAE-Mining, 2012; QinetiQ, 2012). The current popular mature VR mine training systems are mainly composed of a multi/curved screen projector, which could provide some immersion to the trainees, and customized operation platform.

Just like other VR systems, the VR mine training system also contains 5 components: input/output (I/O) Devices, VR Engine, User, Task, and Software & Databases (Figure 2).

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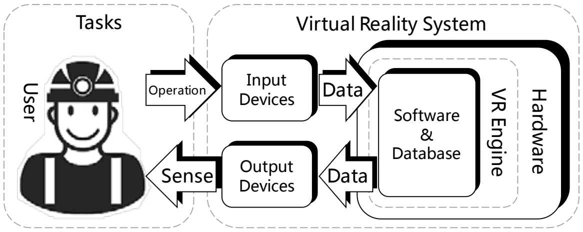


Figure 2: Components of VR system, adapted from (Burdea and Coiffet, 2003).

2. INPUT AND OUTPUT DEVICES

Among the 5 components in the VR mine training system, the I/O devices are critical as they are the exclusive way through which users can interact with and sense the virtual. As a result, all the available I/O devices for the VR systems are summarized in this paper.

2.1 Input devices

Based on previous studies (Mazuryk and Gervautz, 1996; Burdea and Coiffet, 2003; Mihelj and Novak et al., 2014), the common input devices can be classified into two types: physical input devices and automatic track devices, as shown in Table 1. It can be seen that all the automatic track devices are more intuitive and easy to use, while the general type of physical devices such as keyboard and joystick are less intuitive and more difficult to use.

Table 1: Summary of VR input devices.

Category	Type	Devices	Intuitive Level	Difficulty level
Physical	General	Keyboard, joysticks, etc.	Low	Medium/ High
	Customized	Customized operational platform	Medium/ High	Low/ Medium
Automatic	Body tracing	Camera, IR sensor, depth camera, etc.	High	Low
	Movement capturing	Data gloves, gyroscope, etc.	High	Low
	Voice control	Microphone	High	Low

2.2 Output devices

A VR mine training system must have output devices so that the users can "sense" the virtual world. According to Mazuryk et al. (1996) and Kizil et al. (2001), visual sense and auditory sense only take charge of 70% and 20% respectively of the total sensing for human beings, and other three kind senses – tactility, olfaction, and taste sense – only take the remaining 10%. As a result, visual sense is the most important one for users of the VR system.

Based on previous studies (Milgram and Kishino, 1994; Stothard and Squelch et al., 2015), the common visual output devices can be classified as screens, projectors, Head Mounted Displays (HMD), and holographic devices (immature technology) (see Table 2). It can be found that HMD devices are the only available devices that provide the full immersion and at a low/medium cost.

Table 2: Summary of VR display devices.

Category	Type	Immersion	Number of user	Cost
Screen	Normal screen	None	Single	Low
	3D screen	None	Single	Low
Projector	Flat screen fabric	Partial	Single/multiple	Medium
	Curved/multi-screen fabric	Partial	Single/multiple	High
HMD	Small high-res screen	Full	Single	Low/medium
	Small optical projector	Full	Single	Medium
Holograms	Holographic emitter	Full	Single/multiple	Invalid

2.3 Different VR mine training systems

Based on the classification of the input and output devices, a new taxonomy of VR mine training systems, which contains three kinds, is raised as follows:

(1) Screen-based general VR mine training system

The screen-based general system uses a desktop monitor as the output device, and general physical devices, such as keyboard, joystick, etc. as the input devices. The whole system has little/no immersion, and is mainly used to develop the basic VR mine training systems.

(2) Projector-based customized VR mine training system

This is currently the most popular VR mine training system, and there are many commercial products in the market (CAE-Mining, 2012; QinetiQ, 2012; ImmersiveTechnologies, 2015). The output devices for visual sense are projectors with different kinds of screen fabrics – flat, multiple, curved, domed, etc. At the same time, a lot of customized operational platforms based on the real equipment are used in this kind of system. With the help of projectors and large screen fabrics, this system could provide some immersion to the users.

(3) HMD-based intuitive VR mine training system

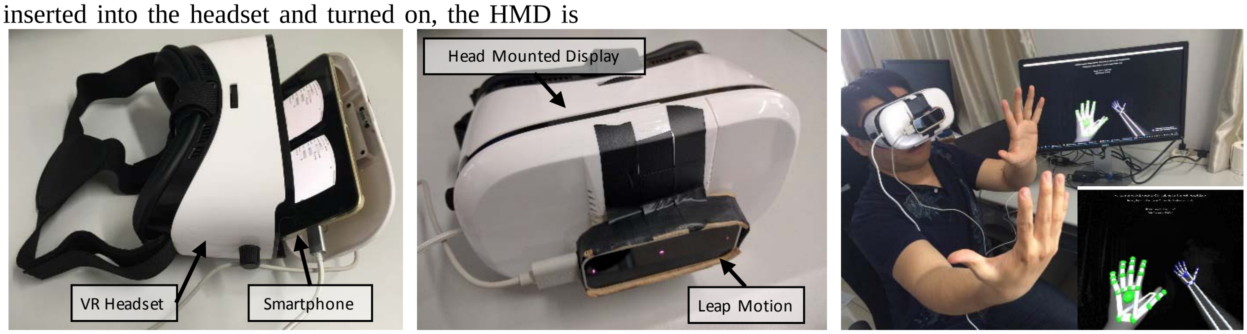
The HMD-based intuitive system means that the high immersive visual output devices (Head Mounted Display) and intuitive input devices (auto tracing & capturing devices) are employed in the system. In this kind of system, trainees can feel full immersion, and interact with the virtual environment and equipment naturally and intuitively. For now, the immersive natural system is not wildly developed and used, but it is the most advanced system and the future of mine VR training system.

3. AN INTUITIVE VR MINE TRAINING SYSTEM

In this paper, a new VR mine training system, which is a HMD-based intuitive system, was built for drilling scenario training in coal mines. In this system, the movement track device was used to capture the trainee's hands' movements and gestures, and the HMD was used as the visual output device through which the trainee can feel full immersion. At the same time, a screen-based general system was also built as a control system. The HMD used in this system, was composed of a VR headset and a NEXUS 6P smartphone. When the smartphone is inserted into the headset and turned on, the HMD is ready to use, and the user could see the virtual environment through the lenses of the headset. With the help of the sensors build-in the smartphone, such as the gyroscope and the accelerometer, the smartphone could track the user's head turning, and the pictures in the HMD could update along with the head's movement.

The intuitive input device used in this system was a Leap Motion movement tracker with IR camera built-in. The Leap Motion was glued in the front cover of the HMD as shown in Figure 3(b), and it had a valid tracking angle of 135°, which is sufficient to track the user's hands (Figure 3(c)).

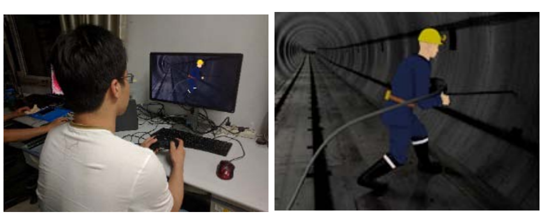
At the same time, a screen-based general system was also built as a control system.



(a) Composition of the HMD (b) Input device and Output device (c) User's hands' recognization

Figure 3: HMD and Leap Motion as I/O devices.

As for the software & database and VR engine parts, the Blender and Unity 3D software were employed: the virtual miner model was built in Blender, and the underground coal mine scene, the trigger and interaction rules between the user and the virtual environment, etc., were developed and coded in Unity 3D.



(a) Screen-based general VR training system

(b) HMD-based intuitive VR training system

Figure 4: Two different training systems.

In Figure4, the pictures on the left show the real utilization situation of each system, and the pictures on the right show the graphics that the user could see from the screen or the HMD. It can be seen that in the screen-based general system (figure 4 (a)), the user is controlling the character to drill by using a joystick, and the screen shows the third person view of the drilling scenario, which means that the immersion of the system could not be high. In the HMD-based intuitive system (figure 4 (b)), the user can experience the first person view through the HMD, and at the same time, thanks to the gyroscope built in the smartphone, the turning of the head could be monitored, and the sight in the HMD could change in real time. What's more, the user could manipulate the virtual miner's hands directly, instead of the whole virtual character, and through the previous mentioned Leap Motion device, the user could control the fingers respectively, which means the user could do some more complicated movements and gestures to interact with the virtual drill in the virtual environment.

4. RESULTS AND DISCUSSION

In order to evaluate the effects of each mining training system, ten students tested both training systems. After that, they filled out questionnaires about the two systems to evaluate the levels of immersive, intuitive, interactive, easy to use, and easy to learn. Each aspect was evaluated in five grades. The results are shown in

.

Through the results, it can be seen that the HMD-based intuitive VR training system has a dramatically higher immersive grade (4.8) than the screen-based general system (1.3), and 1.5 to 2 times higher grade of intuitive, interactive and easy to use, this means that the HMD-based system has a better user experience than the screen-based system. As to the easy to learn – the training results of each system – the screen-based system is only a little lower than the HMD-based system, which means that both systems have quite good training results, and the HMD-based one is a little higher. After experiencing both systems, 9 of 10 students prefer the training experience of the HMD-based system, and would like to use it in the future.

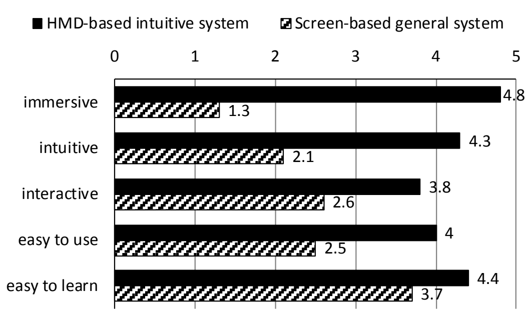


Figure 5: Evaluation of both training systems.

The students also suggested some limitations of the current HMD-based intuitive VR training system, and the main ones are as follows:

(1) In the HMD-based system, a user could not move the character through moving his own body, instead he must use other devices such as keyboard or joystick to move the character in the virtual environment, which will lower the immersion of the system.

(2) With long-term utilization, the user could feel tired or suffer from motion-sickness.

(3) For the current system, the Leap Motion device is used to track the user's hands, while the user could not feel any tactile sense, which will also reduce the immersion of the system, because when people see they are touching something in the virtual environment, they could not feel the tactile sense in the real world.

(4) The users found that they could only interact with the drill, but could not interact with other things in the virtual environment, which is due to the limitations of the current software.

The points mentioned above are the main limitations of the current HMD-based VR system, and most of them are due to the limitations of the hardware and software used in the system. With the development of the VR input/output devices, and the updates of the HMD-based VR training system, the limitations of the current system might be solved in the future.

5. CONCLUSION

This paper classifies the input and output devices of mine training VR system into screen-based general systems, projector-based customized systems, and HMD-based intuitive systems. Using the Head Mounted Display as the output device which is composed of a VR headset and a smartphone, and a Leap Motion as the input device, an HMD-based intuitive VR training system was built. Users can feel full immersion through the HMD and control the virtual character's hands to manipulate the drill just by moving their own hands. After 10 students had tested both the HMD-based system and a controlled screen-based system, they found that the HMD-based system is more immersive, intuitive, interactive, and easy to use, and most of them believe the HMD-based system is better and would like to use the immersive system in the future.

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