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Head-mounted display-based intuitive virtual reality training system for the mining industry

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ABSTRACT

Virtual reality (VR) training technology in the mining industry is a new field of research and utilization. The successful application of VR training system is critical to mine safety and production. Through the statistics of the current research and applications of VR training systems in mining industry, all the input/output devices are classified. Based on the classifications of the input/output devices that are used in the VR system, the current VR training systems for the mining industry could be divided into three types: screen-based general type, projector-based customized type, and head-mounted display (HMD)-based intuitive type. By employing a VR headset, a smartphone and a leap motion device, an HMD-based intuitive type VR training system prototype for drilling in underground mines has been developed. Ten trainees tried both the HMD-based intuitive system and the screen-based general control system to compare the experiences and training effects. The results show that the HMD-based system can give a much better user experience and is easy to use. Three of the five components of a VR training system, namely, the user, the tasks, and software and database should be given more attention in future research. With more available technologies of input and output devices, VR engines, and system software, the VR training system will eventually yield much better training results, and will play a more important role in as a training tool for mine safety.

1. Introduction

Virtual reality (VR) technology is based on computer graphics, which can build virtual scenes and items to be manipulated by the user through input devices, and to be seen, heard, touched, even smelled through output devices, and the user can feel high immersion during the interaction [1–3]. By using a well-designed and built VR system, users can feel almost like they were in the real world. In VR, the environment shown is totally virtual, which is opposite to the real world, and between them there are augmented reality and augmented virtuality. All of these construct the reality-virtuality continuum [4]. Burdea and Coiffet raised the 3I of virtual reality–immersion, imagination, and interaction, as shown in Fig. 1 [2].

Entertainment, especially computer games, is one of the greatest power to promote the rapid development of virtual reality technology, and many new input/output devices designed for VR have been developed. Nowadays, there are many kinds of head-mounted display (HMD) devices in the market, such as the unibody devices–Oculus Rift, and HTC Vive or the separated devices–VR headset plus smartphone solutions. The miniaturization and portability of the VR visual devices have promoted the development of the VR industry dramatically, and there will be more affordable VR devices in the market in future.

Due to the intrinsic properties of VR–to offer almost real world experience in a harmless virtual environment–it is born to be a perfect tool for training, and is now widely used in many fields, such as military, aerospace, aircraft, surgery, etc. After decades of developments, a lot of theoretical and practical experiences have been suggested. Stone raised some basic rules and principles for developing serious games of military; Burdea and Coiffet, Stone discussed the importance of considering the factors of users; Bertram et al. have studied the effectiveness evaluation of VR training systems [2,5,6]. Though VR has been studied and utilized for several decades, there are still many aspects that need to be studied in the future, especially with the rapid technological developments in recent years.

Mining is a typical industry of high risk, and the operators in this industry require sufficient training to ensure safety. Amongst these training tasks, some are very difficult or impossible to practice in the real world, such as mine rescue, escaping from disasters, etc., which makes the VR technology very suitable as training tool

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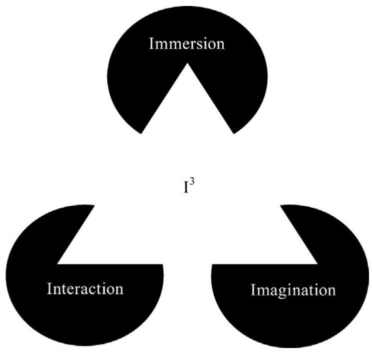

Fig. 1. 3I of virtual reality [2]

for such situations. Kizil introduces the six main benefits of using VR in mining industry, that is, reduced time, unlimited access to expensive/unavailable equipment, cost saving, ability to practice hazardous conditions, learning dispersed over a wide geographic area, and leverage existing computer investments [7,8].

In many mining countries such as Australia, the U.S., Canada, South Africa, the U.K. and China, many researchers have been studying the possibility using VR as a training tool in mining industry for the past two decades [8–15]. Dozens of prototypes have been developed, some of them have become popular products. 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.

In this paper, the components of VR system in mining industry are discussed. Based on the taxonomy of the input/output devices, the VR training systems for mining industry are divided into several types. A prototype of immersive and intuitive VR training system for mining industry is built and tested. Based on the test results, future research directions of VR training systems for the mining industry are proposed.

2. Input/output devices and training system classification

In essence, VR technology is the next generation media for humans to obtain artificial information, and the previous generation is based on two-dimensional screen technology. The biggest difference between them is that virtual reality technology has a completely immersive and intuitive nature of the interactive experience, which will allow users to enter a fully virtual world.

Burdea et al. introduced the five classical components of a VR system, which are VR engine, software & databases, input/output devices, user, and tasks [2]. A VR training system for the mining industry should contain the same five components (Fig. 2).

Amongst the five components of a VR mine training system, the most important one is the input/output devices, because they are the exclusive way through which users can interact with and sense

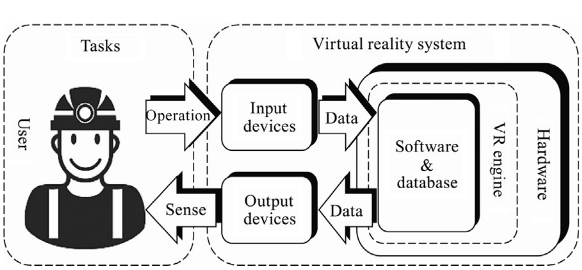

Fig. 2. Components of a VR system.

the virtual environment. The current virtual reality input/output devices of VR training systems are summarized in this paper.

2.1. Input devices

Based on previous studies, the common input devices of a VR system can be classified into two categories: manually operated and automatic capturing, as shown in Table 1 [2,3,16].

One can see that these two types of input devices have great differences. Manual operation devices have a low degree of intuitive, and general devices such as keyboard and mouse are difficult to learn and use by beginners. However, manual operation devices are very mature technology, which makes them very accurate during operation. On the contrary, automatic tracking devices have a much higher degree of intuitive, and very low learning requirements, but due to the use of various sensors and new algorisms, the accuracy of the tracking operations is not guaranteed.

2.2. Output devices

A VR mine training system must have output devices so that the users could "sense" in the virtual world. According to Mazuryk et al., the visual sense and auditory sense take charge of 70% and 20% respectively of the total sensing for a human being [3,8]. The other three senses–smell, touch, and taste only take 10% (Fig. 3). Thus, visual sense is the most important one for users of a VR system.

Based on previous studies, the common visual output devices can be classified as screens, projectors, head mounted displays (HMD), and holographic devices, as shown in Table 2 [4,14].

For these technologies, the screen technology cannot provide a sense of immersion, but the price is cheap, and there are many being used in VR systems. Projector technology is very mature but costly, and CAVE is the earliest system of this type [17]. HMD has been developed a long time ago, but only with the Oculus Rift like HMD devices announced in recent years, it became more popular. Holographic projector technology is the best visual equipment solution for virtual reality, but the technology is still immature, thus cost is not well defined.

As can be seen in Table 2, there are two types of HMD, and the difference between them is mainly whether the screen is transparent or not, which will determine whether the users could see the virtual environment and the real environment at the same time. The screen of small high-res screen device is difficult to be transparent, which will block the real world eventually; while the small optical projector device is based on the optical (transparent) lens technology, hence the user can see the real world through the lens while seeing the virtual items. Strictly speaking, a small optical projector HMD device should be classified as a mixed reality device, but it can also be used in the field of virtual reality.

Through comprehensive analysis, it is found that, only HMD devices are the available devices that could provide full immersion and at a low/medium price, hence it is believed that the HMDs are the most appropriate visual devices for the VR training systems. There is an obvious problem about the HMDs–a single HMD device cannot be used by multiple users at the same time. Bednaz et al. discussed the distributed collaborative framework of VR systems for mining industry, and it turns out that this problem could be solved just by connecting several HMDs and their users into one VR system and virtual environment [18].

2.3. VR training systems for mining industry

Based on the classification of input/output devices, a new taxonomy of VR training systems for mining industry, which contains three types, is raised as follows: