2016

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Recommended Citation

Cheung, H.,& Liu, S. (2016). Development of practical vocational training class making use of virtual reality-based simulation system and augmented reality technologies. *The 10th International Symposium on Advances in Technology Education*, 105-110. Retrieved from https://repository.vtc.edu.hk/ive-it-sp/101

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DEVELOPMENT OF PRACTICAL VOCATIONAL TRAINING CLASS MAKING USE OF VIRTUAL REALITY-BASED SIMULATION SYSTEM AND AUGMENTED REALITY TECHNOLOGIES

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Abstract

Virtual reality (VR) refers to the technologies creating a virtual environment to provide users a sensory simulation of the environment being presented. In Hong Kong Institute of Vocational Education (IVE), we are in the process of developing a VR-based simulation system having four screens surrounding users to simulate an immersive environment. This application is commonly known as the cave automatic virtual environment (CAVE). The objective of our VR-based simulation system project is to apply the virtual reality and the augmented reality (AR) technologies for practical training in vocational education and training (VET).

Our system is used for various training programs in the engineering areas. These include simulation of any workspaces for operations and maintenance training in electrical and mechanical services. Workspace training is important and beneficial to VET students in addition to practical training in school settings. Meanwhile, some workspaces are full of danger and severe casualty can be resulted if inappropriate operations are performed. Our VR-based simulation system manages to provide a solution to complement the shortfalls of workplace training and ensure that students can acquire a range of skills including safety operations under various environments. In this paper, we introduce our design of a class making use of the CAVE system and augmented reality technology. The class aims at providing training for VET students to perform inspection and maintenance procedures in a virtual engine plant room. The class was found to be educational and managed to promote the skill development among students.

Keywords: *CAVE, simulation, virtual reality, vocational education and training*

Introduction

Virtual reality

Cave automatic virtual environment (CAVE) is a computer system impressing users with a feeling that they are inserted into a virtual environment. A pair of stereoscopic glasses is provided to each user to view a huge image that is projected onto four to six connected screens surrounding the user. Some of the CAVE systems also provide each user with a head mounted device to detect the orientation of the head. The contents of the screens are view-dependent and are updated according to the head movement to simulate what the user should see in the reality. Therefore, it is sometimes called virtual reality (VR).

CAVE was firstly introduced in 1992 by Cruz-Neira, Sandin, Defanti, et al. (1992); (1993). It provides users with a very broad field of view that significantly improves the feeling of presence in the virtual environment. Moreover, users do not have to rely on a virtual representation of their own bodies. Instead, they could physically enter the virtual space that greatly enhances the immersive feeling (Cruz-Neira, Sandin, Defanti, et al. 1992; 1993; Kuhlen and Hentschel 2014). The immersive virtual environment allows users having a faster and more comprehensive understanding of complex spatial relationships and allows interacting with objects in the environment using more natural controllers. For example, a user can use LED gloves (motion can be tracked by a camera tracking system) to magnify and rotate the 3D brain structure data in the virtual environment (Defanti, Dawe, Sandin, et al. 2009; Kuchera-Morin, Wright, Wakefield, et al. 2014).

Primarily, there are two categories of CAVE systems, panel-based system and projector-based system. For a panel-based system, each screen is made by a matrix of LCD panels. These LCD panels can display images with higher brightness and contrast compared with the projector-based system. These virtues can alleviate the undesired mismatch between vergence and accommodation which causes less eyestrain. This is particularly important when users focus on near-field virtual objects (Kuhlen, and Hentschel, 2014). However, panel-based system usually lacks floor projection, which significantly limits their immersive character. CAVE2 at the Electronic Visualization Laboratory is an example of the panel-based system (Reda, Febretti, Knoll, et al. 2013). For a projector-based system, images are projected onto the screens using digital projectors. However, the resolution of the system is usually low compared with the panel-based system. To increase the resolution, a number of relatively small projectors are arranged in a matrix with slightly overlapping image tiles. The soft-edge blending technique allows achieving a seamless transition between the tiles to increase the quality. The aixCAVE (Kuhlen and Hentschel, 2014) at the RWTH Aachen University and the StarCAVE (Defanti, Dawe, Sandin, et al., 2009) at California Institute for Telecommunications and Information Technology at the University of California San Diego are two examples of the projector-based system. Researchers applied CAVE in different visualization applications. Bryson and Levit (1991) demonstrated the virtual wind tunnel using CAVE. Nowke, Schmidt, Albada, et al. (2013) applied

CAVE to simulate biologically realistic neural networks. Sampaio, Henriques and Martins (2010) and Sampaio, Ferreira, Rosario, et al. (2010) applied the techniques for development of models related to the construction process in civil engineering education. Gibbon (2008) applied the virtual reality technologies (Cheung, Siu, Feng, et. al, 2008) to demonstrate the circuit issues concerning operational amplifiers and a resonant circuit in the electrical engineering field. Su, Hu, and Ciou (2006) proposed simulation control testing in electrical engineering field.

Augmented reality

Augmented reality (AR) is another set of technologies which overlay extra information on real scene. Generally speaking, virtual reality replaces reality with digital objects while augmented reality integrates digital objects or information on real objects (Milgram, Takemura, Utsumi, et al. 1995). AR systems are characterized with the features of (1)combining real and virtual objects in a real environment, (2)aligning real and virtual objects with each other, and (3)running interactively in real time and in 3D space. (Azuma, Baillot, Behringer, et al., 2001) There are various kinds of AR applications making use of different devices. For example, some apps are developed making use of hand-held devices like mobile phones or tablet computers which capture real-time video and overlay digital objects or information on the video. Another example applications which make use of a camera and a projector. The applications first capture videos and recognize target objects in the scene. Subsequently, digital objects or information are projected over the recognized objects in the scene using the projector. If the projected digital objects do not align well with the real objects, the system can automatically adjust to achieve alignment. This process is very much similar to the process of image registration (Cheung and Siu, 2007).

The first AR system was developed by Sutherland I. at the Harvard University and the University of Utah using a see-through to present 3D graphics. (Tamura, 2002) Caudell and Mizell (1992) developed an experimental AR system to help workers putting together wiring harnesses. Feiner, MacIntyre, Hollerer, et al. (1997) proposed a mobile AR system registering 3D graphical tour guide information with buildings and artefacts. Yamabe and Nakajima (2013) proposed a system framework for augmenting traditional training environments making use of AR technologies. They considered VR-based systems replacing original apparatus with digital devices is not appropriate as this widens the gap between training and practice. They considered look-and-feel of training environment should be as similar to the real one as possible. Krevelen and Poelman (2010) surveyed the state of the art of AR technology as well as some known limitations regarding human factors in the use of AR systems. Vera, Russo, Mohsin et al. (2014) studied the application of AR system in surgical education. Simon, Baglee, Garfield, et al. (2014) proposed an AR-based training programme to identify necessary maintenance tasks for preventive or corrective maintenance.

Project initiative

Conventional vocational training for students is usually restricted to workshop environment. If emergency situations including fire and leaked gas arise, trainees might not be able to respond properly and might result in catastrophic consequences. The reason

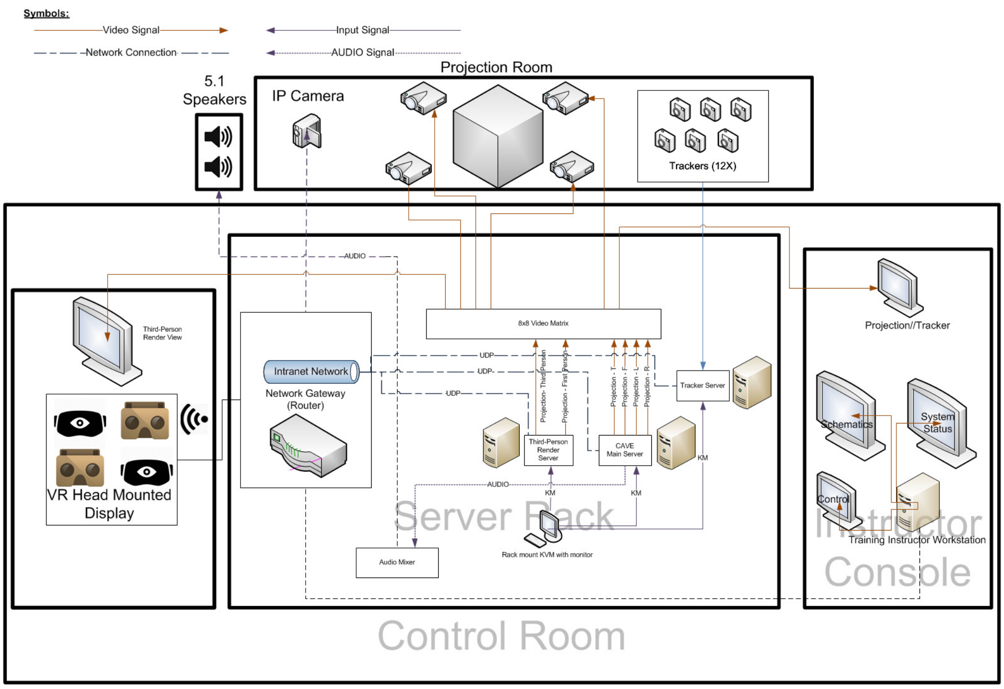

Figure 1, our VR-based simulation system consists of scenario control system, tracker system, image generation system and projection system.

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for the inability to respond properly is the lack of training in emergency situations. Using the CAVE system, teachers are allowed simulating various emergency situations for training purpose. The immersive 3D virtual reality feature of the CAVE system manages to allow the students familiarizing with various situations without actually facing the associate danger and train them to react properly. The use of simulation training in transportation industries in the form of flight, train and car simulators has been proven to be extremely useful for decades. However, simulation training for other industries is not widely used due to high cost in development and maintenance. With technological advancements in necessary hardware and software, the cost is substantially lowered recently.

In order to provide vocational education and training (VET) a mean to improve its effectiveness in training, Engineering Discipline of Hong Kong Institute of Vocational Education (IVE) is in the process of developing an interactive VR-based simulation system equipped with a projector-based CAVE system. The system aims at creating training experiences for trainees and let them become more competent in performing maintenance tasks in multiple locations and improve the ability to react in emergency situations. Students can engage with different situations and directly apply knowledge they learnt from classes. This learning mode well fit into the constructivist learning model (Piaget, 1964) which suggested that students learn by expanding his/her knowledge through experiences.

The system will also adopt a student-centred approach that provides learners with an experience of working on a simplified simulated world. At the same time, the simulation manages to maximize training safety and minimize risk. It will provide a range of flexibility in customizing different parameters of the scenarios and the trainings that allow flexible training time for individual or group trainings.

Figure 2, the primary user has a gamepad. Both the gamepad and the 3D glasses have a "target".

System design of our CAVE

Our virtual reality based simulation system primarily consists of four hardware components, including scenario control system, tracker system, image generation system and projection system. Figure 1 briefly illustrates the system architecture and design of our CAVE. We have a projection room with four screens, which are 4m x 2.75m in size, forming the front, left, right and bottom screen. We use four 3D projectors to project stereoscopic images onto the four screens. Several users wearing 3D glasses walk into the projection room to view the contents of the virtual environment. One of them, primary user, has a remote gamepad controlling the progress of the exercise and both her 3D glasses and the gamepad are attached with a tree like stureture called "target" for tracking purpose as shown in Figure 2.

The purpose of the tracker system is to detect the position and the orientation of the gamepad and the 3D glasses (of the primary user). The two "targets" (attached to the gamepad and the glasses) are composed of several spheres, called markers, which are coated with highly retro-reflective film. The coating essentially is a reflective surface which is capable of reflecting infrared radiation into the direction of the incoming light. There are several infrared cameras, mounted above the projection room, which can detect the reflected infrared light beams. Each marker essentially reflects an infrared light beam back to each infrared camera forming a 3D line in the 3D space as illustrated in Figure 3. If we have two infrared cameras, there are two 3D lines. The tracker server computes the intersection point of the two 3D lines which gives the 3D position of the marker in the 3D space. This method is called triangulation (Hartley and Zisserman (2004)). In theory, we need at least two infrared cameras to position the 3D coordinates of a marker. If we have more infrared cameras, the robustness and accuracy of the computed 3D position is higher.

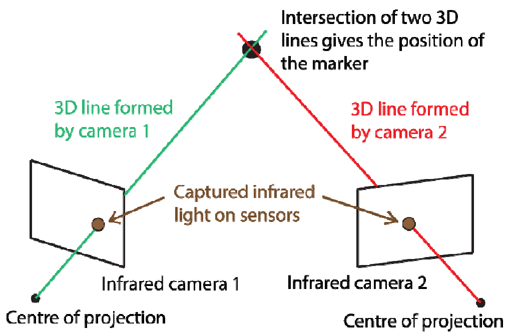


Figure 3, triangulation method to determine the 3D position of a marker using two infrared cameras

Detecting the 3D positions of some markers is not sufficient to identify if the "target" belongs to the 3D glasses or the gamepad. To differentiate the two, it is necessary to detect the 3D spatial configuration of detected markers. Note that the spatial configuration of the two "targets" are different as shown in Figure 2. I.e. the gamepad has a "target" with 3 markers while the 3D glasses with 4 markers. This spatial configuration difference not only identifies the 3D glasses from the gamepad, but also tells the orientation of each "target". In practice, each "target" must have at least 3 markers and must have a unique spatial configuration for the tracker system to work properly. The computed 3D position and orientation information of the gamepad and the 3D glasses are sent to the image generation system which has a game engine to generate the 3D contents of the front, left, right and bottom screens. The whole process, including the tracking and 3D view rendering, is done in real time which accounts for both the immersive feature of the CAVE system and the interactivity between the trainee and the virtual environment.

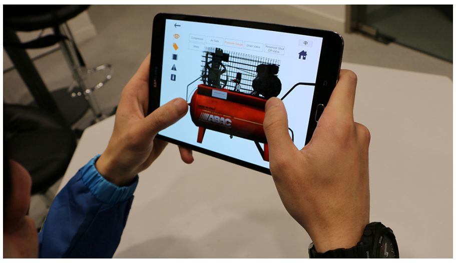


Figure 4, the Browser app showing the details of an air compressor

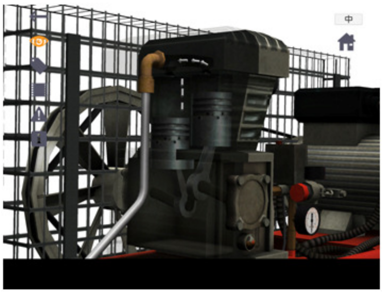


Figure 5, the Browser app allows a close inspection of the details of an air compressor

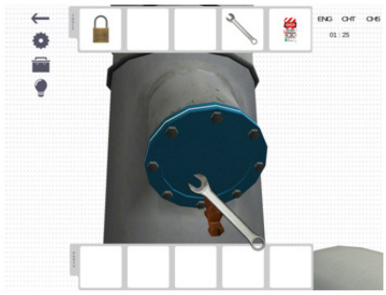
Other tools for vocational training

In addition to developing the CAVE system, we also develop two applications to be used on hand-held devices like tablet computers. One of the applications is called Browser (our engineering code) which carries some learning materials like the descriptions of an air compressor as shown in Figure 4. The apps models some plant room machines in details allowing detailed inspection. For example, a user can drag, rotate and magnify a part of the air compressor for close inspection as shown in Figure 5.

Another application is called Fixer (our engineering code) which is similar to the Browser apps. It allows user searching for faults and using a set of tools to fix the problems. For example, as shown in Figure 6(a), we have four fault cases. In Figure 6(b), a user observes that the water pump is leaking water and uses a spanner to replace a damaged gasket to stop water from leaking.

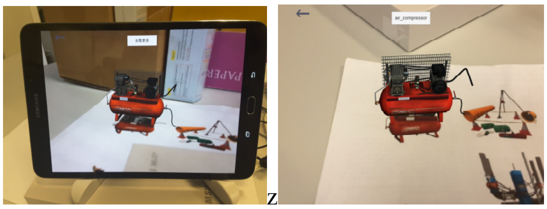
In addition to the plant room machine inspection and the maintenance service training provided by the two apps, we also develop a tool making use of augmented reality (AR) technology. Our tool is built as well on a hand held device like a tablet as shown in Figure 7(a). The key elements of the AR technology is to make use of the in-built camera to capture a video and to keep searching for some specific pre-defined 2D pictures or patterns in the video in real time. If the pre-defined pictures are recognized in the video, the position and the orientation of the pictures are computed. Finally, we compute a perspective transformation matrix for each recognized picture and use it to map a pre-built 3D object onto the video frame.

(a)

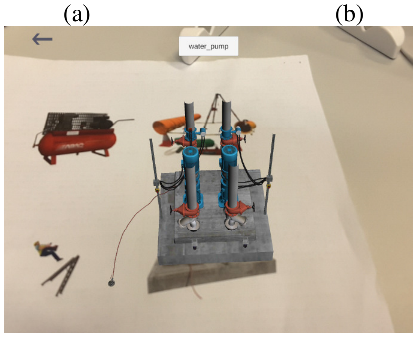


(b)

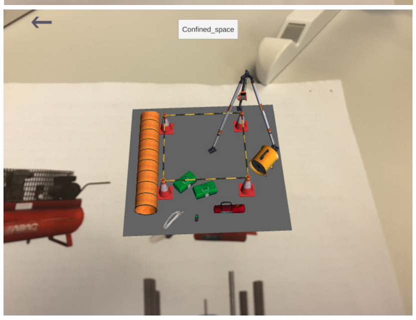
Figure 6, the Fixer apps showing (a)four fault cases, and (b)a user using a spanner to replace a damanged gasket in a water pump to stop water from leaking



(a) (b)



(c)



(d)

Figure 7, augmentation of 3D models including an air compressor, a water pump and the equipment for confined space using AR technology

If the relative position and orientation of the recognized picture changes in time, the perspective of the mapped 3D object on the video frame is also changed accordingly in real time. Therefore, if the user rotates the tablet computer about the picture slightly, a slightly different perspective of the augmented 3D object is shown on the tablet. It appears to the user that a 3D object is placed on the paper and it allows the user inspecting different perspectives of the 3D object by rotating the tablet computer. Figure 7(b) to (c) show the augmentation of three 3D objects including an air compressor, a water pump and the equipment for confined space respectively.

Class design using VR and AR technologies

With our developed CAVE system and the two apps, we design a class for a group of 20 vocational trainees leaded by an instructor. We simulate an engine plant room environment with reference to the engine plant room of Tsuen Kwan O Hospital in Hong Kong. The objective of the class is to train the students the procedures to locate and inspect a faulty machine in the virtual plant room. The class is divided into 5 groups with each group having 4 students. The instructor makes use of the scenario control system to set different scenarios to the groups. For example, a group may have one of the six air compressors unexpectedly having pressure drop from 10 bar to 7 bar.

The instructor initially briefs the students about the plant room and all the groups starts their learning using the Browser apps installed in a tablet computer to prepare themselves performing the inspection procedures in the CAVE system. The instructor select one group of students each time to enter the projection room of the CAVE system while all other 4 groups keep learning with the Browser apps. For the selected group entering the CAVE, one of them is assigned to be the primary user controlling the avatar to navigate inside the virtual environment. They need to locate the faulty machine, to inspect and to identify the problem associated with the machine. In addition, they also need to identify any inappropriate case in the virtual environment. For example, they need to observe and point out that a non-player character is climbing a ladder without enforcing all the safety measures.

After finishing the task in the CAVE, the group leaves the projection room and another groups use the CAVE in turn. If the students manage to identify the faulty machine, they proceed to use the AR tool and the Fixer apps to examine the faulty machine and to try performing the maintenance procedures. If the students successfully complete all the tasks, they can proceed to the workshop to work with the actual machine in the following workshop class.

Discussion

After running the class, most of the students generally found it interesting, educational and playful. They reported that they managed to promote the skill development and to sustain motivation to learn during the training. However, some of the students found that the experience in the projection room caused sickness. This was especially severe for the users other than the primary user when the primary user navigated in the virtual environment.

To alleviate the sickness problem, we modify the game settings including to brighten the virtual environment (VE), to include fewer objects in the VE, to avoid excessive navigation in the VE, to apply simple texture to objects and to avoid objects coming too close to the users. After running the class again, no trainee complained about the sickness problem and enjoyed very much with the class. It appears that these measures are efficacious in alleviating the sickness problem.


(a)
(b)
(c)

Figure 8, (a) A group of student studied the machine using the Browser apps on a tablet computer. (b) The group entered the projection room of the CAVE system to identify the faulty machine. (c) The group performed maintenance procedures in a workshop.

Conclusions

In conclusion, the Engineering Discipline of Hong Kong Institute of Vocational Education developed a VR-based simulation system which is equipped with a projector-based CAVE system. We also developed two applications and a AR tool on hand-held devices to assist student training. A class was designed making use of the CAVE system and the developed tools to train students performing inspection and maintenance procedures. After some trial runs, we found the class is educational and playful for students. It managed to promote the skill development and to sustain the motivation to learn. However, some students reported to have sickness problem using the CAVE system. In view of this, we deployed some changes in the settings and managed to greatly alleviate the sickness problem. We believe this training class surely can well impress the students and well accomplish the training objectives.

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