Ultrasonic sensor + 4D virtual reality simulation environment for safety training

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Abstract

The implementation of Virtual Reality (VR) simulation environment in the training of construction workers has the benefits of minimizing potential risks and decreasing cost. Three-dimensional VR safety training classes can be fulfilled in a manner very close to real world conditions. The aim of this research is to elevate the degree of interaction of the students with the virtual world so that the students can experiment and learn from their mistakes. The authors noticed that if the screen of the VR background is immovable and soundless, it will make the training program vapid and less attractive. In this case, time sequenced 3-dimensional (4D) VR simulation environment provides more functions and lifelikeness in the background. Ultrasonic sensor or radio frequency identification (RFID) technologies can be used in VR Cove to test the direction-control capability, which provides the VR safety training with game environment and sound reflection. The development of the training modules of the proposed system will follow the recommendations and regulations of the Occupational Safety and Health Administration (OSHA). This project focuses on creating an ultrasonic sensor + 4D Virtual Reality Safety-Training System and assessing the perceptual and behavior impacts of the VR environments on a trainee. With the proposed system, students have the chances to improve their coordination of information from different directions, visual and sound timing judgments, coordination of perception, and action. Very complicated or extremely dangerous construction situations can be presented for students in the VR environment.

Keywords: virtual reality, ultrasonic sensor, 4D construction information technology, safety training

1 Introduction

Many attempts have been explored by researchers in using Virtual Reality (VR) to help with simulation. Virtual Reality simulation environment as a training method is used by research institutes and industry labs to improve teaching quality. Three-dimensional Virtual Reality safety training classes can be fulfilled in a manner very close to real world conditions. The term “4D” is used to refer to time-sequenced three-dimensional environments or scenarios, in which time is considered as a fourth dimension in addition to the three-dimensional world. The 4D plus Virtual Reality (4D-VR) has been studied and used as game environments because the combination of 4D and VR can capture and reveal the ever-changing feature of the real world.

The researchers of this study proposed to use ultrasonic sensor technique in the 4D-VR environment, which has great potential in the training of construction workers. The proposed study will bring ultrasonic sensor into the 4D-VR simulation environment as a measurement, a boundary
sensor, and a testing tool for trainer reaction. The aim of this research is to elevate the degree of interaction of the students with the virtual world so that the students can explore the different scenes, make predictions about possible results, experiment with their solutions to the questions or problems asked by the system, and learn from their mistakes.

2 Problem statement

The implementation of Virtual Reality (VR) simulation environment in the training of construction workers has the benefits of minimizing potential risks and decreasing cost. The cost-saving feature of the VR training of construction workers is reflected by the following facts: (1) The VR training systems are usually reusable. There are some embedded databases in the VR training systems for various working environments, risk situations, and potential hazards, etc. By using random selection and combination, the VR training systems can present to the users with different scenarios to practice. (2) The large businesses, such as the military and the air industry, are starting to see VR as the best way to teach workers how to do jobs that are complex, dangerous, or both. VR training programs can save companies money in the long run by cutting down on the amount of costly real equipment, such as heavy machinery, that must be used in training. Equipment operation, especially the heavy equipment operation, is critical in jobsite safety; hence it is an important component in safety training for construction workers. For example, crane operations, scaffolding setup, bulldozer manipulation, etc. all need skilled workers to control them. How to safely and properly use them is a key topic in safety training. By using VR training systems, students can learn the correct equipment functions, operation procedures, and reactions to dangerous situations. (3) Simulation programs also reduce risk to machines, the environment, and even human lives. The 3D or 4D VR simulation systems provide vivid sceneries for users. They can use 3D mice, head trackers or helmets, and other controlling and interference devices to run virtual machines under simulation environments or in VR. The VR environments have trivial harm to human lives, real machines, or the real world. The improved human and environmental safety and minimized potential risks can save the cost of medical bills, insurances, etc. (4) For people working in the construction industry, real-world or hands-on experiences are with great value. But unfortunately, it is not always possible to have real-life experiences in school. VR brings the power of experiential learning into classroom. VR simulation environment for safety training helps students save money in travelling around to get various experiences. It also helps schools or companies to save money in machine setup, operation, maintenance, materials, fuel or gasoline, etc.

The authors noticed that if the screen of the VR background is immovable and soundless, it will makes the training program vapid and less attractive. In this case, time sequenced 3-dimensional (4D) VR simulation environment provides more functions and lifelikeness in the background. In most VR simulation environments, users can utilize 3D mouse, eye goggles, helmets, controllers, and other devices to manage the inter-reaction between the computers and the users. But these devices lack the sensors for boundary detections in construction safety training environments. Boundary detection is critical in VR simulation of construction safety training. It may be OK for users to jump from floor to floor in a computer game. But it sure is dangerous for construction safety trainees to take it as granted or think it is safe to jump between floors, walk through walls, or fall off beams or scaffoldings. Therefore the authors propose to use ultrasonic sensor or radio frequency identification (RFID) technologies in VR Cove to test the direction-control capability, which provides the VR safety training with game environment and sound reflection, as well as boundary detection.
3 Literature review

3.1 The creation of VR simulation environment

The creation of VR simulation environment can be done by using VRML. VRML is an acronym for the Virtual Reality Modeling Language. Using VRML, 3-D virtual worlds can be developed. The most exciting feature of VRML is that it enables users to create dynamic worlds and sensory-rich virtual environments on the Internet, including the ability to: (1) animate objects in real worlds; (2) make real worlds; (3) play sounds and movies within users worlds; (4) allow users to interact with their own worlds; and (5) control and enhance worlds with scripts that users create to act on their own VRML worlds. Figure 1 explains the structure of virtual reality system (Shi 2009).

![VR architecture diagram](image)

The first version of VRML was specified in November 1994. This version was specified from, and very closely resembled, the Application Program Interface (API) and file format of the Open Inventor software component. The current and functionally complete version is VRML97 (ISO/IEC 14772-1:1997). VRML has now been superseded by X3D (ISO/IEC 19775-1).

The major function of VRML is to create a virtual reality environment. Its compatibility with other software products is poor. Another drawback of VRML is its difficulty to represent space on the normal computer screen instead of virtual environment around users. The advantage of VRML and its successor, X3D, is that they have been accepted as international standards by the International Organization for Standardization (ISO) (Ames, 1997).

3.2 VR safety training

The Occupational Safety and Health Act (OSHA of 1970) has made it a rule that employers provide health and safety training. In presenting training sessions, regarding what learners retain from instruction they receive, taking lectures and doing what is talked about can help trainees to retain 90% of what they learned (Goetsch, 1993). Instructors should get the learner actively engaged seeing, saying, listening, and most importantly, doing.

Home et al. (2005) found out that one of the reasons that Virtual Reality technologies were not yet widely used is due to the cost and time required to develop the models. VR models can add the components of interactivity and immersion to building models, which is an undividable part of construction education. When VR is required, some specialist visualising companies are often used. This involvement by third-party specialists adds to the production time and cost of VR models.
However, emerging evidence suggests that adoption of building information modelling software is resulting in productivity gains of 40-100% during the first year (Home et al., 2005).

A few research centres or organizations are conducting research on construction safety training using VR and multimedia. In the research done by Xie and Tudoreanu (2006), the design purpose, visualization feature, user interface, and game engine used of these construction safety training systems have been compared. Xie and Tudoreanu proposed a VR safety training system, which has a set of rules and an expert system. It also has random effects to simulate the various situations that might happen on real jobsites. The system architecture is capsulated so that it can re-configure to different users, and at the same time, be extensible. The system tool included the following parts: risk assessment, hazard identification, safe working procedures, effective communication, skills training, assessment and correction of risk takers, all of which can be loaded into a VR system and used to teach and test the important safety concepts and procedures. It incorporated knowledge rules expressed in regulations, safety manuals, and MSDS. The details of system contents are shows in Figure 2.

![Figure 2. Details of virtual reality safety training system](image)

### 4 System analysis

Figure 3 is the detail ultrasonic sensor + 4D VR safety-training system. In this system, safety database for equipment safety and site work safety are separated and selected.

![Figure 3. Detail of ultrasonic sensor + 4D VR safety-training system](image)
The items for site work safety data are different than items using at equipment safety. For example, the type in site worker safety is as of job type when in equipment safety is equipment type. In site worker safety, the height is OSHA jobsite length and height requirement. In the equipment safety, the range is equipment working range and height features. As same as erection and delivery plan, the safety plan is adjusted with source available also. Safety algorithm is a computer numerical program which uses smart coding and artificial intelligent techniques to make an optimal plan for given resource. The database should include OSHA regulations, building code, equipment operation menu, and so on. The zoning control also needs network and security cameras monitory systems.

Figure 4 shows the safety control system in the ultrasonic sensor + 4D VR safety-training system. A designed sensor location system has readers sited on required positions. Special sensor tags were attached on equipment and workers’ hardhat or helmets. In an intranet environment, sensor location system can arrange a distance for safety control and locating risky locations, such as hoisting area, flammability area, falling zone, and heavy equipment path, then making a warning system for danger movement or possible safety violation. For the learner with sensor goggles or headset on, if he or she entered any of these virtual danger locations, he or she may receive an alert or a reflecting alarm. Also it may have different frequencies to zoning the safety.

Figure 4. Sketch map of safety control system of ultrasonic sensor + 4D VR safety-training system

The use of the ultrasonic sensor is together with a transmitter, helmet-mountable receiver and control box. It is typically mounted into head mounted displays or into eyewear for Virtual Reality and Simulation applications. VR education software provides years of research and proven educational effectiveness to students. It has been proven to 1) engage students, 2) facilitate faster learning, 3) contribute to higher test performances, and 4) create a very high motivation to learn. It has also been especially effective for at-risk students and those that have difficult time learning through traditional means.

5 System implementation

The interface of the proposed system is responsible for communicating actions and feedback from and to the user. Geometric representation and physical properties of the modeled objects are described in the database. The system engine is responsible for creating time dependent events and synchronizing the simulation processes. The system processor is responsible for responding to the system events based on the objects’ properties specified in the database. To achieve scalability in this system, the authors proposed to separate out modules which depend on special requirements that highly vary from one user environment to the other. A virtual clock is established between the server and the client to
synchronize between the incoming client commands and the server command processing. When the time stamp of the client commands fall behind the server clock, the server will ignore these commands- there is no need to process old data.

One task of the core processor of the proposed is to calculate the response of the system users or trainees to events coming from the engine and the interface module. This task is done by the server side. The processor receives the data from the sensors and updates commands from the interface, and accordingly will update the database of the entire system. Meanwhile, time events received by the processor will be handled by performing the following sequence of actions:

Calculate and see if the user/trainee action is safe.

Check OSHA database or expert system and accordingly update the system reaction acting on the VR environment.

Calculate the system suggestion for safe action of the user/trainee according to the current user/trainee action.

Communication between the different modules of the simulator is implemented by various methods. Nodes can export their current status, which can be read by the applet; similarly the applet can send data to update the status of the VRML node. Commands from the interface and from the server all pass through the Java applet which routes them to their destination. The Java applet is also responsible for keeping both general and endoscopic views synchronized. When the server updates the position of the endoscope in the global view, the applet will also update the view point position on the second VRML world.

The ultrasonic sensors used in the 4D-VR Safety Training system help the users or trainees to recognize environment around them. In particular, it is essential function to detect the distance and direction of obstacles around a person in the 4D-VR world. Using ultrasonic sensor costs is low but is highly efficient.

6 Conclusions and future research

This paper presented to use ultrasonic sensor in the 4D-VR Safety Training System, in particular, for construction workers. This system allows user to experience the very complicated or extremely dangerous construction situations without the need to physically visit the place. Ultrasonic sensors are used in virtual reality training. The proposed system allows for future extensions to new sensors.

The next stage of the discussed research, the authors will investigate intuitive interface tools suitable for the application. In the near future the authors will test the system and the operational information of the trainees will be collected.

References


