Human-computer interaction experiments in an immersive virtual reality environment for e-learning applications

Tomasz P Bednarz
CSIRO Exploration and Mining, Brisbane, Australia
tomasz.bednarz@csiro.au

Con Caris
CSIRO Exploration and Mining, Brisbane, Australia
con.caris@csiro.au

Octavian Dranga
Edith Cowan University, Perth, Australia
o.dranga@ecu.edu.au

Abstract: The present work concerns a Human-Computer Interaction (HCI) experiment in an Immersive Virtual Reality (IVR) environment. The user is located at the focal point of a four metre hemispherical dome projection screen. By combining a 5DT data glove with an iPhone 3G, the user can directly interact with a computer program/client. The visualisation is implemented with the Unity 3D 2.5 multiplatform game development tool. The client communicates with a .NET socket server allowing continuous data streaming from connected sensors, i.e., finger flexures, hand gestures (from the data glove) and orientation data (from the iPhone's accelerometer sensors). The main goal of the experiment is to evaluate interactive techniques for users who are training in an IVR environment. An IVR application is demonstrated to highlight the value of the proposed method in an intuitive e-learning experience associated with the teleoperation of underground coal mining equipment.

Introduction

The potential of virtual reality (VR) technology as a major technical advance for supporting education is widely recognized (Byrne, 1993). Several ways in which VR technology facilitates learning has been suggested (Bell and Fogler, 1995). One of its unique advantages is the capability to allow students to visualize abstract concepts and to visit environments and interact with events that distance, time, scale or safety factors make it difficult or impossible to access. These types of learning activities can significantly support the education process in that students are better able to master, retain and generalize new knowledge when they are actively involved in constructing that knowledge in a learning-by-doing situation. As has been observed (Edgar 1969) we only remember 10% of what we read, and 20% of what we hear, but we retain up to 90% of what we learn through active participation. Several programs designed to introduce students and teachers to VR technology have been established and a number of academic institutions have developed research programs to investigate key issues (Ainge, 1996). The efforts are equally split in their use of either a desktop or immersive VR system, although the practical uses have largely entailed the development of desktop virtual worlds (Brown, Cobb, and Eastgate, 1995). This paper reports on our current efforts in developing immersive VR technology for engineering education.

Regan, Shebilske, and Monk (1992) reported on empirical research that explored the instructional potential of immersive VR as an interface for simulation-based training. According to these researchers, VR may hold promise for simulation-based training because the interface preserves both

the visual-spatial characteristics of the simulated world as well as the linkage between motor actions of the student and resulting effects in the simulated world. VR offers the possibility of presenting both small-scale (can be viewed from a single vantage point at a single instant) and large-scale (experienced across time) (Siegal, 1981) spatial information in a three-dimensional format that eliminates the need for students to translate the representation from 2D to 3D. The Cell Biology Project (Gay, 1994) serves as an example of a study focusing on the impact of VR defined in terms of immersion, natural interaction (via hand trackers) and interactivity on the effectiveness of informal education (i.e., self-directed, unstructured learning experiences). The application was developed in three formats (immersive VR, desktop VR and video-tape viewing) and the immersive users scored higher on post-testing of symbolic and graphic retention and were much stronger in terms of level of engagement, although the non-immersive groups were able to retain more cognitive information (at least for the short term). Adamo-Villiani *et al.* (2006) have presented their development of immersive 3D learning environment to increase mathematical skills of deaf children. Their method taught mathematical concepts and sign language through user interaction with fantasy 3D virtual signers and environments. Bell and Fogler (1996) suggest that VR is a good medium for presenting 3D objects and relationships, and for illustrating concepts that have been covered elsewhere, but is not an appropriate medium for getting across factual information and is not a substitute for traditional educational methods. However, when used properly, it can augment traditional methods and lead to improved long-term retention of material. It can also greatly help visually oriented students engage with the learning process.

These important motivations for VR can be of particular benefit to engineering education. This paper focuses on an application of immersive VR that we are developing specifically for the mining industry.

Configuration and operation

One of the most important aspects investigated in this paper, beside VR scenarios, is how users can interact with the proposed system using tools such as finger flexure and orientation sensors; also how the user can navigate in an easy and natural way through the IVR worlds and how specific properties of any chosen object can be easily modified. The human-computer interactions utilizing different sensors are presented in this section as a joint software-hardware engineering solution.

Apparatus

Figure 1 shows the logical flow chart of the existing system for our human-computer interaction experiments in engineering e-learning. The user is the first element in the diagram as they are the source of the interaction in the system via the input devices (intentionally we excluded the mouse and keyboard).
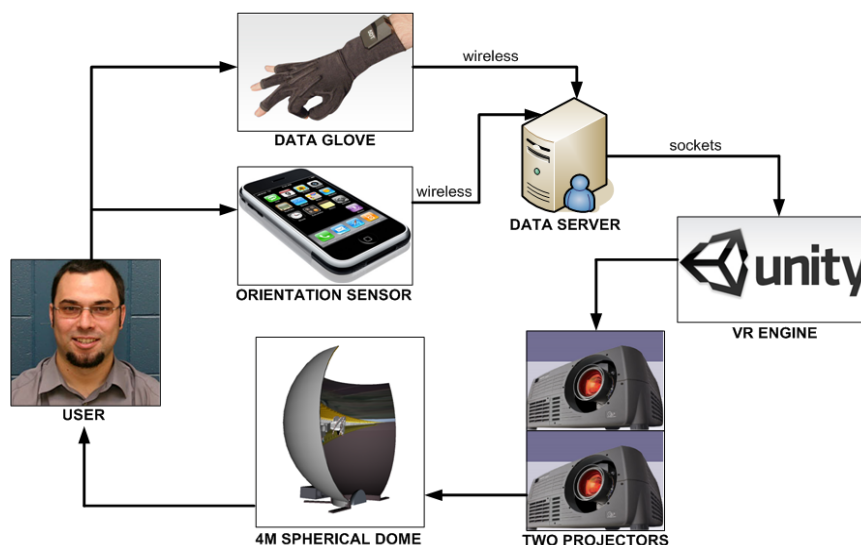

Figure 1: Logical flow chart for the apparatus in the immersive VR experiments.

The experiments are carried out using the following sensors: 5DT Data Glove 5 Ultra (Fifth Dimension Technologies) and an iPhone 3G (Apple Inc) attached on the hand. The data glove is connected wirelessly to a PC using the 5DT Ultra Wireless Kit. The data glove measures the flexure/bending of five fingers, reporting them as integer numbers depending on the intermediate and proximal phalanges of each digit. Prior to running the experiments, the glove is calibrated using software that estimates the minimum and maximum flexion and extension digits for each sensor, and then calculates the normalized floating point numbers from 0 to 1.0, i.e., from maximum extension to maximum flexion. The glove calibration is subsequently used in the experiments to characterise the finger/hand movements.

The orientation information is measured using iPhone's accelerometer sensors that transmit roll data (rotation around the axis that runs from home button to earpiece) and pitch data (rotation around the horizontal axis). There is also information whether the iPhone is moving up or down. The two sensing devices are held and operated in one hand.

The data server is responsible for capturing data sent wirelessly from the data glove and the iPhone and passing them using .NET sockets connection to a VR system. The VR system is built on the Unity3D 2.5 multiplatform game development tool, which is used to display the user interfaces and 3D objects, and to process the interactions transmitted from the input devices. The final output is displayed in an immersive 3D environment on a four metre hemispherical dome screen using two Christie HD3 professional projectors. The projectors are mounted on the ceiling 1.5 metres apart and are located three metres from the focal point of the screen.

Data and User Interface Interactions

Using the 5DT SDK (Software Development Kit) supplied with the Data Glove, sixteen open-close different hand gestures are easily implemented (excluding thumb readings). Gesture number 0 is defined as all the fingers being closed, and the gesture number 15 as all fingers open. The index finger indicates the least significant bit. For example, the index finger point gesture will indicate number 1 and the little finger point gesture will indicate number 8 (Fifth Dimension Technologies, 2004). If the gesture cannot be recognized, -1 value is returned.

All gestures were tested in the following way: the picture of a specific gesture is held on the screen for 1500 ms with 500 ms transitional time between successive gestures. These tests provide 90% of the required responses. Although better results can be achieved when the user has more time to prepare specific gestures, different dynamic imitations are achievable as described in details in (Gold, Pomplun, and Rice, 2008).

For prototype testing, a simple Paper-Stone-Scissors game has been developed. The user interacts with the computer using hand gestures only. The user has three seconds to prepare one of three game gestures: stone (gesture 0), paper (gesture 15) and scissors (gesture 3). The computer randomly picks one figure and compares it with the user's input. The users win when they pick stone against scissors, paper against stone or scissors against paper. If the user and the computer picked the same figure, it is a draw, and in the remaining cases the user looses. The game was tested on ten different people with 100% correct system's recognition of the input gestures 0, 3 and 15.

The orientation data is captured using three accelerometers from the iPhone 3G, i.e., one acceleration along each of the primary axes. This combination enables the detection of device movements in any direction and tracks the device's orientation relative to gravity. Access to raw data takes place through the iPhone's SDK UI Accelerometer object. For our experiments, the reporting interval is set to 12.5 milliseconds (80 Hz update rate) as recommended in the iPhone Application Programming Guide for "suitability in applications needed detection of high-frequency motion such as hitting the device or shaking it very quickly" (Apple, 2009). The raw data needs to be filtered in order to get the current orientation of device and detecting instantaneous motion. Therefore, simplified low-pass and high-pass filters were also implemented.

The data server is implemented in Visual Studio C/C++ 8.0. Both, the data glove and the iPhone are communicating with the server wirelessly. The server's main loop constantly caches input data from the sensors and release them when requested by the client (Unity3D).

The user interface and user interactions are implemented via a schema of interaction modes for our testing system as shown in Figure 2. The system implements two modes of operation: (a) a view mode and (b) an interactive mode. In mode (a), the user is not interacting with VR objects and only watches the scenes presented by the graphics engine e.g., reading text. However, if the user at anytime shakes the iPhone, touches the mode button on the iPhone's screen, or makes the hand gesture number 8 using the data glove, the view mode switches to the interactive. In mode (b) the main menu is displayed on both the dome screen and the iPhone's touch screen. The user can interact with the system using either the data glove or the iPhone's touch screen.
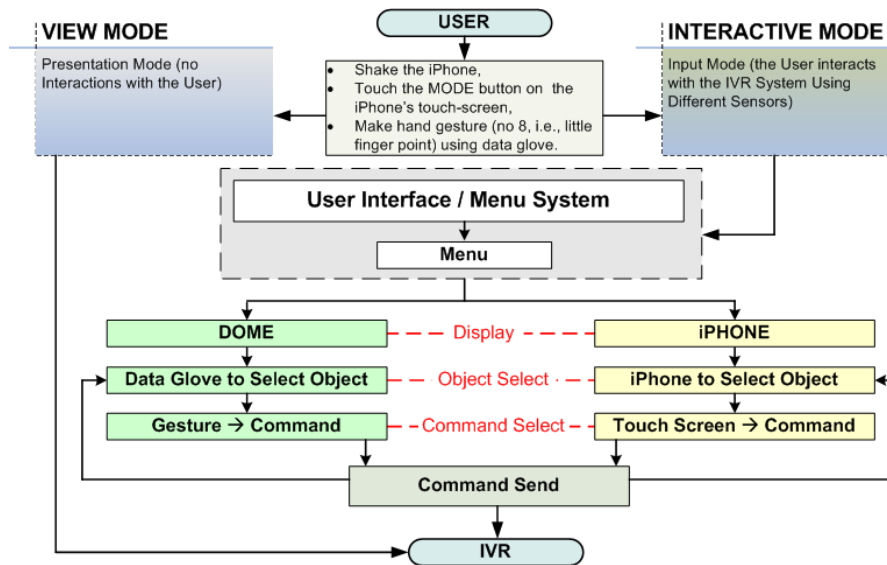

Figure 2: User interface interaction modes.

A small hand-gesture icon, displayed next to the text description on the iPhone, is used to highlight a specific menu item so the user always knows which gesture to make in order to select that specific item. In the same way, the user can select a specific object with the data glove to send commands to VR engine. Modification of the object's states can be additionally made using iPhone's accelerometer feature. For example, by changing orientation of the phone the orientation of a selected object is also changed. We are also evaluating the possibility of using the iPhone as a pointing device: the iPhone is then attached to the right hand that data glove is on, and using indexing gesture number 1 and accelerometer data we are able to track location of the cursor on the dome screen.

IVR Experiment

The main goal of the IVR experiment is to employ the apparatus and methods described above to create a realistic and intuitive e-learning experience within a VR environment. The IVR arrangement presents a 3D mine engineering e-book (Figure 3) for an underground mining equipment system called "Longwall Shearer Guidance" as developed by the CSIRO Mining Automation team. The virtual book responds to the inputs provided by the user. The system is immersive in that the 3D scene fills the user's horizontal and vertical peripheral vision whilst enabling the user to fully interact with the viewed content. The user can flip pages, zoom in and out of the pictures in the e-book, and access/navigate the virtual worlds linked to the text. This functionality makes this system unique when compared to standard books or book viewers, simply because the user can experience the content, therefore will remember more content.

In the present experiment, the user stands in the front of a four metre hemispherical dome which is seen in Figure 3. The user's eyes can see only the pictures and animations available on the screen. This enhances situational awareness, and reduces possible distractions when compared to viewing of the same virtual world on the monitor screen. Thus when the field of view is only partially covered by the content, the user's eyes can easily catch the motion changes in the background not belonging to the visual system (such as a person passing the room). The user attaches the data glove and iPhone to the same hand/wrist for interaction inputs (gestures and orientation).

As indicated in Figure 2, the user can be in two modes: view mode and interactive mode. The view mode is a safe/lock mode, i.e., the user can only read the book pages and cannot do any unexpected or send random inputs to the system, for instance when changing pose or talking to someone using hands to gesture an alternative concept. In the interactive mode, the users interact directly with the e-book, so they can flip the pages using gestures displayed in the right-hand down-corner of the screen or touch equivalent icons on the iPhone's touch screen. Pictures visible on the e-book's pages can be configured as hyperlinks enabling the user to access other content. The user can change linked content to full-screen display by making a specific hand gesture or by touching corresponding menu item visible on the iPhone's screen. Linked content can also be another 3D VR scene (the second picture in the book in Figure 3). In this case, the user is transported to another 3D world where they are presented with additional features such as different camera modes for 3D navigation, the ability to record experiences (so they can be re-played later), and also ability to pick and change object features or orientations. Figure 4 shows a snapshot from a linked 3D world. The user can return to the e-book by making the "stone" gesture or touching the "exit" button on the iPhone.
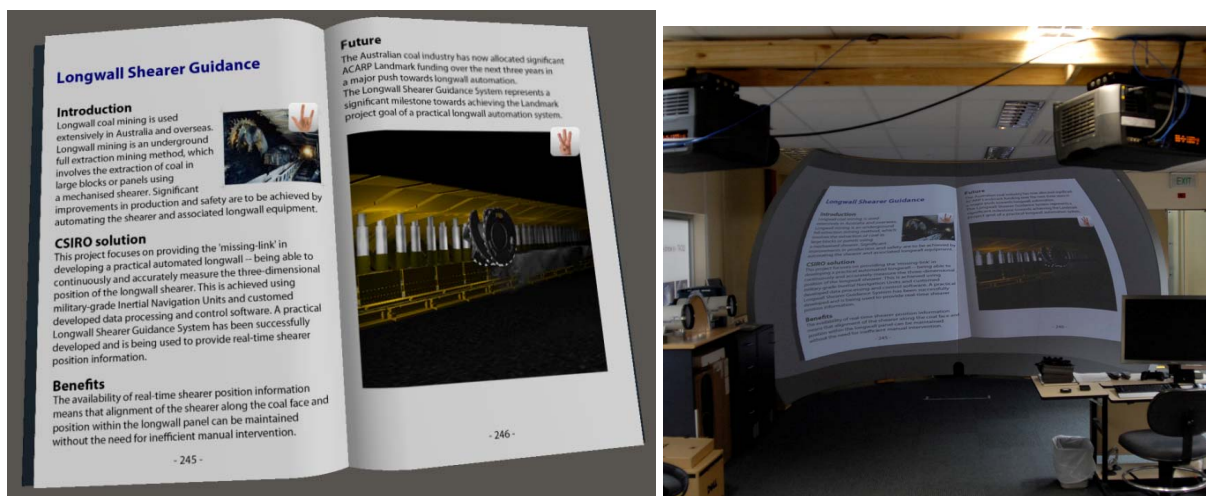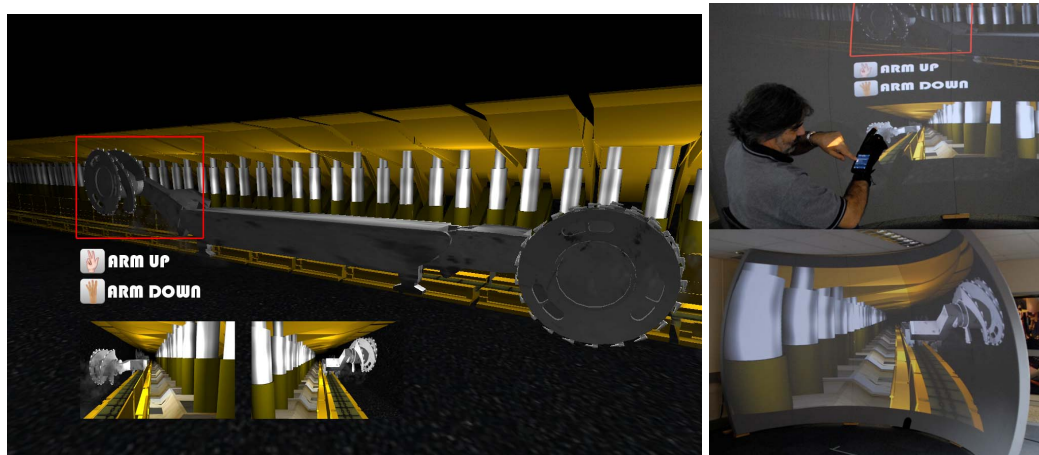

Figure 3: Immersive Virtual Reality E-book.

Figure 4: Inside the virtual mine.

IVR Experiment

As this combination of educational and VR technology evolves, it will have the potential to offer new paradigms for learning. In this paper, we have demonstrated the use of an IVR application for delivering an interactive environment for training users in underground coal mining. The application facilitates an e-learning experience by providing a very familiar object as the target for users to

interact with – a book. Importantly, this IVR system has the potential for providing an "enhanced" teaching medium as humans tend to remember events/situations better when they experience those events in person when the immersive factor is involved. The IVR environment enables a user to physically interact with various 3D objects and behaviours which in turn reinforces the idea that doing leads to efficient learning. Our prototype system can be implemented as an efficient and cost effective e-learning and training platform for different engineering domains. At another level, the same technology could be used in the teleoperation of mining equipment for the Future Mine. CSIRO has already developed VR systems for remotely monitoring underground mining equipment (LASC Longwall Automation - http://www.longwallautomation.com/). Collaborative industry projects are currently underway that will see CSIRO leverage IVR technology to demonstrate that teleoperation can be a reality. It is important that next generation e-learning systems are developed to provide new training mediums for the effective use of advanced control systems in the future.

References

Adamo-Villani, N., Carpenter, E., & Arns, L. (2006) 3D sign language mathematics in immersive environment. *Proc. of the 15ᵗʰ IASTED International Conference*, June, Rhodes, Greece.

Ainge, D.J. (1996). Introducing Primary Students to VR with Virtus WalkThrough: Two Pilot Studies. *VR in the Schools*, 2(1), pp. 10-15.

Apple (2009) iPhone Application Programming Guide, version 2009-06-17.

Bell, J.T., & Fogler, H.S. (1996). Preliminary Testing of a Virtual Reality Based Educational Module for Safety and Hazard Evaluation Training. *Proc. American Society for Engineering Education Annual Conference, Indiana Sectional Meeting*, Peoria, IL.

Bell, J.T., & Fogler, H.S. (1995). The Investigation and Application of Virtual Reality as an Educational Tool. *Proc. American Society for Engineering Education Annual Conference, Session 2513,* June, Anaheim, CA.

Brown, D.J., Cobb, S.V.G., & Eastgate, R.M. (1995). Learning in Virtual Environments (LIVE). *Virtual Reality Applications*, pp. 245-252, Academic Press: San Diego, CA.

Byrne, C. (1993). *Virtual Reality and Education*. University of Washington, Human Interface Technology Laboratory of the Washington Technology Center, Seattle, WA. Technical Publication R-93-6.

Edgar, D. (1969). *Audio-Visual Methods in Teaching, 3ʳᵈ Edition*. Holt, Rinehart, and Winston.

Fifth Dimension Technologies (2004) 5DT Data Glove Ultra Series. User's Manual. Accessed at http://www.5dt.com

Gay, E. (1994). Is Virtual Reality a Good Teaching Tool? *Virtual Reality Special Report*, Winter, pp. 51-59.

Gold, B. J., Pomplun, M., Rice, N. J. (2008). A new way to quantify the fidelity of imitation: preliminary results with gesture sequences. *Experimental Brain Research, 187*, 139-152.

Regian, J.W., Schebilske, W.L., & Monk, J.M. (1992). Virtual reality: An instructional medium for visual-spatial tasks. *Journal of Communication*, 42(4), 136-149.

Siegal, A.W., (1981). The externalization of cognitive maps by children and adults: In search of way to ask better questions. In I. Liben, A. Patterson, & N. Newcombe (Eds.), Spatial representation and behaviour across the life span (pp.163-189). New York: Academic Press.