An immersive virtual environment for learning sign language mathematics

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ABSTRACT

In this paper we describe the development of a new immersive 3D learning environment to increase mathematical skills of deaf children. The application teaches mathematical concepts and ASL (American Sign Language) math terminology through user interaction with fantasy 3D virtual signers and environments. The program can be displayed in immersive devices and includes a gesture control system comprised of a pair of pinch gloves and a 6-degrees-of-freedom wrist tracker.

Keywords

Virtual Reality, Sign Language Education, 3D Animation, 3D Modeling, Virtual Learning Environments

1 Introduction

Deaf education, and specifically math/science education, is a pressing national problem [Holt et al. 1997] [NSF report 1999]. Our project addresses the need to increase the abilities of young deaf children in math with a unique approach: 3D immersive animated signing. The general goal of our research is development of an immersive virtual learning environment in which deaf children (age K-3) interact with fantasy 3D signers and learn basic ASL math terminology and concepts. The interactive application can be displayed in immersive devices such as the 'Fakespace Labs FLEX' [Fakespace Systems FLEX] and is designed to engage deaf learners in "hands-on, minds-on" experiences, leading to deeper understanding of fundamental ideas in accordance with current educational guidelines.

Recently we have created a highly interactive computer animation program (Mathsigner™) for classroom and home learning of K-3 arithmetic skills, aimed at deaf children [Adamo-Villani et al. 2004; Adamo-Villani et al. 2005]. The program, currently in use at the Indianapolis School for the Deaf (ISD), is a web/CD-ROM deliverable 'desktop' application which makes use of standard input devices (i.e., mouse and keyboard). It includes 3D animated signers that teach ASL mathematics through a series of interactive activities based on standard math curriculum.
Because several research findings suggest that immersive learning applications are more effective than non-immersive ones [Youngblut 1997; NCAC report 2003], we have adapted the Mathsigner™ characters for display in a total-immersion environment, and we have developed a fantasy virtual world in which deaf children learn math concepts by natural interaction and direct experience.

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2 Background

Recently, there has been noticeable progress in development of VR applications for people with different types of disabilities. In the area of hearing impairments in particular, efforts have been directed primarily to creation of sign language recognition and synthesis systems [Greenleaf 1992; Vamplew 1996; Hernandez-Rebollar and Kyriakopoulos 2002; Kuroda et al. 2004].

As far as development of virtual learning environments to assist in Deaf education, we have found two noticeable examples of virtual environments for deaf/speech-impaired students: the 'Virtual Supermarket' developed at the University of Nottingham in England [Cromby et al. 1995], and the VREAL (Virtual Reality Education for Assisted Living) project, funded by the U.S. Department of Education [Edge 2001; WSPD 2005; Balk 2005].

Though both the VREAL project and the Virtual Supermarket are valuable examples of VLE for the hearing impaired, we believe that our application improves on the current state of the art in terms of: (a) high quality appearance of the virtual signers and signing motion; (b) complexity of real time interaction between 3D avatars and student; and (c) ease of communication between user and application. The advantages of our virtual learning environment will be discussed in the next sections.

3 Implementation

So far, the 3D learning environment consists of a candy store, a clock store, and two animated characters which respond to the motions and input provided by the user (see fig. 1 and 2).

Figure 1. Interior of candy store and 'Bunny' character (rendering)

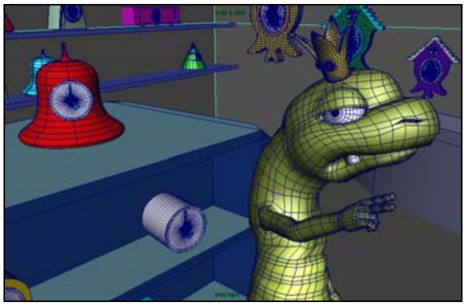

Figure 2. Interior of clock store and 'Lizard' character (polygonal mesh)

The student views the application through a pair of light-weight LCD active stereoscopic glasses as it is projected onto an immersive, four screen FLEX [Fakespace Systems FLEX] display (see fig. 3). This display provides the user with images of the virtual environment projected to the front, side, and floor screens. The user wears an InterSense head tracker [InterSense IS-900 Precision Motion Tracker], which enables the application to determine the position and orientation of the user's eyes; this information is used to re-draw the environment based on the user's perspective, as the direction of the gaze changes. Gesture tracking and recognition is accomplished via a pair of Fakespace Lab's Pinch Gloves [Fakespace Labs Pinch Glove] coupled with an Intersense wrist tracker. Interaction with the environment cues animated responses and sounds from the virtual objects and characters.

Figure 3. User in the FLEX

The interactive content is so far limited to K-1 math curriculum; we are currently programming math activities for grades 2 and 3. The majority of the interactive activities are based on the Mathsigner™ software [Adamo-Villani et al. 2004; Adamo-Villani et al. 2005] and have been redesigned and reprogrammed to function with the immersive application and the specialized input devices. The program teaches mathematics symbols and ASL signs for the numbers one to twenty, and mathematics skills for the four operations.

The application is not limited to display in the FLEX. It can be used on other systems such as a desktop computer, or a Portable Passive Stereoscopic System comprised of a screen and frame, a high-end laptop, two commodity projectors, a pair of polarizing filters, and a pair of inexpensive polarized glasses [Arangarasan et al. 2003] (this 'immersive portable system' will be used for the interactive demo in the 'Incubator').

3.1 System Development

Characters (and environments) were modeled and rigged in Maya 6.5 and animated using motion capture technology. Several software packages and libraries were used to convert the 3D data into a format compatible with the specialized hardware (see fig. 4). Graphics are rendered in the FLEX using OpenSceneGraph [OpenSceneGraph], an open source graphics development toolkit which works on top of OpenGL. Communication between the OpenSceneGraph libraries, the FLEX display system, and the input devices is implemented with the VRJuggler toolkit [VRJuggler]. Sound is configured to work using OpenAL and VRJuggler's Sonix plug-in. OsgCal, an adaptor for the Cal3D character animation library, allows the application to use Cal3D's functions to control skinned character animation within the OpenSceneGraph driven virtual environment

All 3D models were exported into the four components necessary for use with Cal3D functions: .cmf (mesh file), .csf (skeleton file), .caf (animation file), and .crf (texture file). Once exported, the separate files were reassembled as a model node within the scene graph of the osg program using the osgCal libraries.

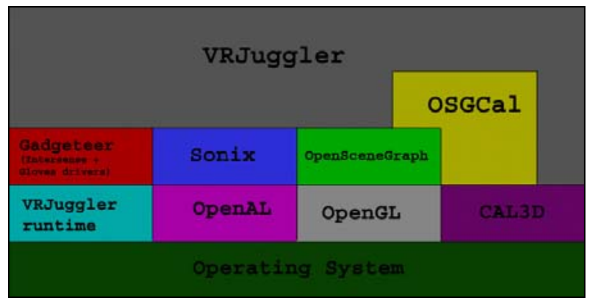

Figure 4. System Architecture

OsgCal functions are used to control the playback of the animation clips. When the program receives key input signals from the user, the osgCal startLoop and stopLoop functions cue the appropriate signing animations. When other character animations are required, such as walking motions and facial expressions, osgCal functions blend the various animation segments, thus providing a smooth transition between signing motions and other character behaviours. In this way, a variety of animations, including motion captured hand signs, facial expressions, general body movements, and locomotion patterns, can be exported from Maya as separate clips and blended and/or layered in real time to create a character that moves fluidly and realistically in response to the user's input.

3.2 Gesture Control system

The gesture control system, comprised of a pair of pinch gloves and a wrist tracker, allows the user to: (1) grasp and release virtual objects; (2) input a limited number of ASL hand-shapes; and (3) navigate the virtual environment.

Each pinch glove consists of a flexible cloth glove with strips of conductive cloth sewn onto the end of each finger as well as the inside palm. When the user connects the tips of two fingers, or fingers and palm, the conductive cloth is joined and a signal is sent to the system allowing the program to determine which of the user's fingers are touching. The InterSense IS-900 wrist tracker uses ultrasonic and inertial tracking to determine the position and orientation of the user's hand within the 3D environment. For example, this method of gesture detection enables the user to grasp objects within reach by pinching the thumb and forefinger together. Tracking information enables the program to identify which object in the scene is closest to the user's fingers when the user grabs that object with the gloves. The tracking information also allows that object to remain in the user's grasp as the user moves the hand around the scene. When the user separates her fingers, grasped objects are released at the user's new hand position. For instance, the student can grasp and move a certain number of candies from the candy jars to the counter and get signing feedback from the virtual character, as well as manipulate other objects in the scene.

The Pinch Gloves are also used to input a limited number of sign language gestures. Particularly, the application can determine if the user is signing any of the ASL numbers from 0 - 9 based on the connections formed by the user's fingers. Since the pinch gloves detect hand gestures based on contact between fingertips and fingertips and palm, the number of hand shapes that can be recognized is fairly limited. Future developments involve using the motion capture 18-sensors cybergloves for real-time gesture input and recognition.

The gesture control system is used for simple scene navigation as well. The student can pinch her ring finger and thumb together and rotate her arm in either direction to rotate the environment around her. She can also touch the palm with the pinky, ring, and middle fingertips and point in a direction to move to that area of the environment. This comfortable navigation method eliminates the need for a hand held navigation device, such as a wand, and gives the user the ability to use both hands to interact with the virtual objects in a natural way.

4. Conclusions and future work

In this paper we have presented a new immersive virtual environment in which deaf children learn math concepts and ASL math terminology through interaction with 3D virtual signers and objects.

The application has been evaluated throughout its development by deaf adults, Purdue faculty and students knowledgeable in sign language and deaf related issues who have provided positive feedback on the readability of the signs and the effectiveness of the program. Full-scale evaluation of the application with children age K-3 will be carried out in Fall 2006 in collaboration with the Indiana School for the Deaf (ISD).

Though just a prototype, our program has several advantages over existing examples of immersive virtual learning environments for the Deaf.

(1) *High realism/fluidity of the 3D characters' signing motion.* The application includes 3D fantasy avatars modeled as *seamless* polygon meshes, rigged with a human-like skeletal deformation system, and animated with motion capture technology. Using a state-of-the-art motion capture suit, worn by an experienced signer, has allowed for capture and real-time playback of highly realistic signing movements. Furthermore, the use of seamless characters that deform organically as they move has significantly improved fluidity and believability of the signs. Display and interaction with seamless characters has been one of the major challenges of this project. In general, 3D avatars displayed in immersive environments are segmented characters made of rigid components which rotate without changing shape; the result is robotic, puppet-like, unrealistic characters unable to fully engage the user. Research findings show that fluid, non-mechanical motion is fundamental not only to learning sign language effectively, but also to the reinforcement of the deaf child's self esteem and self-concept [Lang et al. 1993]. For this reason we have invested our research efforts in development of a natural gesture language, emotionally appealing to deaf children .

(2) *Complex real time interaction between 3D avatars and student.* Our virtual signers give directions and respond to the student's actions/questions in real time in ASL. No two dimensional video of the teacher needs to be dropped down on the computer display to give instructions, as in the VREAL project [Edge 2001; Balk 2005]. Superimposing a two dimensional image of the teacher over the virtual environment detracts from the feeling of presence and breaks the illusion of total immersion in the 3D world. Our 3D avatars act as virtual teachers, interact with the user while moving within the virtual space, and can be viewed from different points of view, thus supporting the feeling of immersive-ness. In addition, we are currently working on development of a control system that allows anyone who wears the mocap suit to control the movements of the 3D character. The 'actor's' motions are applied to the 3D avatar in real time, therefore a teacher could answer an unpredicted student's question in ASL directly through the virtual signer.

(3) *Natural communication between user and application via a simple glove-based gesture control system.* Though there has been significant progress in development of glove-based sign language input recognition systems, the majority of virtual learning environments for deaf students still make use of standard input devices. In our application the deaf learner can navigate the environment, grasp objects, trigger events, and respond to questions using hand gestures only.

Currently, the main limitations of the application are: (1) the small number of ASL hand shapes that can be input and recognized by the system; (2) the high cost of the equipment; and (3) the potential health and safety issues associated with use of immersive devices such as head mounted displays.

In future implementations the pinch gloves will be replaced by a pair of 18-sensors cybergloves which allow for input of all ASL hand poses. The research team is also working on development of a new low-cost device for natural input of hand gestures. We anticipate that the device will be able to interface with the immersive application and will provide a less expensive alternative to the data gloves.

Even with a more affordable input device, the high cost of the system remains a limiting factor of all immersive VR applications. Presently, our program is targeted at school systems, not individual customers.

The possibility of health and safety issues associated with use of head mounted displays is a problem of all immersive applications designed for children with disabilities. In case of inability to wear a head mounted display, the application can be displayed on a standard computer monitor and navigation can be accomplished with a joystick.

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