3D SIGN LANGUAGE MATHEMATICS IN IMMERSIVE ENVIRONMENT

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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. Our application improves on existing examples of virtual learning environments for the hearing impaired in terms of: (1) high realism/fluidity of the 3D characters’ signing motion; (2) complexity of real time interaction between student and 3D avatars and environments; and (3) natural communication between user and application via a simple glove-based gesture control system.

KEY WORDS
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 [1] [2]. 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’ [3] 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 [4] [5]. 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 [6] [7], 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. The specific objectives of this work are: (1) display of Mathsigner™ animated 3D signers in the FLEX [3]; (2) design and 3D modeling of two fantasy environments; (3) realization of math interactive learning/testing activities based on standard K-3 math curriculum; and (4) implementation of a basic gesture control system which includes a pair of Fakespace Labs’ pinch gloves [8] and a 6 degrees-of-freedom tracker by Intersense [9]. The specialized input devices allow the user to interact directly with the application by detecting when the user makes gestures that can affect the motion of the virtual signer. For instance, when the child picks up a certain number of candies from the candy jar, the 3D avatar comes forward and produces the corresponding number sign. When the avatar signs a question such as ‘how many lollipops are on the counter’, the child responds by producing the correct ASL number hand-shape with the pinch glove.

In section 2 we discuss: problems associated with Deaf math education, benefits of virtual reality (VR) technology in education, and state-of-the-art in development of VR learning environments for hearing impaired students. In section 3 we describe our application including: models and animation, system architecture, gesture control system, and interactive content. Conclusive remarks and future work are presented in section 4.

2. Background

2.1 Problems associated with Deaf math education

Research demonstrates that deaf individuals are significantly underrepresented in the fields of science and engineering [10]. Historically, it has been difficult for them to gain entry into higher education that leads to
STEM careers. There are several factors contributing to this disparity: (1) A significant delay in deaf children’s reading comprehension. (2) The difficulty (hearing) parents have conveying in sign language basic science/mathematical concepts. There are currently no tools for efficient learning of signs related to math concepts. (3) The inaccessibility to incidental learning (exposure to media in which mathematical concepts are practiced and reinforced). Deaf youngsters lack access to many sources of information (e.g., radio, conversations around the dinner table, and others) and their incidental learning may suffer from this lack of opportunity. Consequently some mathematical concepts that hearing children learn incidentally in everyday life have to be explicitly taught to deaf pupils [11].

Our project seeks to: (1) use a new technology to teach mathematics to deaf students who use sign language to communicate; and (2) provide a model for teaching technology for deaf people in general that can contribute to improving deaf education around the globe.

2.2 Virtual Reality in education

The documented effectiveness of Virtual Reality (VR) as a learning tool and the potential of immersive Virtual Reality Environments (VRE) to help disabled students are the motivating factors behind our research.

VR is a technology that allows users to explore and manipulate computer-generated, three dimensional, interactive environments in real time [7] [12]. VR is based on the theory that people do not experience reality directly, they receive a series of external stimuli which are interpreted by the brain as reality. ‘If a computer application can send the same external stimuli that the brain can interpret, then the simulated reality is potentially indistinguishable from reality’ [13]. There are two main types of VR environments: desktop and total immersion. As mentioned previously, in this paper we are concerned with total immersion VR environments which are usually presented on multiple, room-size screens, or through a stereoscopic head-mounted display unit. The user interacts with the environment with specialized equipment such as a data glove and/or a tracker. Sensors on the head unit and/or data glove track the user’s movements/gestures and provide feedback that is used to revise the display, thus enabling smooth, real time interactivity.

Existing data suggest that VR technology offers significant, positive support for education in general [7] [13]. Although the benefits of VR experiences need to be defined in a more comprehensive way, recent studies show that VR often provides a more effective learning tool than traditional classroom practices, students enjoy working with virtual worlds, and the experience is highly motivating [6]. Research also shows that VR is particularly suitable to math and science education because of its ability to ‘bridge the gap between the concrete world of nature and the abstract world of concepts and models’ [14]. This makes it a valuable alternative to the conventional study of math and science which requires students to develop understandings based on textual descriptions and 2D representations [15].

In regard to disabilities education, literature findings suggest that VR has advantages over other teaching technologies because it can fulfill the majority of the learning requirements of students with disabilities [16]. Some of the most commonly encountered needs of people with learning impairments include: control over environment; self-pacing; repetition; ability to see or feel items and processes in concrete terms (difficulty with abstract concepts); safe and barrier-free scenarios for daily living tasks; and motivation [17].

For example, in our application the deaf child can explore a controlled, barrier-free virtual candy store and communicate with the virtual store keeper in ASL. With the help of the 3D signer, the child learns the concept of numbers (and corresponding ASL signs) in a concrete way -by counting candies-, she develops addition and subtraction skills by adding or removing candies from the counter, and she can answer the store keeper questions in sign language by producing ASL number hand-shapes with the pinch glove. In addition, she can repeat the same learning tasks over and over again and receive predictable, consistent feedback.

2.3 Survey of existing VR applications for the Hearing Impaired

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 [18] [19] [20] [21].

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 [22], and the VREAL (Virtual Reality Education for Assisted Living) project, funded by the U.S. Department of Education [23] [24] [25]. Researchers at the University of Nottingham have developed a series of desktop VEs to assist in teaching of daily life skills, as well as ‘Makaton’, a sign language used in the UK by people with learning disabilities. Assessment studies showed that disabled students who used the VE were able to perform everyday life activities (i.e., a shopping task at the supermarket) in a shorter time and with a lower number of mistakes. Students also showed a significant increase in the number of Makaton signs that they knew.

In the VREAL project, engineers from Veridian [26] have teamed up with six schools for the Deaf and have adapted the technology used in military simulations to create an elaborate immersive virtual learning environment for deaf children. The environment includes replicas of an elementary school, supermarket, farm, and post office. Students use joysticks and head mounted
display glasses with motion sensors to navigate the virtual world and learn life skills, language arts, math, and science. The software has embedded video of the teacher signing the instructions; the teacher can also stand in front of a video camera and sign to the student while the image appears in real-time on the student’s display screen. Five schools across the US used the program in 2004 and assessments show that students improved their test scores by an average of 35% [25].

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. The student views the application through a pair of lightweight LCD active stereoscopic glasses as it is projected onto an immersive, four screen FLEX [3] display (see fig. 1). This display provides the user with images of the virtual environment projected to the front, side, and floor screens. The user wears an In terSense head tracker [9], 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 [8] coupled with an Intersense wrist tracker [9]. Interaction with the environment cues animated responses and sounds from the virtual objects and characters.

3.1 Models and animation

In order to display the Mathsigner™ characters (a bunny and a lizard) in the FLEX, we have reduced the models’ polygon count and implemented a new facial rig. A lower polygon count is necessary in order to maintain the high frame rate and real-time interaction needed in the FLEX. To realize high visual quality with a limited number of polygons, we have optimized the 3D surfaces by concentrating the polygons in areas where detail is needed the most: the hands and the parts that bend and twist (i.e., elbows, shoulders, wrists, and waist). With such distribution of detail we have been able to represent realistic hand configurations and organic deformations of the skin during motion. Each character has been set up for animation with a skeletal structure that closely resembles a real human skeleton and the geometry has been bound to the skeleton with a smooth skin. The face of each 3D signer has been rigged with bone deformer, the only technique supported by Cal 3D [27]. Figure 2 shows both character models and the ‘bunny’ character rig.

The candy store and the clock store, represented in figures 3 and 4, have been constructed of several polygonal surfaces whose overall poly-count does not exceed 50,000 polygons.

To achieve fluidity and realism of motion, the virtual signers are animated with a library of signing clips recorded directly from an ASL signer wearing a Metamotion 19-markers optical motion capture suit [28] and a pair of Immersion 18-sensors cybergloves [29]. Keyframe animation was used to animate various facial expressions such as eye blinks, eyebrow deformations, and mouth movements; directional constraints were used to control gaze direction.

The application can also be displayed on other systems such as a desktop computer. To maintain the feeling of immersiveness, the child can wear a head mounted display and navigate the environment using the same gesture control system.
3.2 System Architecture

Several software packages and libraries were used to convert the data into a format compatible with the specialized hardware (see fig. 5). Graphics are rendered in the FLEX using OpenSceneGraph [30], 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 was implemented with the VRJuggler toolkit [31]. Sound was configured to work using OpenAL and VRJuggler’s Sonix plug-in. OsgCal, an adaptor for the Cal3D character animation library, allowed the application to use Cal3D’s functions to control skinned character animation within the OpenSceneGraph driven virtual environment.

All models were created as Maya 3D files and then 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.

OsgCal functions were 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.

3.3 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.

3.4 Interactive content

The interactive content is so far limited to grades K-1; we are currently programming math activities for grades 2 and 3. The majority of the interactive activities are based on Mathsigner™ [4] [5] 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.

For instance, in one activity the child practices the association between the concept of number, the mathematical symbol, and the ASL representation. After walking into the candy store, the child uses the pinch glove to ‘pick’ a certain number of candies from various jars. After she releases them on the counter, the virtual store keeper (Bunny) comes forward and signs the corresponding ASL number, while the number symbol appears on the cash register (see fig. 6).

![Fig. 6](image1)

Fig. 6. Three representations of number ‘two’: ‘2’ candies on the counter, Bunny signing ‘2’; math symbol for number ‘2’ on cash register

The student can then practice addition and subtraction skills by asking the store keeper to put more (or remove some) candies on the counter. She does this by touching the ‘MORE’ or (‘LESS’) call bell with the pinch glove (see fig. 7). The Bunny adds (or removes) a random number of candies and signs the question: “how many candies are now on the counter?” The child signs the answer with the pinch glove and receives feedback in ASL and math symbols.

![Fig. 7](image2)

Fig. 7 ‘More’ and ‘Less’ virtual call bells

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), one of the leading institutions in Deaf Education. Children will interact with the program using a ‘portable immersive system’ consisting of a screen and frame, a high-end laptop, two commodity projectors, a pair of polarizing filters, and inexpensive polarized glasses [32].

4. Conclusion 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. 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.** As mentioned in section 3.1, 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 [33]. 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 [23][24][25]. 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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