Integration of Assistive Technologies into 3D Simulations: An Exploratory Study

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Abstract— Currently, there are limited, commercially available video games for people with disabilities. Sim-Assist is a software system that aims to allow people with disabilities to interface with a three-dimensional simulation game of Air Hockey. This is accomplished through various integrated assistive technologies, such as brain-computer interfacing, voice commands, and speech-to-text capabilities. With Sim-Assist, users are able to play Air Hockey without depending on sight, and in a hands-free manner. We conducted an exploratory study to provide the foundation for integrating assistive technologies in 3D simulations, including scientific simulations and serious games. In this paper, we introduce the research and development of assistive technologies, focusing more on the BCI software component; outline our system design and implementation; provide a short walkthrough of the interface; and briefly discuss our preliminary results.

Keywords- Assistive technologies; brain-computer interfaces; speech-to-text; Air Hockey; 3D simulation

1 Introduction

According to the 2014 Disability Statistics Annual Report, the average percentage of disability in the United States population in 2013 was 12.7%; this translates to approximately 41 million people in the United States with some disability [1]. Recently, assistance for people who are care-dependent has gained importance as a research field because it could potentially improve the quality of their lives as well as their relatives'. Blindness and vision impairment also increases rapidly as people grow older, particularly after the age of 75 [2].

Software-based assistive technology (SBAT) research is the main motivation for this paper. Our system, Sim-Assist, aims to integrate SBATs into a 3D simulation. The main goal of Sim-Assist is to allow people with disabilities to play the 3D virtual game Air Hockey. In the near future, we plan to use Sim-Assist as a foundation to integrate assistive technologies (AT) into 3D scientific simulations.

This paper aims to provide an exploratory study of the possibilities of integrating assistive technologies into a 3D environment. In Section 2, we investigate the surveyed research and development in SBATs. In Section 3, we outline the system design and implementation of our system. In Section 4, we provide a brief walkthrough of Sim-

Assist's interface. In Section 5, we discuss our preliminary results. Finally, we provide our concluding statements and discuss the directions of our future work in Section 6.

2 SBAT Background

Software-based assistive technologies are products that offer people with disabilities better accessibility to computers. For those who are unable to see, hear, speak, or lack motor skills, assistive technologies can alleviate their lives a little more. Some of their distinguishing categories include brain-computer interfacing, gesture recognition, and speech recognition. Brain-computer interfacing mainly targets users who lack motor skills, but can also be used by users who are unable to see, hear, and speak; gesture recognition targets users who are unable to see, hear, or speak; and speech recognition targets users who are unable to see and possibly those who lack motor skills.

One of the main challenges pertaining to developing software for assistive technologies (ATs) is the unsuccessful collaboration between developers and disability specialists. The disjoint between the functionality requirements of disabled users and the efforts of system developers creates poor usability of the end product for the users. Another challenge is that the complex solutions are not necessarily the best. The more tools that are embedded in a program, the more complex the system becomes, making it more difficult for users to learn. There also seems to be a large spectrum in the research and development of assistive technologies because there are various types of disabilities. This ranges from aiding students learn in the academic environment (applies to those with learning disabilities, blindness, and deafness) to assisting the elderly.

Research in software-based assistive technologies is important as society grows increasingly more technologically advanced. As computers are meant to improve the quality of our lives, they are used daily. Therefore, it makes sense to use computers as one of the tools, if not the main tool, for assisting people with disabilities. In order to keep up with the advancements in everyday technology, research in the software for such computers for assistive technologies becomes important. The most distinguishing characteristics of software-based assistive technologies are the abilities to convert text from the computer to auditory speech and vice versa, and respond to: speech commands, gesture commands, and certain brain signals. These substantial advancements within this area would benefit people who have a disability such as: auditory, hearing, speech, or motor impairments.

2.1 Related Research

Assistance for people who are care-dependent has gained importance as a research field because it could potentially improve the quality of their lives as well as their relatives. Such people may be dependent due to motor, sensory, or cognitive impairments. As a result, performing daily life activities such as feeding, hygiene, personal care, etc. may be difficult. Gomez et al. presented and evaluated a system that shows adaptive manuals for daily life activities for people with disabilities [3]. This proposed system is based on mobile devices and Quick Response (QR) codes, and will help with the rehabilitation process of patients with acquired brain injury. Additionally, Donoghue et al also aimed to create a system for people with motor disabilities [4]. Specifically, they developed a human application of neural interface systems (NICs) for people with paralysis. However, the NIC is in its early stages of development. The pilot trial results provided proof that a neuron-based control system is feasible. Thus, in this system, signals can be detected, decoded, and used for real time operation of computer software, ATs, and other devices.

According to the 2012 National Health Interview Survey, 20.6 million American adults reported experiencing vision loss [2]. Individuals who experience vision loss can be referred to those who claim that they have difficulty seeing, even while wearing glasses or contact lenses, and people who are blind or unable to see at all. Blindness and vision impairment also increases rapidly as people grow older, particularly after the age of 75 [5]. At this age, people will struggle to learn Braille and become accustomed to visual impairment without dependence on others. With this issue as motivation, Narasimhan et al developed system to provide the visually impaired an independent shopping experience [5]. This system will allow the visually impaired shopper to find the correct aisles and shelves that contain the desired product. The system can also distinguish between different products of the same type (e.g., Marinara sauce vs. Alfred sauce) once the general shelf location of the desired product has been identified. This system can also be used for accomplishing other daily tasks such as cooking.

Although there are different levels of disability, assistive technologies should not solely target severe disabilities. According to Edyburn, little attention has recently been dedicated to the assistive technology needs of students with mild disabilities [6]. Mild disabilities may consist of learning disabilities, behavioral disorders, and mental retardation. Some tools such as iPing, Co:Writer, and WebMath have been developed for these targeted users, but there is little evidence suggesting students with mild disabilities have access to such technologies [6]. In addition, due to the lack of performance measurement tools for assessing users' progress in the academic field, it is difficult to justify claims that the technology will enhance performance.

There have also been efforts to develop assistive technology for the elderly. So far, assistive technology targeted towards those who are older has yet to improve the quality of their lives. To target this issue, Bright and Coventry suggested potential design strategies to maximize a product’s usability and usefulness for older adults [7]. By doing so, their main goal was to show the importance of considering both psychological and socio-emotional design requirements when creating such technology.

2.2 Development Efforts

It appears that research and development efforts have not yet advanced to a stage that allows people with disabilities to interact with 3D environments. However, there are existing user interfaces (UIs) that allow people with disabilities to interact with 2D environments in such a way that is more user-friendly and accessible for them. Through the developments of these existing works, we may see user interfaces for 3D environments in the future. We explore these mentioned works and the methods that were used in such interfaces.

Visual Impairments.

There are various degrees of visual impairment, also described as “low vision” [8]. Variations of low vision may include: a diminished acuity; the loss of one’s field of vision; one’s sensitivity to light; and distorted vision or loss of contrast. Currently, a large selection of assistive technologies is made commercially available to the general public such as screen readers and magnifiers, braille keyboards, and text-to-speech software. However, these generic products only solve he most basic problems that one with low vision must encounter. Researchers are now exploring alternative methods that can further expand the limited capabilities of these people.

Auditory Interfaces.

People who are blind depend heavily on their sense of hearing. Previous research in spatial audio revealed that it has potential as a new medium for creating nonvisual interfaces [9]. Researchers Winberg and Hellstrom used spatial audio to create an auditory interface that utilizes direct manipulation for graphical user interfaces (GUIs) to become more accessible for the blind [10]. Although direct manipulation improves the average user’s usability and learnability of a system, it is not available in modern screen readers that most blind users depend on [10].

Previous research in this type of interaction for blind users revealed systems that include using tactile devices with audio [11, 12] and a system that uses 3D audio and a data glove [13]. However, in these systems, only a subset of the interface objects are presented to the user, and the user has to browse the auditory space in order to get an overview of the object. Therefore, the user is interacting directly with interface objects instead of using direct manipulation, according the definition mentioned earlier. Another system that uses auditory interfaces is a system developed by Pitt and Edwards [14]. In this system, the cursor becomes a “virtual microphone” that is used for selecting items from a menu [14].

In order to determine if it is possible for a UI to utilize auditory direct manipulation, and if this method of interaction is worth pursuing, Winberg and Hellstrom implemented an auditory form of the game “Towers of Hanoi” [10]. Each disc had a corresponding sound that was different in pitch and timbre. The smaller the disc, the higher the pitch. The sounds also had slightly different tunes with respect to each other to further distinguish the size of the disc. The tower the disc is located on would be determined by the various levels of stereo panning and amplitude envelopes. Furthermore, the vertical position of the disc is distinguished by the length of the sound. In this system, the mouse is similar to the one used by Pitts and Edwards. Users can move the cursor to each tower based on differences in volume. Results from testing this system revealed that auditory direct manipulation is possible and possesses potential of being significant for blind computer users [10].

Custom Interfaces.

Most graphical user interfaces are designed to only cater towards the general public. However, there are some cases where the interface can be easily rendered to suit one’s unique capabilities. For users with restricted vision, enlarging the fonts and visual cues appropriately may suffice. Similarly, for users who partially lack motor control, it may be easier to interact with interfaces that incorporate widgets with large targets so that dragging is unnecessary. In cases where the use of ATs are required, a specific GUI design may be desired. For instance, it might be more user-friendly to design a hierarchical structured interface for navigation through UIs that utilize screen readers.

When designing a GUI, it is important to focus on the users' needs. However, it is unreasonable to design a specific GUI that handles each individuals' unique preferences. A paper written by Gajos et al proposes the idea of generating a custom user interface which would better suit users, especially for users with visual and motor impairments [15]. The authors present a system called SUPPLE++ that automatically generates UIs that caters specifically towards either an individual's motor or vision capabilities, or both. Their preliminary results indicated that their system allowed one user to complete tasks, which she could not perform using a standard interface. Compared to other users, the SUPPLE++ allowed the user to save time by 20% [15].

Motor Impairments.

Most of the interactions between the user and the GUI rely on selection operations [16]. Actions such as inputting data can also be achieved by selecting various letters through on-screen keyboards. This type of selection operation is executed by pointing the cursor at a desired area of the screen, and clicking to indicate the selection of the item the cursor is pointing to.

For people with motor disabilities there are several devices that can be used as an alternative for the mouse. For example, the "Tonguepoint" [17], as the name suggests, is a device in which the user can operate the cursor using his/her tongue. Results for users who have tested this system revealed that they were able to achieve a performance level that was only 5-50% slower than users who used a standard pointing device.

Another alternative device is the "Headmouse", which is a pointing device that moves the cursor based on head movements [18]. This is similar to Emotiv's Neuro Mousecontrol application that allows the user to control the cursor using head movements while he/she is wearing the Epoc headset [19]. However, whereas the Neuro Mousecontrol application depends on cognitive action to trigger left and right mouse button operations, the Headmouse device achieves these actions when the user dwells over a particular key on an on-screen keyboard for a set period of time, or by using a remote switch. There are also more complex approaches for computer interface functionality such as eye-tracking systems. These systems only depend on the user's ability to control the gaze of his/her eye. The cursor follows the eye's line of gaze, and the clicking operation is executed whenever the cursor remains in a location for a certain amount of time, which is similar to the Headmouse device.

Another complex approach is the Brain-Computer Interface that uses electroencephalogram (EEG) signals. However, Andrew Junker developed a device called Cyberlink that allows the user to control the cursor using both electromyography (EMG) (produced by muscle movements from the head and neck) and EEG signals (produced by thoughts) [20]. Unfortunately, this method of interaction hinders the overall control process of the cursor because intensive concentration is required, which may be difficult users.

Barreto et al. proposed a system that only utilizes EMG signals for cursor control [16]. In their approach, cursor movement depended on the natural and voluntary movements of the user's face such as clenching different sides of the jaw (left, right, and both) and eyebrow movement (up and down). These types of movements are usually controllable for people who are impaired from the neck down. The system was tested by six subjects that participated in 20 trials. In each trial, subjects were asked to click on the Stop button by moving the cursor from one corner on the computer screen to the center, where the button is located. Results have shown that the subjected required an average of 16 seconds for completing the task [16]. Though this time is notably greater compared to the amount of time it would take for an unimpaired subject to accomplish the same task using a mouse, the response time would still be usable with most standard GUIs. In addition, this proposed interface may potentially be more affordable and portable than other complex interfaces like the eye-tracking system.

Issues/Limitations.

In the case of auditory interfaces, one issue is its scalability as the complexity increases. In Winberg and Hellstrom's Towers of Hanoi game, only five discs were used and users seemed to perform relatively well. However, Towers of Hanoi had rule restriction that were able to offer some guidance for the users. In a desktop interface, in which there will inevitably be a larger amount of objects, will blind users benefit from auditory direct manipulation?

Another issue in auditory interfaces is representing the selection state in a GUI. The selection state for when users execute selection operations such as highlighting text or selecting objects to drag and drop needs to be represented. In the game Towers of Hanoi, users were not able to recognize whether or not they were actually moving the disc to the next tower instead of just hovering the cursor over each tower. Furthermore, if large numbers of interaction objects are present, the user may be limited to his/her memory. To forget the location of an object would be time consuming for the user to constantly check each item present one by one for the correct object. Another issue would be using various sounds could cause the user to forget the meaning of each sound during the beginning stages of using the system. This means that auditory interfaces may be more difficult to learn for users.

For UIs that accommodate specifically to people with motor impairments, there may be some possible disadvantages depending on the category of motor disability. For instance, a user with cerebral palsy may not be able to operate the Tonguepoint device due to lack of motor abilities in the tongue. Similarly, a user with spinal fusion may not be able to move his/her head, thus unable to fully operate any of the mentioned BCI systems. However, for those who are capable of operating a BCI system, one limitation is the reaction speed of the cursor. In addition, it takes a considerable amount of concentrate to train and execute commands. If the user becomes distracted while training the system, it will be difficult to accurately perform a desired task. Furthermore, it is difficult for one to measure the effectiveness of a BCI system against a mouse when executing the same tasks. This is because Fitts' law is unable to describe the performance of people with disabilities [21].

Two major disadvantages of eye tracking systems are that they are significantly expensive and require a considerable amount of focus to control. If the user loses focus and unintentionally stares into one location on the UI, he/she may accidentally click the cursor. Another limitation is that the calibration of the device can be easily lost if the user changes position with respect to the screen [16]. Furthermore, gazing at a location that is out of the camera's field of vision will hinder the system's operation.

3 System Design and Implementation

Our system uses a 3D version of the Air Hockey game, implemented by us. Sim-Assist is innovative because it allows people to play an engaging game such as Air Hockey with reduced effort. In addition, there are no existing commercially available video games that incorporate brain-computer interface (BCI) technology.

The main functionalities of Sim-Assist include: the ability to move the Air Hockey paddle using BCI capabilities; an audio notification for each new score; and the ability to input player information, restart, and pause and resume the game using speech. The implemented requirements of the Sim-Assist system are shown in Table 1. The intended users of this system are people with visual and motor impairments, or both. However, people without disabilities may also use Sim-Assist to experience a new form of gaming (BCI-based).

Sim-Assist was developed in C++ on a Microsoft Windows platform, using Microsoft Visual Studio 2012. To play the Air Hockey game, Sim-Assist requires the Emotiv Epoc headset for all BCI-related user inputs [19]. To record the user's voice for speech commands and speech-to-text capabilities, the Microsoft Kinect peripheral was used, with a dependency on the Microsoft Speech Platform.

The Sim-Assist system, from a high-level perspective, consists of different layers in its architecture, as shown in Fig. 1.

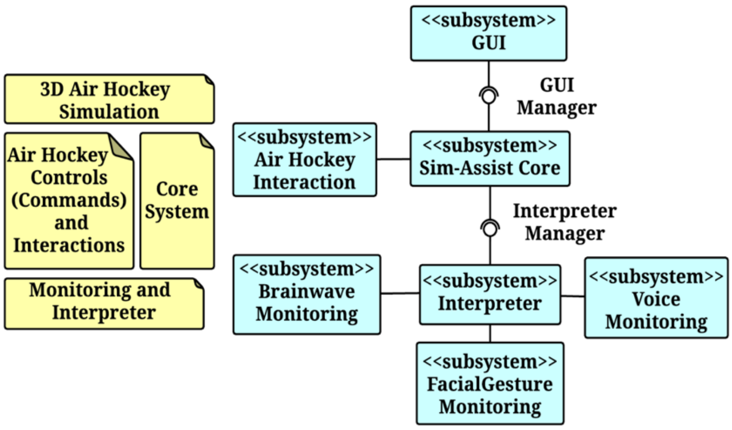


Fig. 1. System-level diagram of the Sim-Assist system. Layers are represented in yellow, and components are represented in blue.

Table 1. FUNCTIONAL REQURIEMENTS FOR SIM-ASSIST

Functional Requirements
Sim-Assist shall:
● Display a 3D simulation game of Air Hockey.
● Allow the user to control the mouse using head movements.
● Grant the user the ability to control the mouse using various thoughts.
● Permit the user to use voice commands to pause/un-pause the game using speech.
● Notify when user scores a goal.
● Enable the user to toggle voice detection.
● Allow the user to input player information using speech.
● Present the option to select number of players.
● Provide the capability to quit the game using speech.
● Enable the user to enter/exit full screen mode using speech.
● Authorize the user to assign facial expressions specific to mouse control.
● Permit the user to assign thoughts to specific mouse control.
● Accept multiple users to play at one time.

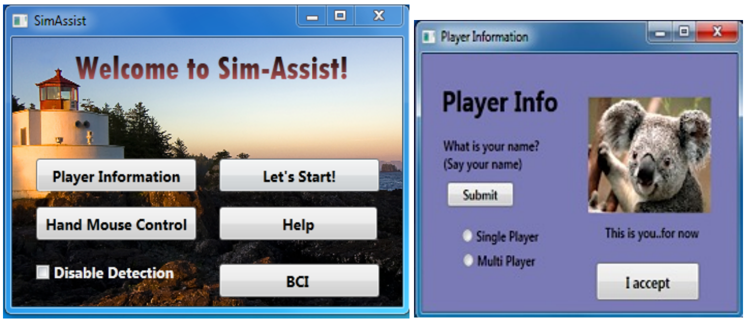
The lowest layer is the monitoring and interpreter, where Sim-Assist detects speech, facial and head gestures, and brainwaves. This is accomplished by the brainwave, facial gesture, and voice monitoring subsystems. The interpreter subsystem then takes these possible commands and determines if they are actual commands. If so, they are sent to the Sim-Assist core system. This system is responsible for all the major decisions within the system, including holding registered commands, as well as managing GUI information. The top layer of Sim-Assist is the Air Hockey game, which consists of the GUI subsystem that communicates with the Sim-Assist core system.

4 System Walkthrough

Upon startup, Sim-Assist will greet the user with a welcome window, as shown in Fig. 2a. The user must enter his or her information prior to playing Air Hockey, as shown in Fig. 2b. The system will prompt the user to enter his or her name verbally. A database of approximately 200 popular names (both genders) in the U.S. is used to help the system recognize the user’s name. The user also has the option to select how many players will participate in the game (one or two).

Once player information is submitted, the user must click on the “BCI” button from the welcome window. The training session for the headset will launch, together with Emotiv’s “Neuro Mousecontrol” application. Once the training session is completed, the user can map trained commands to the mouse control. This will allow the user to move the mouse, along with playing the game, using his or her thoughts.

Finally, the user can launch the game by clicking on the “Let’s Start!” button. The user will be presented with an Air Hockey table, along with a scoreboard, two paddles, and a puck, as shown in Fig. 3.



(a) (b)

Fig. 2. a) Sim-Assist welcome window; b) Player information window.

It is important to note that our settings were that Player 1 could control the paddle using only his or her thoughts and facial expressions, while Player 2 can control the paddle only with keyboard presses. Either player could also: enter or exit full screen mode, as well as pause, resume, or restart the game using speech commands.

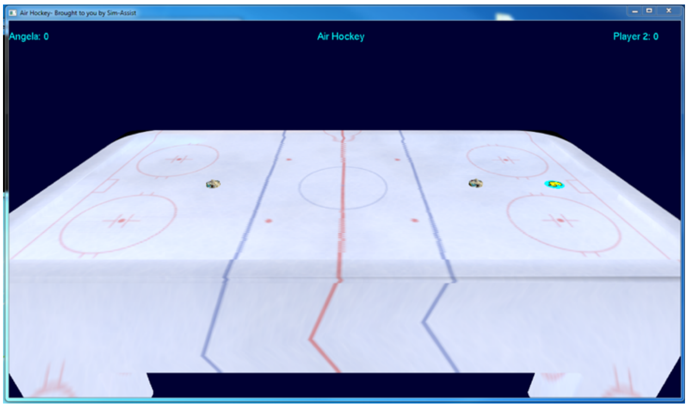


Fig. 3. Snapshot of 3D Air Hockey game

5 Preliminary Results

One limitation of our system was that Player 1 could use only BCI controls, while Player 2 could use only keyboard controls. Upon system testing, we realized that the Air Hockey game is too difficult to play with BCI controls alone. While playing the game, Player 1 was under too much stress and had difficulties executing certain thoughts accurately. Since Player 2 could control his or her paddle using only keyboard presses, this served as an unfair advantage. Consequently, in our future versions, we plan to fix the current player settings of the game.

One significant constraint in our system was that in order for Player 1 to use the Epoc headset, he or she needed to have little or no hair, as shown in Fig. 4. Otherwise, the sensors on the headset were unable to detect any signals.

Fig. 4. Player using an EEG headset to interact with the 3D Air Hockey game

Because the Epoc was used, an advantage of Sim-Assist is that there are many different types of thoughts the user can use to map to a specific mouse control. To compare, systems that use NeuroSky's "MindWave" headset will operate only if the user is in a focused or relaxed state [8]. Using this headset will be too restrictive for developers to create a robust system.

6 Conclusion and Future Work

Sim-Assist allows people with disabilities to interface with a three-dimensional simulation game of Air Hockey. Inspired by the HeadMouse and Barreto's system, Sim-Assist users can also interact with the interface using facial expressions and head movements. Our system utilizes brain-computer interfacing, voice commands, and speech-to-text capabilities, which target people with visual and/or motor impairments. We will leave the addition of text-to-speech capabilities for future work.

Sim-Assist serves as a foundation to integrate assistive technologies into a larger variety of 3D simulations. Once further improvements are made, we will be able to apply its concepts to 3D scientific simulations. We plan to use the concepts of AT-integration from Sim-Assist for the virtual watershed simulation environment that is part of the NSF-funded Western Consortium for Watershed Analysis, Visualization, and Exploration (WC-WAVE) project, as shown in Fig. 5 and Fig. 6 [22]. This will allow scientists and researchers with disabilities to interface with and navigate through a 3D environment.

We also strongly consider using a different EEG head-set. We hope that with the newest Emotiv Epoc model, Epoc+, we will have more accurate EEG readings and be able to write our own mouse control application.

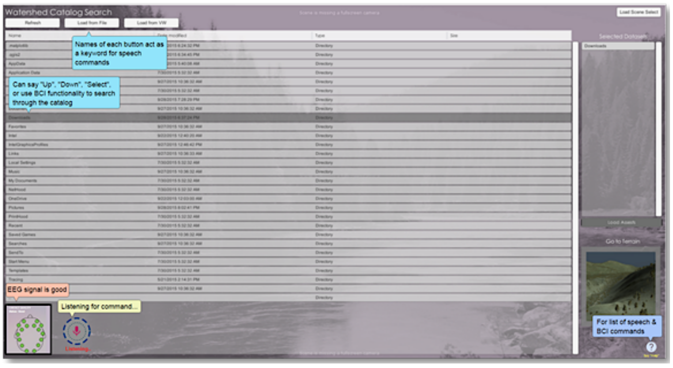


Fig. 5. Mock-up interface of Catalog Search in the Virtual Watershed Platform with AT-integration

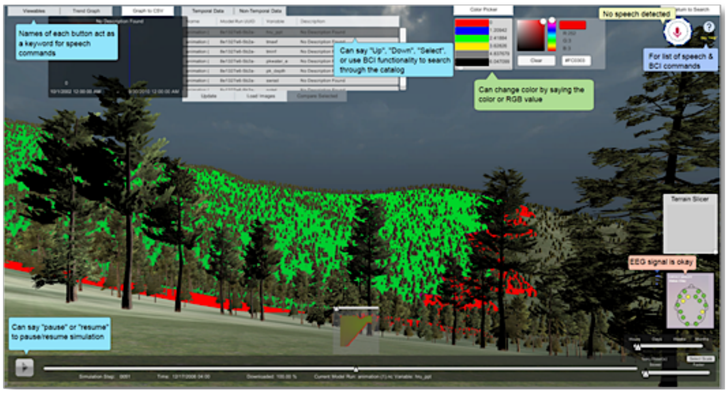


Fig. 6. Mock-up interface of the Virtual Watershed Platform with AT-integration

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