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Constructivist Physics Learning in an Immersive, Multi-User Hot Air Balloon Simulation Program (iHABS)

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Abstract

This paper describes and discusses an immersive multi-user Hot Air Balloon Simulation (iHABS) project that allows students to experience virtual hot air ballooning. The iHABS project enables students to pilot a hot air balloon as well as learn fundamental physics principles in a fun, exciting, engaging, and collaborative setting.

We briefly survey the use of hot air ballooning in physics teaching and the use of VR technologies in support of learning. We then discuss the pedagogical support provided by iHABS. Next, we proceed with a detailed description of the iHABS system followed by a discussion on the design of interaction techniques, the system design and its implementation.

Keywords : Virtual reality, education, interaction techniques.

1 Introduction and Motivation

Hot air ballooning is well-known as an exciting sport but few people realize that hot air ballooning is actually a remarkable demonstration of fundamental scientific principles including the Archimedes' principle of Buoyancy and the law of Thermodynamics. However, due to the inherent danger of asking a student to pilot a real hot air balloon, the object is not used to convey these physics concepts. With the emergence of VR technology that can create "virtual presence" and allow users to do dangerous things safely in a virtual environment, we believe that implementing an immersive hot air balloon simulation that supports constructivist physics learning may be an effective way to help students learn these underlying physics principles.

The iHABS project implements an effort to build an immersive, multi-user hot air balloon simulation program based on educational theories of cognitive and social constructivism. The goal of iHABS is to utilize immersive VR technology and the advantages of collaboration among users to create an effective, engaging, and fun virtual hot air ballooning environment for students to learn the physics principles in a constructive fashion.

2 Background Research

The use of hot air ballooning in teaching physics was first introduced by Haugland [1995]. He stated that various topics of physics could be taught through the domain of hot air ballooning. Among these topics, Buoyant force, the concept that states the net force due to air pressure is an upward force, is the most commonly concept misunderstood by students. Item 12D of Force Concept Inventory [Hestenes et al. 1992] showed that Buoyant force was hardly recognized by students at any level. Interviews with 16 graduate students revealed that only two of them really understood the concept of Buoyant force. Thus, one fundamental motivation of implementing iHABS is to correct the misconception of Buoyant force.

Almost all the existing hot air balloon simulators were developed for entertainment rather than supporting learning. Only one hot air balloon simulator [Haugland 1995] has been developed on the basis of teaching physics. This program is a 2D simulator. It was developed based solely on instructional design principles and is only used as a supporting resource to classroom teaching rather than as an independent learning tool.

The Newtonian World and Maxwell World of the ScienceSpace project [Dede et al. 1996] developed by George Mason University show that VR features are effective in helping students to understand abstract science concepts. On the other hand, testing results from the Virtual Reality Gorilla Exhibit [Allison et al. 1997] indicate that VR systems allow students to learn via first-hand experience in environments that would normally be too dangerous or impossible for them to experience in the real world. These researches indicate that immersive VR presents new and exciting educational opportunities.

At this point in time, research on multi-user immersive VR in education is still in its infancy. Only two well-known and established multi-user immersive VR projects have been reported on so far. They are the NICE (Narrative Immersive Constuctionist/Collaborative Environments) by Electronic Visualization Lab (EVL), University of Illinois (Roussos et al. 1999] and GCW (Global World Change) by Human Interface Technology Lab (HITL) at the University of Washington [Winn and Jackson 1999]. These two projects concluded that in order to maximize the potential for VR to facilitate collaborative learning, there is a need to structure cooperative learning and more research is needed to develop effective collaborative learning strategies respectively.

3 Pedagogical Support

As indicated by various VR educational researchers [Dede 1996; Winn 2002], constructivist learning theory provides a valid and reliable basis for a theory of learning in an immersive virtual environment. Thus, the design of iHABS is based on constructivist principles, incorporating both the cognitive and social constructivism paradigm.

According to Youngblut [1998], all educational VR applications that explicitly embody some form of pedagogy support constructivist learning, either using an experiential or guided-inquiry approach. In iHABS, both of these approaches are integrated because we strongly believe this integration provide a more effective and engaging learning experience.

Cognitive constructivism emphasizes that learning is an active process, and direct experience, making errors, and looking for solutions are vital for the assimilation and accommodation of information. In iHABS, students can enjoy first-person knowledge about piloting a hot air balloon that are only accessible to them in real life as a third person experience. Students can control the temperature of the hot air balloon. By doing so, they are left to find out how it affects the vertical speed of the balloon and also indirectly determines the horizontal speed. They are also required to land on a suitable landing spot because if they fail to do so, they will crash the hot air balloon. In addition, iHABS also allow the student to virtually experience and be aware of the changes in weather conditions (atmospheric variables) as the balloon rises to a higher altitude. This active, experiential approach is believed to be able to motivate the students in the learning process.

To enhance the effectiveness of learning, iHABS also relies on the guided-inquiry approach. This approach is implemented in several ways. First, students are allowed to change various parameters such as the balloon size, balloon load, ground temperature as well as sea-level pressure and observe how it affects the maximum altitude and ascending rate of the balloon. In addition, various charts are provided to help them to visualize the changes of atmospheric variables with change in altitude and to guide them in determining the temperature that will allow the balloon to take-off. Finally, students are given a list of tasks and a set of questions to answer. This method is targeted to improve their cognitive and critical thinking skills as well as to lead them to the understanding of the underlying fundamental physics principles.

The learning approach based on Vygotsky's [1998] social constructivism indicates that learning and development is a social, collaborative activity. In iHABS, collaboration can take place formally, within the VE, or informally, outside of the VE. Formally, in the iHABS VE, students can communicate and collaborate with each other through an audio chat system.

Informally, students are encouraged to collaborate among themselves to construct knowledge based on their experience in the iHABS VE. For example, prior to entering into the iHABS VE, students are paired-up and asked to set different balloon sizes for the simulation. Upon emerging from the iHABS VE, they can compare their simulation results and co-construct their knowledge relating to how different balloon sizes affect the maximum altitude attainable and ascending rate of the balloon by building upon each other's ideas. This informal collaboration will enhance the learning process because a student does not need to run the simulation multiple times to obtain this particular knowledge.

4 The iHABS Learning Environment

The iHABS project is an active experiential and exploratory learning environment for secondary through college level students.

4.1 System Description

Virtual world: The virtual world of iHABS is named "Paradise Island". Students see this virtual world through a head mounted display (HMD) that presents a stereoscopic view of the virtual world. They interact with the virtual world using a data glove. The virtual island consists of the take off site and the landing site separated by high mountains. This landscape design simulates the risk of hot air ballooning in a real-world situation and thus, imposes an implicit challenge to the students to land at an appropriate location. Failing to land on an appropriate location, such as landing on the mountains or in the sea, may result in a serious "virtual" accident. In iHABS, every student is represented as an avatar that can be pre-selected by oneself before the start of the simulation system. A snapshot of two avatars at iHABS take-off site is as shown in Figure 1.

Phases of hot air ballooning: Before commencing the simulation, students are informed that there are generally three phases of a hot air balloon flight, namely take-off phase, balloon navigation phase, and landing phase. Throughout these phases, they are prompted with a list of tasks and questions that guide them to pilot the hot air balloon and to construct knowledge on various aspects of physics.

Figure 1: Two avatars at iHABS take-off site

Control panel: The most basic task for students in this system is to find out how to pilot a hot air balloon. In order to pilot the hot air balloon, students can access a control panel in the hot air balloon. The control panel is illustrated in Figure 2.

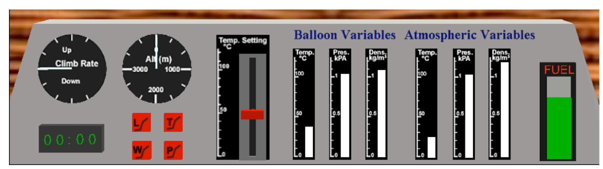

Figure 2: A hot air balloon control panel

The basic components of the control panel consist of the temperature control slider, the altimeter, the variometer, the timer and the fuel indicator. Among these components, only the temperature control slider is operable by students. Using the data glove, students can move the slider to set the temperature of the hot air balloon. The remaining four components are all simulated in real-time to reflect appropriate current values. The altimeter displays the current height of the hot air balloon. The variometer shows the current ascending/descending speed. The timer indicates the time taken since the take-off. The fuel indicator reveals how much propane gas fuel is left for flying the balloon.

Several additional components are embedded in the control panel to guide students in constructing knowledge on the physics principles. These components are indicators that display the current properties of the air namely temperature, pressure and density in the hot air balloon and its surroundings. These values are also simulated in real-time for different altitudes. Finally, four additional graph visualizer buttons are provided. Pressing any of these buttons launches the respective graphs. One of the most useful graphs is the load chart that provides guidance to students on the temperature to be set in order to make the balloon take off. The remaining three graphs show how the properties of the surrounding air (temperature, pressure, and wind speed) change with altitude. We emphasize that the indicators on the control panel are provided only as a guide for the students to construct their personal knowledge of the physics principles and not as an end to the knowledge itself.

Virtual toolkit: Students can gain access to a virtual toolkit that allows them to change various parameters such as the balloon size and balloon load. They can also observe how the changes in parameters affect the maximum height and ascending rate. Students are also allowed to modify the weather conditions, specifically the ground temperature and sea-level pressure to enable them to find out how the different weather conditions can affect hot air ballooning.

Virtual menu: iHABS also contains a virtual menu that enable students to activate certain system commands such as “Exit System”, “Reset View”, and “Reset Simulation”.

Top ten achievers database: Finally, the system records and stores the ten fastest flight duration in the database. Students can use these timings as a benchmark to improve their ballooning skill and timing to complete a flight. Indirectly, students are motivated to learn the underlying physics concept.

4.2 Design for Interaction Techniques

4.2.1 User-system interaction

Generally, there are three categories of user-system interaction tasks namely navigation, object selection/ manipulation, and system control [Bowman et al. 2001]. User-system interaction methods in iHABS are selected based on the criteria of naturalness, sense of presence, accuracy, ease of learning, and ease of use.

Navigation: We have evaluated several methods of navigation including the natural walking method, gaze-directed steering method, and pointing (hand-directed) steering method. Among these methods, natural walking is the most natural method but it has the disadvantage of being unsuitable for large VEs due to the fact that it requires a large empty physical space for navigation. The gaze-directed method and the pointing method are suitable for large VEs because they can support remote distance navigation. Comparing these two methods, the gaze-directed method has the advantages of ease of learning, naturalness, and accuracy although the pointing method is more comfortable. In order to maintain a high degree of naturalness, and also to provide the ease of remote navigation, two navigation methods are implemented in iHABS. The natural walking method is used for short distance movement and the gaze-directed method is used for remote distance navigation. To navigate to a remote location, users simply gaze in the direction that they wish to go and provide a specific “start” gesture. To stop walking, they give a command to the system by providing a specific “stop” gesture.

Object selection/manipulation: Three most common object selection/manipulation methods have been investigated. They are the classical hand, Go-Go, and ray-casting [Bowman 2001]. The classical hand method is the most natural method. In the classical hand method, object is selected by intersecting the virtual hand with the object thus simulating the way we manipulate objects in the real world. However, this method limits user to selecting objects within arm-reach. In contrast, both the Go-Go and ray casting methods allow selection of remote objects but in a less natural manner. In iHABS, the only object that can be selected and manipulated is the control panel of a hot air balloon. The setting of the control panel is only performed when the user is inside the basket of the balloon. Since the basket is small in size and the user can easily move around the basket using gaze-directed navigation method, remote selection of objects is unnecessary. Thus, the classical hand method is chosen because it has the advantages of naturalness and ease of learning over the Go-Go and ray-casting techniques. Figure 3 illustrates interaction of a user with the control panel using the virtual hand.

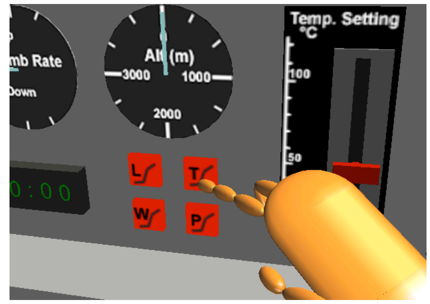

Figure 3: A virtual hand accessing the control panel

System control: We have explored two interaction techniques with system control interfaces, namely the floating menus and the “pen and tablet’ technique [Bowman et al. 2001]. Floating menus suffer a lack of precision and contribute to a significant occlusion of the VE. Compared to floating menus, the “pen and tablet” technique is easier to use, is faster to execute and does not clutter a user’s view unless being accessed. However, it will still cause arm fatigue and discomfort to the user after prolong usage as user needs to hold a physical device. To counter the limitation of these two methods stated above, the “surface-constrained gesture activated menu” is introduced in iHABS. This is a hybrid method that combines gesture input with virtual menus. The menu is activated only when users provide specific gestures thus minimizing occlusion of VE. Once activated, the menu is displayed right in front of the user and is placed within comfortable reach. The classical hand technique is used to select the menu items. During the selection process, the user’s virtual hand is constrained to the surface of the virtual menu. This approach simulates the effect of the “pen and tablet” technique, thus overcoming the inherent lack of constraint problem of floating menus. In addition, it does not cause arm fatigue and discomfort to the user.

In iHABS, there are two system control interfaces, namely the virtual menu and the virtual toolkit. When users select an item in the virtual menu, the appropriate system command will be executed. For the virtual toolkit, once an item is selected, user is required to key in a numerical value for the selected parameter using a *virtual number keypad*.

4.2.2 User to user interaction

In iHABS, users can communicate and collaborate with each other verbally using an audio chat system. The earphone and microphone used in the audio chat system are embedded within the HMD.

4.3 System Design and Implementation

Design Framework: iHABS has been designed using the design framework of C-Visions, a Socialized Learning through Collaborative, Virtual, Interactive Simulations System [Chee and Hooi 2002]. This framework is a generic, object-oriented software framework, and its design is based on the Model-View-Controller (MVC) architecture derived from the Smalltalk programming language. The Model component implements the virtual world, virtual objects, and the underlying laws that govern the behavior of the virtual objects. The View component implements the virtual world browser. It listens for events and renders them in the 3D browser. The Controller component implements support for actions taken by the user in the virtual world.

Network architecture: iHABS utilizes C-VISions network component. This component propagates events from every user to all other users in the virtual world. There are two types of events. Semantic events are handled by TCP/IP. User location change events are handled by UDP. To support object persistence, the state of all objects in the virtual world is constantly recorded onto a database.

Simulation consideration: iHABS is implemented entirely in Java and Java3D. Like most simulation programs, iHABS is a simplification of reality. Nonetheless, it contains the most important elements of real hot air ballooning in its implementation. Specifically, 2 elements are simplified. First, the wind direction and wind speed are not real-time simulated. The wind blows from the west to the east and this direction is fixed throughout the simulation. The wind speed is fixed at different values for different range of altitude. Second, the take-off site and landing site are predetermined. In fact, this simplification is co-related to the simplification of the wind characteristics. The purpose of these two simplifications is to focus students on the core objectives of iHABS rather than being distracted by too many insignificant variables and decisions.

Gesture training: As mentioned in the previous section, gesture is used quite often as an interaction technique in iHABS. To ensure high accuracy in gesture recognition, a gesture training module is implemented. This module obtains the specific gestures required from a first-time user and saves it to a configuration file for recognition purpose in the iHABS system.

5 Future Work

In the near future, we would like to commence empirical research to study how students learn using our system. We plan to evaluate the effectiveness of the immersive simulation in conveying the underlying physics principles and the usability of the system, in particular the interaction techniques. In addition, we will explore the effectiveness of collaborative learning in a multi-user immersive VR environment and assess its implications in education.

iHABS needs several improvements. Collaboration among users in iHABS is limited to voice communication. We plan to do more research to explore other possible collaboration techniques that can be used in a multi-user, immersive environment.

In addition, one of the current guided-inquiry approaches being used is prompting students with a list of tasks and questions in every phase of ballooning simulation. We believe this approach can be enhanced by incorporating autonomous pedagogical agent support in the system. Thus, another area of our future research is to introduce autonomous agent technology and to evaluate the advantages and disadvantages of this implementation in enhancing the learning experience.

6 Conclusion

In this paper, we have set out our research work in developing a hot air balloon simulation system in an immersive, collaborative setting. The pedagogical basis of this system is firmly rooted in both the cognitive and social constructivism theory. From the cognitive constructivism perspective, we have blended the experiential approach with guided-inquiry approach to make the learning experience more enriching and effective. Social constructivism can take place formally, within the VE, and also informally, by encouraging the students to collaborate among themselves outside of the VE. We believe this informal collaboration is significant in contributing to the effectiveness of learning.

While immersive VR seems to offer promise as an effective science learning tool and has the potential to facilitate collaborative learning, much more research work needs to be done before it will actualize in the classrooms. Two areas that especially require attention are VR interaction techniques and collaboration techniques.

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