Application of Haptic, Visual and Audio Integration in Astronomy Education

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Abstract

This paper describes a multi-sensory virtual reality application for astronomy education. The application developed in this work allows Grade 6-9 students to learn about the Solar System through the exploration in a virtual environment with visual, audio and haptic feedback. Evaluation by school teachers and students shows that the haptic enabled virtual reality experience makes astronomy education more interesting and interactive, and helps students understand astronomy phenomena.

Keywords: *haptics, education, multi-sensory interaction, user interface.*

1 Introduction

Studies have shown that immersive computer-based learning enhances students' ability to absorb complex information. Many abstract concepts in physics, geometry, and chemistry can be better understood through multi-sensory interaction including vision, audition and haptics, as comparing to traditional textbooks. Especially haptics, which provides "hands-on" experience to students, makes learning more interesting and interactive.

A number of research projects have been conducted to add vision, audition and haptics in educational applications. A generic force feedback slider and a software application simulating a catapult are developed by Kretz et. al. to provide tactile and visual feedback to users for learning system dynamics [1]. In [2], Inoue et. al. proposed the new e-learning framework which is combined micro-world style ILE(Interactive Learning Environment) and VR(Virtual Reality) concept. Their study shows that using the PHANToM haptic device instead of a mouse in the virtual experiment of elementary dynamics makes the manipulation of virtual laboratory more intuitive and direct. An enhanced haptic virtual reality application for geometry education is described in [3]. It allows the user to create and edit a scene that consists of 3D geometrical objects in order to form and solve complex geometrical problems. An educational tool based on a haptic interface used to teach physical phenomena at a nanometer scale is presented in [4]. Treviranus et. al. investigated the integration of non-visual modalities including haptics, 3D real world sounds and speech into spacial curriculum [5].

As an attempt to apply the techniques of vision, audition and haptics integration to astronomy learning, we developed an educational application focused on the Solar System, which is introduced in the Grade 6 - 9 curriculum. Our objective is to explore how a multi-sensory platform can help students understand astronomy phenomena and add more fun in astronomy learning; what role vision, audition and mainly haptics, can each play in a typical astronomy educational application; and what limitations/drawbacks may exist in applying visual-haptic-audio technology into astronomy education.

2 Design of Solar System Application

The Solar System application is developed on a Matlab/Simulink platform. The Virtual Reality Toolbox is used for graphic rendering of different virtual scenes in VRML format. The haptic effects are designed with the combination of standard modules provided by the proSENSE Virtual Touch Toolbox [1], such as spring, damping, elevation grid, etc., and customized modules written as S-functions for some specific effects. The hardware components of the set-up include a desktop computer (with Pentium 4 3.0GHz processor and Nvidia GeForce 4 MX 440 AGP video card) for graphic and haptic rendering and a PHANToM Omni device [2] for haptic interaction. The Omni device is also used as a 3D mouse to activate different functionalities through the haptics enabled user interface. The position of the Omni device is scaled to map its physical workspace to different virtual scenes.

[1] Product of Handshake VR Inc., http://www.handshakevr.com.

[2] Product of SensAble Technologies Inc., http://www.sensable.com.

The orientation and scaled position of the Omni device end effector is represented by a 3D space shuttle in every virtual scene.

2.1 Overall Structure

The Solar System application consists of six subsystems: startup scene, navigation panel, orbits, gravity, sizes, surfaces. The startup scene can be switched to the navigation panel by pressing a button on the Omni device. There are nine haptic icons displayed on the navigation panel representing the nine planets, as shown in Figure 1. The user can select any two of the planets to compare in one or more of the four aspects: orbits, gravity, sizes, surfaces. Under each of the above subsystems, the user can switch to another subsystem using the tab control located on the left of the scene as shown in Figure 2, or return to the navigation panel to reselect planets for comparison by pressing a button on the Omni device outside of the tab control or any other components of the user interface such as a radio button. Facts regarding the specific aspect of the selected planets are displayed when the user places the space shuttle at the information icon, which is located at the top-left corner, for a short moment.

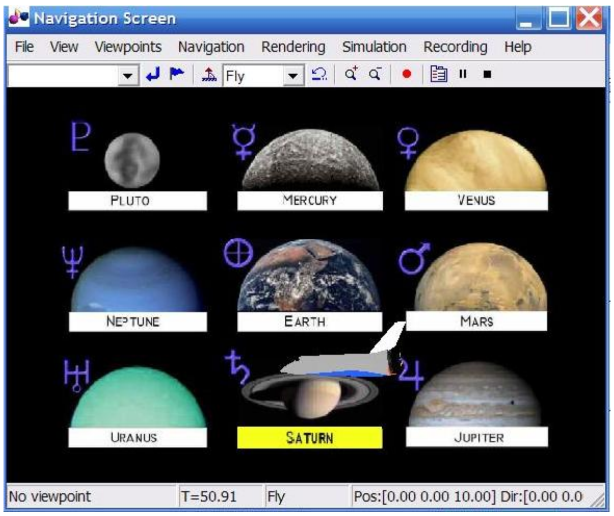

Figure 1: Navigation Panel

2.2 Haptics Enabled User Interface

To make the learning more interesting, we implemented haptic effects on the components of the user interface, for example, the icons on the navigation panel as shown in Figure 1 and the tabs and radio buttons as shown in Figure 2, and integrated them into the 3D virtual scenes.

The haptic effects for the UI(User Interface) controls are essentially gravity wells, which are not unusual in haptics enabled virtual reality [6]. A gravity well creates a spring force (that is, proportional to distance) attracting the user to a pre-specified point in the workspace within a certain area of effect. In our case, for each haptic UI control, the spring is located at the center of that control and the area of effect is a 3D box with the same location and dimension as the graphical region of the control along the X and Y axis and a certain thickness along the Z axis.

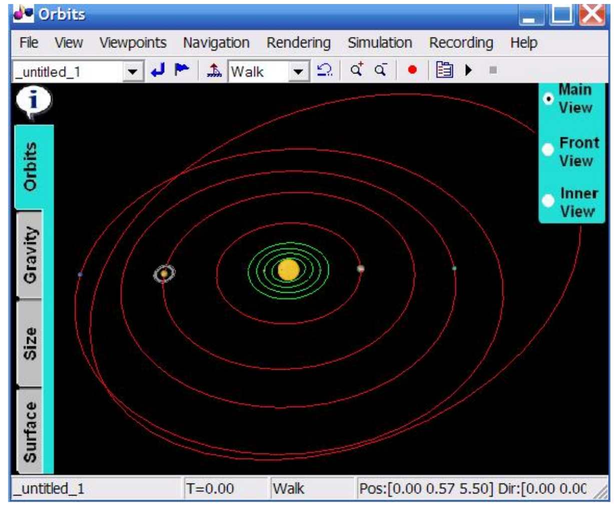

Figure 2: Tabs, Radio Buttons and Info Icon

During some initial evaluation by school teachers, we found that without stereo vision and experience with virtual reality applications, the users' depth perception is quite limited. It was sometimes difficult for them to find the location of the haptic UI controls along the Z axis. To overcome this problem, we implemented a virtual wall in the navigation panel to restrict the depth of the device motion to be in front of the wall. For the other UI controls such as the tabs and radio buttons, since they are located in virtual scenes containing other objects that require large work space, we cannot limit their depth by a virtual wall. Instead, when the scaled device position is within the area of a haptic UI control along the X and Y axis but not along the Z axis, an additional force along the Z axis is applied to pull the device towards that control. As the integral of a constant over the sample time, the magnitude of the force is slowly built up so that the user will not feel an impact of force changing from zero to a large value. When the device has been pulled close enough to the haptic UI control, i.e. within the area of its gravity well effect, the additional force along the Z axis will not be applied any more. The force applied to the device will be generated by gravity well only.

2.3 Haptics in Gravity Comparison

The gravity on each planet in the Solar System is different. To help students understand how much difference in gravity exists between the two selected planets, we developed animation of flying the space shuttle from above one planet to another planet with a ball attached to the shuttle through an elastic band, as shown in Figure 3.

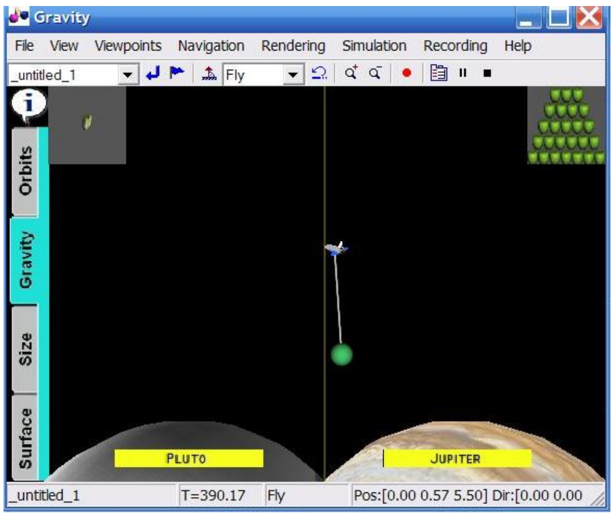

Figure 3: Animation for Gravity Comparison

The physics behind the animation is modeled with the assumption that the elastic band can be represented by a first-order spring and a damper. The dynamics of the ball can be derived using Hooke's law and Newton's Second Law as follows:

$$f_1(t) = K(l(t) - l_0) - Bv(t) + mg; \quad (1)$$
$$a(t) = f_1(t)/m; \quad (2)$$
$$p(t) = \int_0^t \int_0^t a(t)dtdt; \quad (3)$$

where $l(t)$ is the current length of the elastic band, which can be calculated as the distance from the shuttle to the ball, and $l_0(t)$ is the initial length of the elastic band, K is the spring coefficient. $f_1(t)$, B, $v(t)$, m, g, $a(t)$, $p(t)$ denote the current total force applied on the ball, damping coefficient, current velocity, mass, acceleration of gravity of the current planet, acceleration and position of the ball respectively. The length, orientation, and center location of the elastic band is calculated according to the position of the space shuttle and the ball. As the mass of the shuttle and the elastic band is ignored in the animation, gravity on the ball is the only external force to the system consisting of the space shuttle, the elastic band and the ball. Thus the force applied to the Omni device should be calculated as follows:

$$f_2(t) = -(K(l(t) - l_0) - Bv(t)). \quad (4)$$

When the space shuttle flies from above one planet to another planet, the gravity acceleration changes, therefore the dynamics of the ball and the force applied to user also changes immediately. This animation provides a vivid demonstration of the concept of gravity, and allows the user to directly feel the difference in gravity between planets. To provide an additional visual clue to the user, we added a translucent plane in the virtual scene as an imaginary wall between the atmosphere of the two selected planets. When the ball is going through the imaginary wall, the value of gravity acceleration changes at the same time.

2.4 Surface Characteristics and Phenomena

In the subsystem of surface comparison, the surface characteristics and some unique phenomena on each planet are illustrated as if a piece of surface sample is cut out from that planet. For each planet, the surface sample is featured by a crater for Mercury, a thick cloud layer above the terrain for Venus, Olympus Mons for Mars, a mountain and a lake for earth, a windy cloud layer for Saturn, the Great Red Spot for Jupiter, the Great Dark Spot for Neptune, a blue gas layer for Uranus, and a question mark for Pluto (surface conditions for Pluto are still unknown). An example of comparing the surfaces of Neptune and Earth is shown in Figure 4.

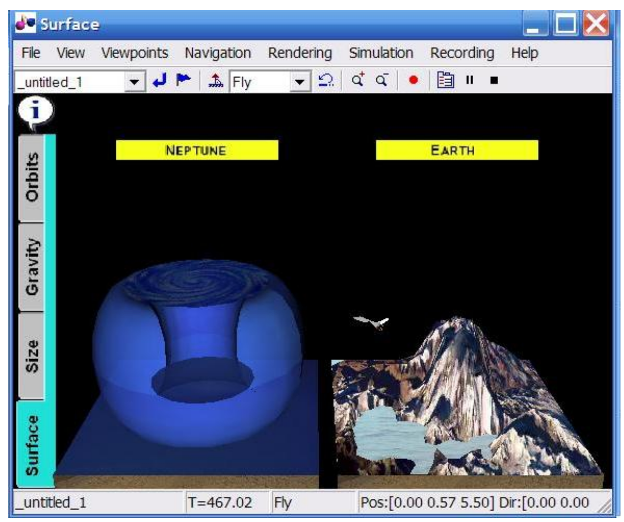

Figure 4: Surface Comparison

Terrains such as mountain, crater and volcano are developed as *ElevationGrid* nodes in VRML standard. Through the haptic rendering of *ElevationGrid* provided by the proSENSE toolbox, user can feel these terrains. The wind effect is generated by a constant force in the same direction as the texture transformation. The thick cloud or gas layer are simply described by translucent texture and viscous damping.

To demonstrate the Great Red Spot and the Great Dark Spot, which are giant storms on Jupiter and Neptune, a simplified storm model is developed with both graphic and haptic effects. The side of the storm is graphically modeled as an *Extrusion* node with a circular cross section and a straight line as spine. And *IndexedFaceSet* nodes are utilized to model the top and bottom, with the texture of a swirl rotating along the Y axis. Hapticly, the storm is described by its center, size, height and strength. The direction of storm force is generated by first projecting the vector from device position to the storm center onto the X-Z plane and then calculating its perpendicular direction on the X-Z plane so that it is tangential to the current circular cross-section of the extrusion. The magnitude of force is proportional to the storm strength and the difference between the storm size and the distance from the device to the storm center. In other words, the closer the device is to the storm center, the larger force will be generated. Thus when the user places the shuttle anywhere in the Great Red Spot or the Great Dark Spot model, the storm force will push the Omni device to make a swirl-like trajectory. Figure 5 shows a 3D plot of the "swirl-like" trajectory reproduced with experimental data of the Omni device end-effector position.

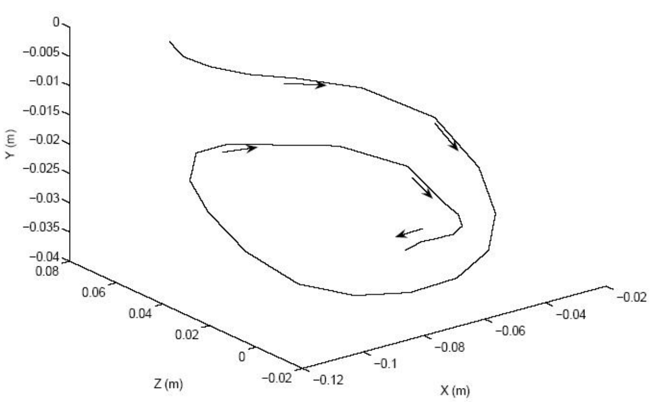

Figure 5: Omni Device Trajectory in the Great Dark Spot

2.5 Other Visual and Audio Features

Besides the features described in the previous sections regarding the integration of graphics and haptics, there are other components of the Solar System application that are mainly presented visually. For example, in the subsystem of orbits, the user can select different viewpoints including main view, front view and inner view, using the haptic radio buttons located on the right of the virtual scene. In addition, we made the orbits of the two selected planets flashing by changing the transparency of the orbits periodically. In the subsystem of sizes, the selected planets are displayed as 3D spheres with relative sizes.

Audio clips of musical pieces are added to this application for each subsystem and each planet icon in the navigation panel. The audio clips are selected to match the contents so that while the students are learning astronomy, they are also enjoying a relaxed learning environment with classic music. A good example is that for the icon of Earth, we selected part of Vivaldi's "Four Seasons - Spring" to reflect the fact that earth is the only planet in the Solar System that has life.

3 Evaluation and Discussion

The Solar System application was evaluated by teachers, administrators and Grade 6 students from the Waterloo Region District School Board in Ontario, Canada. A draft version of the application was firstly evaluated by the teachers and administrators. Modifications and new features were implemented based on their comments and suggestions. Then the teachers, administrators and a group of students evaluated the new version.

The teachers and administrators liked the 3D graphics and the novel way of astronomy education with haptic interaction. They believed that multi-sensory computer software will help students understand better and have more fun in learning. They suggested that the following features can be incorporated into the Solar System or other applications in astronomy education:

- assessment components such as leveled quiz;
- training of using haptic device before using the learning application;
- access to on-line information on Solar System through this program;
- "speech to text" audio components to read the facts;
- more contents such as telescopes, galaxies, history of the creation of the Solar System, etc.

Inspired by the surface comparison, some teachers found that it will be useful to employ haptics in simulation of weather and natural disasters such as hurricane, tsunami, etc. in science education.

The students liked the haptic interaction very much. Some students commented that using the Omni device in the learning application is "a neat and fun new way to use a computer". They also came up with ideas to improve usability and create new haptic and graphic effects. Some of their suggestions are listed as follows:

- while orbiting the shuttle can be pulled into every planet's orbit by gravity;
- sound/smoke can be generated from the space shuttle thrusters;
- the navigation panel can be changed from vertical to horizontal to reduce fatigue;
- a car/rover instead of a space shuttle can be used to explore the surfaces of the planets.

The students were quite intrigued by this kind of multi-sensory application. Some students even asked if temperature could be implemented in a multi-sensory application so that they can feel the relative temperature difference between planets.

4 Conclusion

A multi-sensory virtual reality application for astronomy education was presented. The techniques in developing haptic effects for user interface, astronomy phenomena and animation were discussed. Evaluation by school teachers and students shows that virtual reality with visual, audition and especially haptics can help students understand astronomy facts better and make astronomy learning more interesting and interactive.

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