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# A Virtual Universe Utilizing Haptic Display

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## Abstract

This paper summarizes a virtual reality universe application in which a user can travel between four virtual worlds through the use of haptic buttons. Each of the worlds demonstrates different aspects of haptic rendering which together create a wide base for force feedback effects. Specifics of the rendering algorithms will be discussed along with possible uses and modifications for other real-life applications.

## 1. Introduction

Haptics is a growing field in the virtual reality (VR) community, and will continue to grow as its significance becomes more clear. Increases in computing power and more sophisticated haptic interfaces have already shown the value of the sense of touch in VR, and while it is still a relatively new field, its potential is enormous. Haptics can add a new dimension to data visualization, as well as increase one's sense of immersion, and create a more effective human computer interface.

At Sandia National Laboratories, haptic research has focused on creating a new level of interaction with VR environments. The PHANToM haptic interface, a serial, three degree of freedom, force feedback device was incorporated into the EIGEN virtual environment on a Silicon Graphics Indigo 2 Impact workstation for researching haptic rendering. Although the PHANToM has worked well in EIGEN with this research, the principles in this paper apply for other haptic devices and VR environments. A virtual universe application was created to demonstrate the force rendering algorithms, in which four separate worlds could be accessed by pushing haptic buttons. The four worlds (Illusion, Weight, Field, and Poly) and the aspects of haptic rendering that they represent are described below.



## 2. General Interaction

The virtual universe application begins in a control panel, a virtual wall with four buttons each containing a picture of the world to which it leads. A small sphere, the cursor, is controlled by the PHANToM. The wall is haptically rendered as a normal force that is proportional to penetration depth [2]. The buttons, which are flush, have a different spring constant than the wall and can therefore be moved into the surface. At a threshold value the button force discontinues, and the user appears in the new world. Several first time users have commented that they like the effect of the button's force suddenly stopping, leaving them in the new world.

This general structure works well for demonstrations, yet it could be effective for other applications as it is a convenient way to move between related sets of data. The different worlds could be used to display parts of a larger data set and be easily traversed, or they could contain general information that one would often access from a main world.

## 3. Friction, Textures, and Intersensory Discrepancy

The first world, Illusion, received its name from an exploration of intersensory discrepancy between our visual and proprioceptive senses, of which it has been shown that vision is dominant [3]. In Illusion, the user can see and touch a sphere inside a box. By changing a slide bar, the graphical representation of the sphere changes to an ellipsoid (lengthened along the x axis) while the haptic

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representation remains the same. When the user moves the cursor across the ellipsoid in the x-y plane, the cursor visually moves farther than when the ellipsoid is circled on the y-z plane. Yet physically the user is still touching a perfect sphere. This effect leads many users (though not all) to believe that the sphere actually 'feels' longer as well. The illusion is more effective as the user spends more time feeling the sphere while looking at it. It also increases effectiveness with the introduction of friction and texture. This dominance of sight over touch does not negate the value of haptics, yet by realizing this concept, one might take advantage of people's ability to smoothly incorporate discrepancies among their senses. In some situations, an object can feel different than it looks and still seem real.

After the initial inclusion of friction and texture, a larger variety of different materials was desired for simulation. The friction in these materials is currently accomplished with damping effects that are proportional to penetration depth. In simulating friction, a key concern is stability. Initially, the cursor's current and previous positions were projected to the sphere's surface (or any object's surface in a general case) and a vector was created from subtracting the projection of the previous point from the projection of the current point, which gave the direction of the friction. Stability was then achieved by averaging this vector over a history.

The textures were created by modulating the surface of the sphere with a combination of several sine waves and several square waves of differing amplitudes and frequencies. Then the materials were described with combinations of friction and texture that were intuitively created and fined tuned until things 'felt right'. The materials created include wood, both polished and rough; sandpaper; cobblestone; a magnetic material; water and a thicker viscosity fluid; rubber; plastic; and a sticky material.

There are several concepts of interest in creating these materials. In materials that were not supposed to be compliant, the visual image of the cursor was kept from entering the sphere (because the force is proportional to penetration depth, the cursor partially moves into an object it is touching) which made it seem harder. This is an example of a use for the intersensory discrepancy described above. With the magnetic material, the magnetic attraction needed to approach zero as the cursor moved towards the sphere for stability reasons. The sticky sphere was created by adjusting the friction to have an inward radial component. The water sphere consisted of only a damping term (the cursor could feely move through the sphere). It was enhanced by using alpha blending, so it was transparent which added to its realism. Finally, in a method similar to that of the sticky sphere, a damping term applied in the outward radial direction added to the spheres' stiffness when desired.

## 4. Dynamics

The second world, Weight, is an application in which the cursor is attached to a weight by a spring, visually modeled as a sphere on a rubber-band. The directions of the forces on each are computed by subtracting their center coordinates and normalizing the resultant vector, and the magnitude is computed from their distance apart. A gravity term is added to the force on the weight. The motion of the object is modeled from physics, and thus, given the forces, the acceleration is found from $\mathbf{a} = \mathbf{f} / m$, where **a** is a vector representing acceleration, **f** is a vector representing force, and m is the mass of the object. Velocity and position are then found by integrating acceleration over time, using a chosen time value in the equations rather than finding it from the servo rate. A virtual floor was then added on which the ball could bounce. The sound of this collision was presented in which the volume was determined from the ball's velocity.

Taking advantage of the freedom in choosing the time variable lead to an interesting result. By decreasing the value of only the time variable, the object not only moved slower but also felt more massive and felt as if it were moving through a viscous fluid. This effect, for example, might be used in combination with damping to create the effect of a clay material in an object modeled by point masses (i.e. vertices on a polygonal object). One might also take advantage of the fact that the force on the cursor does not necessarily need to be the same force applied to the mass. This could be used to change how things feel, while maintaining a physics model.

Of the four worlds, Weight requires the least amount of programming code, yet it is often people's favorite application. Users can feel the momentum and inertia of the sphere, both of which occur naturally from the motion equations described above, which is a powerful effect.

## 5. Vector Field Representations

The third world is called Field and contains a mapping from a vector field to the forces felt by a user. The vector field, electric potential, is created from virtual point charges which a user can place or delete to make any arbitrary formation. Then the electric potential, which is referred at infinity, is mapped onto forces that the user can feel. This allows a user to search the field and find places where the individual charges cancel, thus leaving 'weak' spots where the cursor can explore. One should note that a user is not feeling actual forces created within the physics, but instead is feeling a mapping of data into forces. Because the user is feeling an abstraction, this can be a powerful tool in understanding various vector fields or even other types of data.

Another feature of this world is the interface of the PHANToM to the EIGEN craft's movements. The cursor is in a box, similar to that in Illusion, except that when the cursor touches one of the walls of the box, the ship moves appropriately. This is an intuitive form of navigation and also works well with general exploration because the user can easily change between a craft movement and haptic exploration. A user would move the craft until an object was inside the box, and then would have haptic access to it. This makes large areas available for interaction in fine detail.

## 6. A Polygonal Force Representation

A main focus in the haptic work at Sandia National Laboratories was the incorporation of force feedback into already existing technology. Because applications were previously mainly visual, this incorporation of haptics was greatly encouraged by methods that would work well in combination with already defined graphical methods. Therefore, an algorithm was developed in which the user could touch arbitrary polygonal data sets [5], i.e. surface defined objects which are common in graphics.

This algorithm creates a force that is normal to the currently touched polygon, and interpolates over edges as the cursor moves to different polygons. The magnitude of this force is defined by penetration depth which presents a visualization issue. The cursor can be lost within a compliant object. To resolve this issue, a 'Bendable Polygon' algorithm was used in which the current polygon was divided into six polygons, and neighboring polygons were also split to make the object remain seamless as shown in Figure 1. When Gouraud shaded, this technique works well and can lead to lower levels of detail, as objects can then be described by larger polygons.

The vertices of the object are then attached by springs to a framework consisting of base points from which the graphical vertices can be pulled away. With the inclusion of additional springs among the vertices and to the cursor, the object is deformed as the cursor pushes into it. The friction and textures can be added for material properties. As polygonal data sets increase in size, windowing of the local area can decrease computational time and make them renderable in real time.

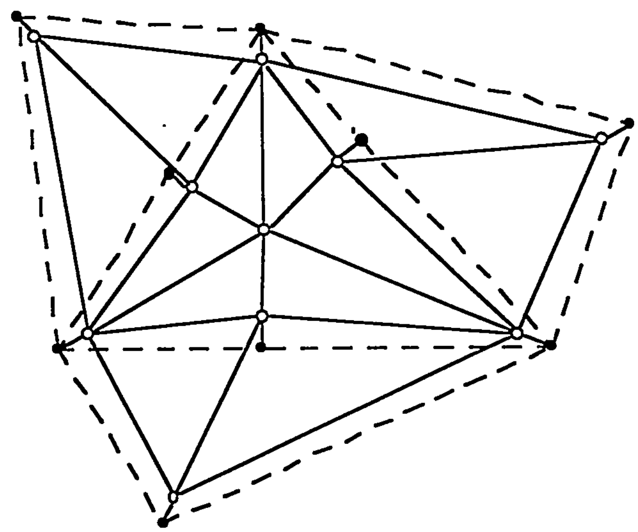

**Figure 1: Graphical deformation in the polygonal representation of forces.** The dashed lines represent the object while it is not deformed, and the solid lines represent the polygons that the user sees after it is deformed. Filled in circles are base points and open circles are graphical vertices, which are connected by springs.

## 7. Conclusions

The four worlds represent a base for the haptic rendering that will soon be applied to other real-life applications. In addition to finding applications for the concepts described and finding the most effective methods of haptic exploration, there are continued efforts to increase the base of haptic effects. Work is currently being done on developing a more effective friction models and texture creation. Combinations of visual, haptic, and audio effects combined will continue to be explored. More advanced user interfaces, such as a haptic control panel that moves with the ship, similar to that in an airplane, is being researched. Such an interface would include switches, buttons, etc., and could possibly replace the mouse completely. The polygonal method of force representation is being expanded to work with larger data sets, and other surface modeling techniques are being explored. Overall, the modeling that has been done has shown the potential of haptics in the virtual environment, and these successes are expected to continue.

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## 9. Acknowledgments


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