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PHANToM Haptic Device Implemented in a Projection Screen Virtual Environment

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Abstract

This research combines the PHANToM 1.5 haptic device with a six-sided projection screen virtual environment in order to explore the benefits haptic devices bring to this type of immersive environment. The PHANToM is placed on a specially designed and constructed work stand which allows the device to be moved anywhere in the virtual environment. An algorithm has been developed which maps the size of the CAD model represented in the virtual environment, or the movement of the CAD model, to the working space of the PHANToM. Two applications are explored which illustrate using the PHANToM for different tasks: exploring a large NURBS surface and installing an aircraft rudder pedal assembly.

Categories and Subject Descriptors (according to ACM CSS): H.5.2 [User Interfaces]: Haptic I/O; I.3.7 [Computer Graphics]: Virtual Reality

1. Introduction

A key component of virtual reality (VR) systems is the ability to immerse a participant in a computer generated virtual environment. Immersion refers to the sense of "being there" that a user feels in the virtual world; the greater the sense of immersion, the more real the virtual world appears [1]. The level of immersion a user feels in a VR environment is related to the number of senses stimulated, such as sight and hearing [2]. However, most virtual reality systems are lacking in a key area of stimulation, namely some form of physical or haptic feedback.

Haptics refers to the sensing of force, weight, or other physical properties through feeling and touch. The additional information from haptic feedback has the potential to make certain tasks, such as part assembly, much easier than with a traditional computer interface.

Our goal is to build an application where participants can select parts and assemble them in a very natural manner that closely mimics assembly in the real world. In order to accomplish this goal, some sort of haptic feedback is required. The haptic device used here is SensAble Technology's three degree-of-freedom PHANToM [3].

Since haptic devices are usually combined with either a stereo monitor or head mounted display, this research examines the issues surrounding the use of the PHANToM in a six-sided projection screen synthetic environment, the C6 at Iowa State University.

The C6 consists of six 10 ft by 10 ft projection surfaces configured as an enclosed room. Each of the four walls, the ceiling and the floor are projection surfaces. An SGI Onyx2 Reality Monster with 24 R12000 processors and 6 graphics pipes with Infinite Reality2 graphics powers the C6 display. One user is tracked and all users wear active stereo shutter glasses to view the virtual environment. Interaction is performed using an RF wand or gloves. The tracking is wireless and therefore the tracked user is not tethered to any one place in the room[4]. A diagram of the C6 setup appears in Figure 1.

The C6 is controlled with the VRJuggler software, a complete framework for virtual reality applications that may be used on a variety of virtual reality devices [5]. VRJuggler provides the libraries to manage the multi-pipe stereo display and position tracking. The actual graphics are drawn with OpenGL.

2. Related Work

Adding some form of haptic feedback to a virtual environment and evaluating its usefulness has been a goal of several research projects.

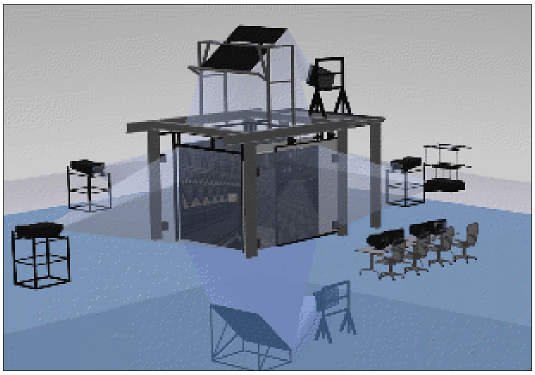

Figure 1 The C6

Researchers at the University of North Carolina at Chapel Hill are using haptics to explore extremely small objects with the nanoManipulator. This device combines virtual reality with a single stereo screen display, a force-feedback stylus, and an atomic-force microscope (AFM) to let scientists observe and interact with molecular structures. The haptic device allows users to control the tip of the AFM and manipulate objects on the nanoscale surface [6].

Some of the concepts in this paper are similar to research done on workspace scaling for teleoperation by Preshce and Hirzinger. They define different workspace volumes for the master and slave portions of a robotic manipulator, and explore the effects on a user of scaling the motion and forces between workspaces [7].

Research performed by Volkov and Vance shows the addition of haptic feedback significantly decreases task completion times. They used a PHANToM and a desktop monitor display to evaluate part designs for criteria such as ease of use by human operators [8].

In most cases, the haptic devices are used with a single monitor display, or at most a larger stereo workbench as with the nanoManipulator. This research combines a haptic device with the fully immersive projection screen virtual environment.

3. Implementation

Bringing the PHANToM into a projection screen virtual environment presents several challenges. Since the PHANToM is essentially a desktop device, using it in the large projection screen environment requires the PHANToM to be mobile so it can be positioned anywhere in the environment and adjustable to accommodate users in various positions. Second, the PHANToM's 19x27x37 cm physical workspace is much smaller than the projection screen environment's 10x10x10 ft volume. Some method must be used to make the PHANToM useful over large portions of the virtual environment. Finally, a program must be written to integrate the operation of the PHANToM with the software controlling the virtual environment and any other simulation software.

3.1. Phantom Stand

Physically supporting the PHANToM in the virtual environment was accomplished by designing and building a stand to hold the PHANToM. This stand rolls about on four castor wheels, which may be locked to keep the stand from moving when the PHANToM is in use. Stand height is adjustable from 28 to 42 inches to accommodate different users and postures. Since the orientation of the phantom stand is needed when mapping the PHANToM's motion to the virtual environment, magnetic tracking devices, such as the Ascension Technologies MotionStar used in the C6, must be compatible with this stand [4]. As magnetic materials adversely affect the accuracy of such trackers, the phantom stand was constructed out of bonded PVC plastic and stainless steel hardware. When the stand is in the virtual environment a magnetic tracking device is attached to one of the legs. A model of the stand appears in Figure 2.

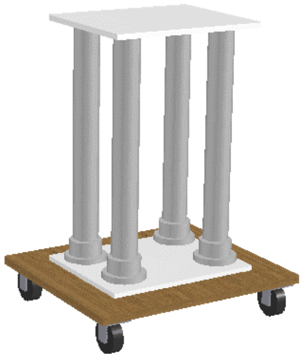

Figure 2 Phantom stand

Since the PHANToM is connected to a controller box, and that controller connects to the SGI Onyx2 computer, care must be taken when routing these cables to minimize their interference. A small opening in the C6's door screen allows the cable from the PHANToM to be run outside the chamber to the controller. Users should take care not to trip over, or roll the stand over, the portion of the cable in the virtual environment. Figure 3 shows a diagram of this setup.

3.2. Virtual Volume

To address the mismatch between the PHANToM's physical workspace and the size of the virtual environment, the concept of a virtual volume is presented. This consists

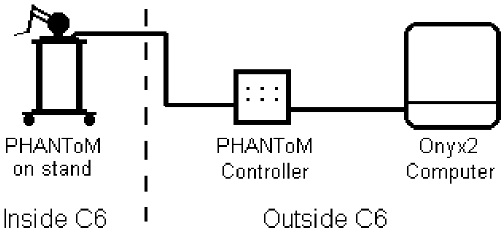

Figure 3 PHANToM connections

of a user-defined quadrilateral volume of space in the virtual environment that correlates motion of the PHANToM's physical endpoint to a virtual position in the environment. This approach is similar to that taken by Preshce and Hirzinger in their work on workspace scaling for teleoperation [7].

A virtual volume is defined by selecting two opposite corners in the virtual space with a wand. The known orientation of the phantom stand, obtained from the magnetic tracker affixed to one leg, is used to orient the volume to match the PHANToM. To simplify the creation, the volume is dynamically drawn between the first point and the current wand position until a second point it chosen. The completed volume may then be translated about the virtual world and/or scaled to the desired size. Rotation of the volume isn't permitted, since that would produce a mismatch between the alignment of the physical PHANToM and the alignment of the virtual volume. Figure 4 shows the outline of a virtual volume with a red sphere representing the virtual PHANToM endpoint.

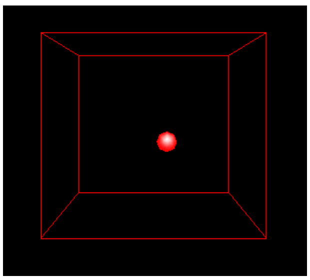

Figure 4 Virtual volume

Since the virtual volume isn't constrained to be a cube, the PHANToM's physical workspace is constructed to match the form of the virtual volume, so a single scale value suffices to match motion of the PHANToM's physical endpoint to the virtual world. This value, *world_haptic_scale*, is determined from the largest dimension of the virtual volume and the *max_workspace_size* parameter as in the equation (1) below.

$$world\_haptic\_scale = \frac{max\_workspace\_size}{PV[largest\_dimension]} \quad (1)$$

The *max_workspace_size* represents the largest dimension of the PHANToM's physical workspace. In some cases it is useful to confine the physical PHANToM endpoint to a box of modest size, ensuring that the user doesn't run out of device travel or collide the endpoint with the bulk of the physical PHANToM. At other times it may be desirable to make the physical workspace limits much larger, allowing the PHANToM free movement throughout its entire range of travel. For this work the *max_workspace_size* is set to 120 millimeters, which prevents the PHANToM endpoint from colliding with the physical device or the phantom stand.

When using the PHANToM, the virtual endpoint position is confined to the virtual volume, just as the physical endpoint is confined by the PHANToM's physical workspace. Motion of the actual PHANToM is scaled to match motion of the virtual endpoint. This way the limited PHANToM physical working volume can be matched and used over an arbitrarily large space in the virtual environment.

3.3. Phantom Driver

Integration of the PHANToM's GHOST software and vrJuggler is handled by the phantom driver program. The phantom driver is a C++ class that builds the haptic scene graph, loads the haptic geometry, positions the virtual PHANToM endpoint in the virtual environment, scales motion of the PHANToM to the virtual volume, and communicates with the rest of the simulation.

Actually constructing the physical workspace from the virtual volume dimensions and the *max_workspace_size* and assigning this workspace to the PHANToM is performed by the phantom driver. The phantom driver also loads any haptic geometry if it is required by the application. This geometry may consist of simple primitives and/or polygonal meshes. Once the phantom driver has the workspace set up and the geometry loaded, it uses GHOST to build the haptic scene graph. A diagram of this scene graph appears in Figure 5.

A key feature of this scene graph is the placement of the Phantom and the Workspace objects into the PhantomParent separator. This allows the position of the PHANToM device and its workspace to be translated and rotated in the haptic space to match the position of the virtual volume in the virtual environment simply by applying the proper transformations to the PhantomParent, since moving

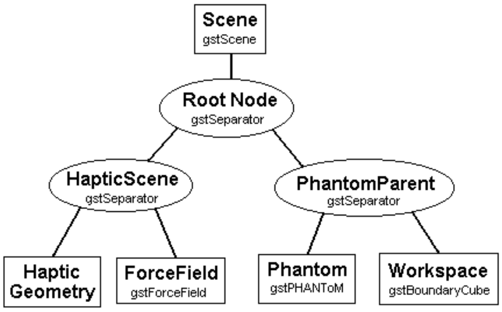

Figure 5 Haptic scene graph

the PhantomParent separator moves both the PHANToM and it's workspace.

With the PHANToM positioned to match the virtual volume and all geometry scaled accordingly, the phantom driver initializes the PHANToM and starts the haptic servo loop process. This servo loop runs at roughly 1000 Hz and is responsible for keeping track of the position of the PHANToM and forces applied to the PHANToM to ensure smooth haptic feedback [9]. As seen in Figure 6, GHOST sets up this loop as a separate process and handles communication between the user's application and the haptic servo loop.

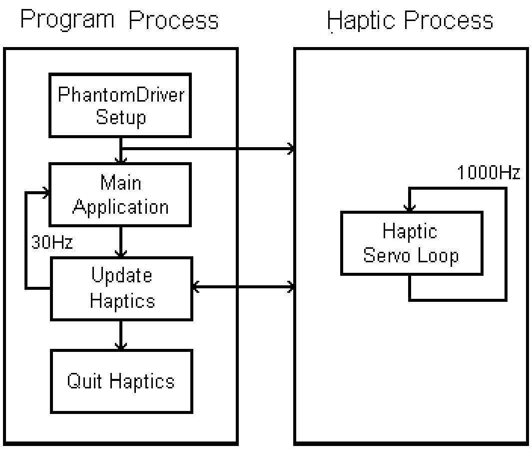

Figure 6 The haptic servo loop

4. Example Applications

In this research two example applications are presented that demonstrate some advantages of using the PHANToM in a projection screen virtual environment: a NURBS surface exploration example and a virtual assembly application that uses Boeing's VPS (Voxmap PointShell) software.

4.1. NURBS Surface Example

The simple NURBS surface example demonstrates using the GHOST software to build the haptic representation of an existing NURBS (Non-Uniform Rational B-Spline) surface. The geometry is then displayed in the virtual environment where the user may define a virtual volume around any portion of the surface and interact with the surface haptically. Figure 7 shows an example of such a surface.

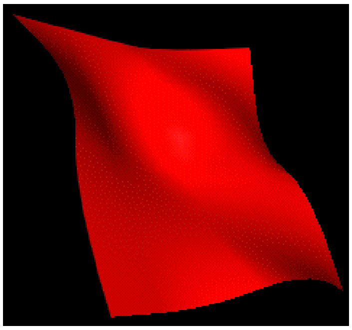

Figure 7 NURBS surface

This application lets the user experience the additional information about an object's shape through the sense of touch while exploring the differences between the PHANToM's physical workspace size and the virtual volume workspace. The effects of misalignment between the virtual volume and the physical PHANToM were also tested with this example.

4.2. Virtual Assembly Example

The virtual assembly example has the user manipulate the PHANToM in an attempt to install a rudder pedal assembly into a simplified model for the lower front portion of a light aircraft. The haptic feedback provides a fast and intuitive way for a designer to determine if the assembly task can be completed.

Boeing's VPS software is used to detect collisions between the pedal assembly and the aircraft structure. Physically based modeling is used to calculate the forces resulting from any collisions. GHOST is used to return these haptic forces to the PHANToM. The VPS software allows this program to calculate haptic forces at very fast [10]. Figure 8 shows a user manipulating the pedal assembly with the PHANToM in the C6.

Using haptic feedback in the virtual environment shows several benefits in this example. It is fast and intuitive for a user to determine if the rudder pedal assembly may be inserted into the proper location. Placing the pedals requires the assembly to be turned on its side, placed part

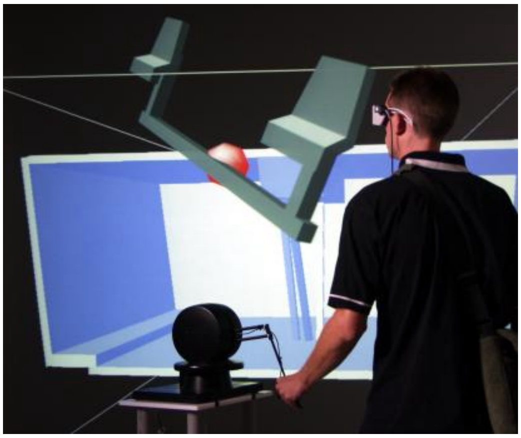

Figure 8 Virtual assembly application with PHANToM

way under the panel, twisted around the cables, and finally set upright. Manipulating the pedal assembly with the PHANToM using haptic feedback is far easier than attempting to use the traditional keyboard and mouse approach.

5. Conclusion

After using this application and experimenting with the examples, some conclusions can be drawn about how haptic feedback and the projection screen virtual environment benefit the user.

- Haptic feedback makes manipulating a complex part through confined spaces faster and more intuitive than using a standard keyboard and mouse approach.
- Being able to touch objects with the PHANToM provides additional information about the geometric structure, which may be visually noticeable.
- The projection screen virtual environment makes interference issues encountered in a particular task easy to discover and remedy.
- Since several people may observe the virtual environment and share the PHANToM in the same simulation, the projection screen environment enhances collaboration between users.

For the examples presented in this work, the differences in workspace size between the physical PHANToM and the virtual volume appear relatively unimportant.

While the addition of haptics to the virtual environment improved the ability of users to interact with digital models for the examples presented, there are some guidelines that should be followed to ensure a high quality haptic feedback experience in an immersive projection screen based virtual environment.

- Avoid positioning much of the phantom in a location that does not align with the user's viewpoint.
- Avoid making the virtual volume excessively large, as this reduces the quality of the force feedback.
- Avoid positioning the phantom stand in the direct line of the user's sight.
- Keep the PHANToM and its stand outside of the virtual geometry.

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