SIX DEGREE-OF-FREEDOM HAPTIC SYSTEM AS A DESKTOP VIRTUAL PROTOTYPING INTERFACE

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ABSTRACT

This paper describes a new six degree of freedom haptic interface with a large translational and rotational range of motion. The 6DOF haptic interface is demonstrated with an example industrial-scale virtual prototyping simulation which shows a moderately complex object interacting with an arbitrarily complex virtual environment, using a full-service collision detection and response package to calculate the force and torque response in all six degrees of freedom.

INTRODUCTION

We are presenting the PHANTOM™ Premium 6DOF Prototype, a force feedback system which provides force and torque feedback in six degrees of freedom within a large translational and rotational range of motion.

The 6DOF haptic system addresses applications which need to simulate arbitrary object-object interactions, which involve collision detection and 6DOF reaction force calculation. In these applications, the user controls one object which can probe, feel, and maneuver around many other objects in a virtual environment. Many applications in virtual prototyping, including virtual assembly, assembly path planning, and maintainability studies, depend heavily on being able to realistically simulate these types of interactions. In particular, the aircraft and automotive industries can benefit from using this technology for virtual prototyping – parts are large, physical prototyping is prohibitively expensive, and the ease of assembly and maintenance are major concerns. Other application areas for the 6DOF haptic system include teleoperation, assembly and maintenance training, medical simulation, molecular simulation, and 6DOF data visualization.

While a number of 6DOF devices have been developed in the past (see Agronin [1987], Bejczy and Salisbury [1983], Berkelman and Hollis [1997], Cybernet [1998], Salcudean and Parker [1997], for some illustrative examples), none of them are specifically designed for prolonged desktop use with a large range of motion in all degrees of freedom. We believe that a large range of motion, especially in the rotational degrees of freedom, contributes significantly to the realism of a virtual environment. Force and torque feedback in a device with a large range of motion gives the user the ability to move and rotate his or her hand freely in space, allowing the hand to follow the same path in space as the object being controlled in the virtual environment.

Figure 1: 6DOF Prototype in use.

SYSTEM OVERVIEW

The PHANTOM Premium 6DOF Prototype is a desk mounted force feedback system that provides full force and torque feedback to

the user. This system consists of the device itself, accompanying power electronics, a PCI interface card, and the GHOST® Software Developer's Kit (SDK). Currently the system is configured to run under the Windows NT environment.

The 6DOF system provides force feedback in three translational degrees of freedom, as do the other members of the PHANTOM family. The peak force of the device is 4.9 lbf and the nominal positioning resolution is 0.001 inch at the end effector. Typical backdrive friction is approximately 0.75 oz. The translational range of motion is about 16"x23"x33", approximating the range of motion of the human arm.

The 6DOF system provides torque feedback in three orthogonal rotational degrees of freedom through a powered gimbal. The peak torque is 95.3 oz-in and the nominal resolution is 0.013 degrees in each axis. Typical backdrive friction in rotation is about 2 oz-in in the yaw and pitch directions and about 1 oz-in the roll direction. The rotational range of motion is 330 degrees in the yaw and roll directions and 220 degrees in the pitch direction.

The 6DOF device is driven by a 6-axis power amplifier box and interfaces to a Pentium based Windows NT computer via a PCI controller card. PHANTOM Device Drivers provided with the device handle force and position calculations, and maintain the haptics update rate to ensure high fidelity. High level interactions with the device use the C++ API in the GHOST SDK v2. GHOST functions calculate and apply 3DOF point force effects based on geometry and material properties of objects in the workspace.

Using new extensions we have developed for the 6DOF system, custom torques can be superimposed onto the 3DOF forces calculated by the GHOST SDK. For more control over force calculations, 6DOF applications can read a 4x4 homogeneous transform describing the global position and orientation of the end effector, calculate 6DOF contact forces within the application, and command these custom-calculated 6DOF global forces and torques to the PHANTOM device using another GHOST function. This is the method used in the demonstration to supply externally calculated contact forces and torques to the device.

DEMONSTRATION: 6DOF SYSTEM WITH BOEING VPS™ VIRTUAL ENVIRONMENT SIMULATION SYSTEM

In this demonstration, the 6DOF system is integrated with a full service collision detection and contact response calculation package called Voxel PointShell™ (VPS), developed at the Applied Research and Technology Department of the Boeing Company. The demonstration allows the user to control the position and orientation of a moderately complex manipulated object in an arbitrarily complex, industrial scale rigid virtual environment using the 6DOF device. The forces and torques acting on the test object are calculated by the VPS software. The VPS application uses voxel-based representations of the objects in the environment and a surface "point shell" representation of the test object. This method is able to detect approximate surface contact between the test object and the environment very efficiently – the calculations can be done at the haptic update rate of 1000Hz, despite the virtual environment complexity of several hundred thousand polygons. Force calculations are based on applying a simple repelling force at any point that is 1 voxel away from contact with objects in the environment. The simulation and real time motion control modules run on a Windows NT computer while the graphics module runs on a separate Silicon Graphics Octane.

This demonstration illustrates the power of 6DOF haptic rendering software used in conjunction with a desktop 6DOF haptic device. Together, they provide the ability to realistically simulate assembly and maintenance conditions in a complex environment. The PHANTOM Premium 6DOF Prototype, integrated with VPS for 6DOF haptic rendering, can be a valuable tool for meeting assemblability and maintainability goals in a faster, easier, and more intuitive manner. We hope that virtual assembly and maintainability studies with the 6DOF system will help industry to advance further in integrating virtual prototyping into their design processes.

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