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HAPTIC DEVICES FOR DESKTOP VIRTUAL PROTOTYPING APPLICATIONS

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Abstract: *Desktop virtual prototyping spans a wide range of activities, from product visualization to fit analysis, dynamic simulation and maintenance analysis. Maintenance analysis is concerned with the investigation of whether or not a component can be inserted into and extracted from its target environment. This activity is particularly significant in automobiles, where components must be accessible for speedy repair. The desktop based workspace could have a great impact when used as a design aid in conjunction with a virtual prototyping application.*
This paper describes the design requirements for a haptic device for witch the application involve maintenance analysis. This application, presents a virtual prototype haptic feedback system developed within Delphi platform. The aim of this paper is to extract knowledge from these theories that can be useful for the purpose of research in the field of motor rehabilitation.
Keywords: *haptic device, haptic feedback, virtual prototyping, maintenance analysis*

1. INTRODUCTION

Haptics is a enhancement to virtual environments allowing users to "touch" and feel the simulated objects with which they interact. Haptics is the science of touch. The word derives from the Greek haptikos meaning "being able to come into contact with". The study of haptics emerged from advances in virtual reality. Virtual reality is a form of human-computer interaction (as opposed to keyboard, mouse and monitor) providing a virtual environment that one can explore through direct interaction with our senses. To be able to interact with an environment, there must be feedback. This type of feedback is called haptic feedback.
In human-computer interaction, haptic feedback means both tactile and force feedback. Tactile feedback allows users to feel by her skin things such as the texture of surfaces, temperature and vibration. Force feedback reproduces directional forces that can result from solid boundaries, the weight of grasped virtual objects, mechanical compliance of an object and inertia.
Haptics has great potential in education-feeling is believing-especially in science and technical areas, where forces are very important, being able to interact with a computer simulation and literally feel the results. Students can develop a feel and appreciation for a particular subject even before they have the detailed mathematics background to handle the equations.

2. HAPTIC DEVICES

Haptic devices (or haptic interfaces) are mechanical devices that mediate communication between the user and the computer. Haptic devices allow users to touch, feel and manipulate three-dimensional objects in virtual environments and tele-operated systems. Haptic devices are input-output devices, meaning that they track a user's physical manipulations (input) and provide realistic touch sensations coordinated with on-screen events (output) [1].
Haptic interfaces are relatively sophisticated devices. As a user manipulates the end effector, grip or handle on a haptic device, encoder output is transmitted to an interface controller at very high rates. Here the information is processed to determine the position of the end effector. The position is then sent to the host computer running a supporting software application. If the supporting software determines that a reaction force is required, the host computer sends feedback forces to the device. Actuators (motors within the device) apply these forces based on mathematical models that simulate the desired sensations. One haves been developing haptic interface devices to

permit touch interactions between human users and remote virtual and physical environments. Examples of haptic devices include consumer peripheral devices equipped with special motors and sensors (e.g., force feedback joysticks and steering wheels) and more sophisticated devices designed for industrial or scientific applications (e.g., PHANTOM haptic device, FALCON haptic device) [2].

3. DESKTOP VIRTUAL PROTOTYPING

Desktop virtual prototyping refers to the process by which a new design can be evaluated on a computer without the need to create a physical prototype. The benefits are many and profound: reduced cycle time, reduced cost and increased flexibility facilitate a much more interactive, concurrent and efficient engineering process.
Doing this analysis in the real world is easy, because the operator can feel surface constraints and contact forces as he or she rotates and manipulates a part into place.
Replicating the same task in an interactive virtual prototyping application is much more difficult. The software is required to perform collision detection and compute a response in a complicated environment, which is a very challenging problem to solve [3].
Assuming that the software issues can be addressed, the user is still limited by the human-computer interface. An ideal interface should provide an easy way to control the position and orientation of a virtual object in 3D space. It should also provide the user with an intuitive 3D interface to obtain contact information. This computer interface must control an object in free space who has six degrees of freedom (x, y, z, roll, pitch, yaw). Trying to manipulate an object through a tortuous path in maintenance analysis using only visual feedback can be very difficult. With haptic devices this action is very easy.
There are some six degree-of-freedom (6DOF) haptic devices on the market that provide a sense of touch; their ranges of motion are typically limited but the user can map freely the object's movement. This sense of touch includes not only translational force feedback, but rotational or torque feedback. When two objects interact, 3DOF contact forces can occur anywhere on the objects. The distance between the center of gravity of each object and an outlying contact point constitutes a moment arm, resulting in a 3DOF reaction torque due to the contact force [4]. This reaction torque combines with force and vision helps the user to manipulate objects in the real world. The lack of this 6DOF force/torque feedback would make it difficult to control virtual objects in a simulation.
We believe that a useful device in a virtual maintenance analysis scenario must satisfy the following requirements:

- it must allow the user to move his or her hand freely in a reasonably unrestricted working volume in translation and in rotation on the desktop;
- it must provide a sense of touch;
- it must do so in all six degrees of freedom.

4. SIMULATION OF A MAINTENANCE ANALYSIS TASK

In this paper, we will the use the virtual prototyping Delphi software and haptic feedback hardware. We will explore the design requirements for a force feedback device for maintenance analysis applications [5].
We present a novel prototype device based on desktop workspace device, and describe its integration into an example application that includes a simulation of a maintenance analysis task for an automotive engine.

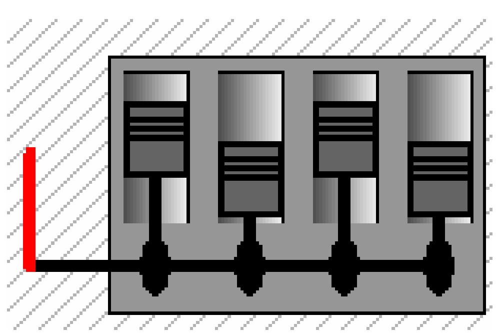

Figure 1: Virtual engine

We will present also two virtual prototypes in the automotive industry, as the first potential area of application in maintenance analysis using only visual feedback.

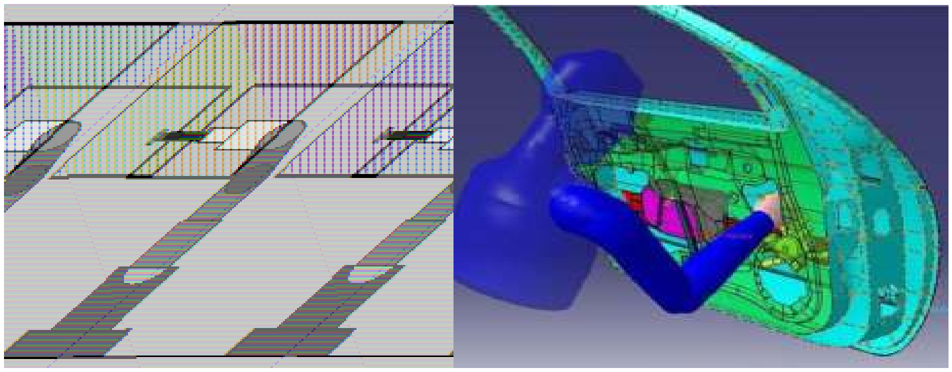

Figure 2: Examples of the virtual prototyping applications

In the design of any product, it is always important to ensure that it can be assembled and disassembled speedily and without problems. If this technology were packaged into major CAD systems, it would speed up the product development cycle and allow better products to be designed and prototyped in less time and cost. The device can also improve the realism in other virtual simulations that can benefit from 6DOF force feedback [6].
Companies which are most likely to benefit from this technology are those in the automotive industries, where the parts are many and large, maintainability is a major concern, and it is prohibitively expensive to produce physical prototypes. In the long run, however, all product design can stand to profit from such a desktop design aid.

5. DESIGN REQUIREMENTS FOR A HAPTIC DEVICE

As we mentioned earlier, there are three key requirements for a haptic device for maintenance analysis applications: large range of motion allowing the user to move his or her hand freely on the desktop; providing a sense of touch; possessing six active degrees of freedom.
The translational and rotational range of motion is based on informal discussions with maintenance engineers for engines in the automotive industries to understand their needs in maintenance planning and analysis. Since the parts and assemblies are large, a larger range of motion in the workspace would be more realistic. The rotational range of motion is based on experience with small workspace devices, which required excessive clutching motions that reduced the usability of the device.
The rest of the requirements are based on simple haptic experiments and common rules of thumb for designing haptic devices.
Another consideration is that the peak force and torque should be high enough for “crisp” feedback but not so high that it causes repetitive hand injuries [7].
By stressing design principals of low mass, low friction, low backlash, high stiffness and good back drivability we have devised a system capable of presenting convincing sensations of contact, constrained motion, surface compliance, surface friction, texture and other mechanical attributes of virtual objects.

6. HAPTIC DEVICES FOR MAINTENANCE ANALYSIS APPLICATIONS

Based on these qualitative design requirements, we will present the Phantom 6DOF haptic device and Falcon haptic device, who can used in maintenance analysis applications. The 6DOF force feedback is very valuable in this type of applications.

6.1 Phantom haptic device

The Phantom is a convenient desktop device which provides a force-reflecting interface between a human user and a computer. Users connect to the mechanism by simply inserting their index finger into a thimble. The Phantom tracks the motion of the user’s finger tip and can actively exert an external force on the finger, creating compelling illusions of interaction with solid physical objects. A stylus can be substituted for the thimble and users can feel the tip of the stylus touch virtual surfaces.

This paper describes the Phantom haptic interface, a device which measures a user's finger tip position and exerts a precisely controlled force vector on the finger tip.
The device can also improve the realism in other virtual simulations that can benefit from force feedback in six degrees of freedom (6DOF) [8]. The Phantom 3.0/6DOF devices version allow users to explore application areas that include virtual assembly, virtual prototyping, maintenance path planning, teleoperation. Simulating torque force feedback makes it possible to feel the collision and reaction forces and torques of a part in a virtual assembly path, or the rotational torques supported by a remote "slave" robot in a teleoperation environment. These devices provide force feedback in three translational degrees of freedom. Additionally, the systems provide torque feedback in three rotational degrees of freedom in the yaw, pitch and roll directions. The Phantom 3.0/6 DOF has a range of motion approximating full arm movement pivoting at the shoulder. The Phantom HighForce/6DOF version devices have a range of motion approximating lower arm movement pivoting at the elbow. The Phantom 3.0/6DOF devices connect to the PC via the parallel port interface.
The Phantom Premium 6DOF is a desk mounted force feedback system that provides six degree-of-freedom force and torque feedback. The system consists of the device itself, accompanying power electronics, a remote/safety switch, and a PCI interface card. The Phantom Premium 3.0 is a serial robot with 6 DOF. The device is leveraged from haptic technology developed and implemented in standard Phantom force feedback devices [Figure 1].
The Phantom Premium 3.0 is a large haptic device that accommodates free arm and hand motions about the shoulder as the center of rotation. The Phantom Premium 3.0 base uses cable capstan drive trains. Its motors are equipped with co-located position sensors. The base motor (primarily responsible for left-right motions or x motions) is grounded. A cable transmission converts motor rotations to the rotation of a large disk which carries the rest of the mechanism. The second and third motors (primarily responsible for up-down and in-out motions, or y and z motions) ride on a ring mounted on the large disk, using a cable-capstan drive. The second and third motors control the position of two linkages in a four-bar parallel linkage design. The sensor-motor packages measure the endpoint position and provide force feedback in three translational degrees of freedom.
To provide torque feedback, a proprietary instrumented gimbals is attached to the last link of the Phantom (the link we typically call the shin). This instrumented gimbals encapsulates three additional sensors and actuators in a compact package. The gimbals provides torque feedback in three orthogonal rotational degrees of freedom. It allows largely unencumbered movements of the hand with the wrist as a center of rotation. The end effector takes the shape of a handle and measures less than an inch in diameter. It is roughly the size and shape of a large permanent felt tip marker. It sports one switch which can be programmed to produce visual and/or haptic effects.

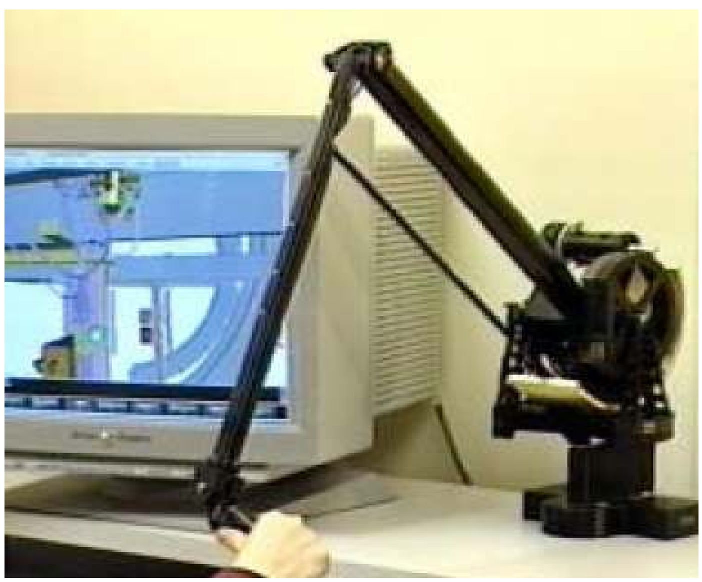

Figure 3: Phantom Premium 6DOF haptic device

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. Low level communications between the PC and the PCI card are handled by the Phantom Device drivers (PDD). The PDD maintains a 1 kHz servo update rate to ensure stable closed loop control of the device. The device kinematics and other robotic calculations are handled within the PDD. High level force and position calculations are provided by the the Software Developer's Kit (SDK). The SDK provides a high level C++ programming interface for generating haptic effects.

Haptic effects handled by the SDK can be based on geometry (such as point haptic exploration), or on force-time profiles (such as sinusoidal vibrations and jolts). The user can define their own custom force fields [9]. Currently the SDK only supports 3DOF forces based on point haptic exploration. Using new extensions allow a 6DOF application to read the Denavit-Hartenberg homogeneous transform, describing the global position and orientation of the end effector, calculate 6DOF forces and torques in the application, and command these 6DOF global forces and torques to the device.

6.2 Falcon haptic device

The Novint Falcon is a pointing device with three arms coming out of the main body of the device. Each arm is capable of pulling and pushing, and is updated every 1/1000 of second. In addition to the arms there is an interchangeable handgrip, with three programmable buttons on it.

Figure 4: Novint Falcon haptic device

The Falcon haptic device consists of a spherical grip, connected via three arms to a roughly conical housing, which sits on a weighted base. The housing contains sensors and motors attached to each arm; via triangulation, the sensors can determine where the grip is in three-dimensional space via the arms, and the motors can translate the grip in three-dimensional space via a cable-drive mechanism, in order to provide haptic feedback to the user. The grip also has a cluster of four buttons on top of it and can be easily removed and replaced with other grips. At the flattened point of the Falcon's conical housing is a Novint Falcon logo, that lights up in different colors to indicate the state of the device.
Falcon haptic device is a Delta parallel robot [10]. Parallel mechanisms are a natural fit for haptics, because they offer good stiffness and robustness at a relatively low cost. Stiffness in particular, is important in haptics, because motors can’t respond instantaneously.
A grip's position in real space corresponds to the location of a cursor in the three-dimensional virtual world. And when that cursor touches a virtual object, the Falcon device sends an analogous force back to the grip. Likewise, forces that the user exerts on the grip are translated into cursor movements.
The Falcon haptic device generates its real world forces with three small joystick-sized motors connected to the device's three arms, by a cable linkage. The system can produce a force in any direction, within its 4 x 4 x 4 inch working envelop.
Novint's control software for the Falcon adjusts the motor current - in accordance with what's happening in the virtual world - with textbook physics equations, determining the magnitude and vector off all the forces and deflections. The system updates current positions - real and virtual - at 1 kilohertz. Falcon system achieves a sub-mm resolution.
The Falcon may be getting its start as a game controller, but the Falcon isn't just one device, it's a haptic platform that could be applied more broadly, as a 3D input/output device for a variety of computing systems, including design and analysis software used by engineers.

7. CONCLUSIONS

Using and testing the haptic devices is a very educational experience. While we knew approximately what we wished to achieve, we were able to gather valuable feedback by having the real haptic device in our hands and feeling the impact of torque and force feedback. We consider that the desktop based workspace could have a great impact when used as a design aid in conjunction with a virtual prototyping application.
We studied PHANTOM haptic device and we did some qualitative human perception experiments and informal surveys and questionnaires in an effort to quantify some of the design parameters of the FALCON system.
Haptic devices can bee integrated into the Delphi software, which simulates maintenance analysis in a large scale industrial environment. We have created on some desktop virtual prototyping system for automotive industry. We targeted maintenance analysis applications in particular. We think that the 6DOF haptic technology in continuing research will provide much value to virtual prototyping applications on the desktop.
Companies which are most likely to benefit from this technology are those in the automotive industries, where the parts are many and large, maintainability is a major concern, and it is prohibitively expensive to produce physical prototypes. All product design can stand to profit from such a desktop design aid. In the design of any product, it is always important to ensure that it can be assembled and disassembled speedily and without problems. Haptic technology was packaged into major CAD systems and it would speed up the product development cycle and allow better products to be designed and prototyped in less time and cost.

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