

# **Haptics: The Technology of Touch**

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## **Introduction**

Haptics -- the newest technology to arrive in the world of computer interface devices -- promises to bring profound changes to the way humans interact with information and communicate ideas. Recent advances in computer interface technology now permit us to touch and manipulate imaginary computer-generated objects in a way that evokes a compelling sense of tactile "realness."

With this technology we can now sit down at a computer terminal and touch objects that exist only in the "mind" of the computer. These interactions might be as simple as touching a virtual wall or button, or as complex as performing a critical procedure in a surgical simulator.

This paper outlines some of the history that has led to the current state-of-the-art in haptics, the emergence of a new haptic interface device, the application potential it offers, and the enabling technologies that will permit pervasive use of haptics.

## **Sensing and Manipulation: A Co-Dependence**

The term "haptics" has been used for years by researchers in human psychophysics who study how people use their hands to sense and manipulate objects. Unique among our sensory modalities, haptics relies on action to stimulate perception. To sense the shape of a cup we do not take a simple tactile snapshot and go away to think about what we felt. Rather, we grasp and manipulate the object, running our fingers across its shape and surfaces in order to build a mental image of a cup. This co-dependence between sensing and manipulation is at the heart of understanding how humans can so deftly interact with the physical world.

Recently the term "haptic interfaces" has begun to be used by human interface technologists to describe devices that measure the motions of, and stimulate the sensory capabilities within, our hands. There is a long and respectable history in the development of devices to permit humans to control remotely located robots (tele-manipulators). Yet, it has taken the explosion of computer capability and the yearning for better ways to connect to newly complex computer-generated worlds to drive the creation and development of practical devices for haptic interaction.

## **A Feel for Remote Control**

For as long as people have been remotely controlling machines, devices have been built to give us a sense of feel when controlling remote actions. Even before the days when we needed to safely manipulate hazardous radioactive materials, remote manipulation devices had been built. Early on these took the form of simple lever- and cable-actuated tongs on the end of a pole. These evolved into mechanical contrivances with elbows, wrists and crude hands. So-called "hot-cell manipulators" enabled workers to grasp a flask and pour a dangerous liquid. The worker could move, orient and squeeze a simple pistol grip to control the remotely located "tongs" to perform the work. Mechanical links and cables communicated motions and forces between the humans and a remote hand.

Early researchers quickly recognized the need to transmit these motions and forces with as much fidelity and speed (bandwidth) as possible. They struggled to find ways to eliminate friction and sloppiness in the mechanical actions. From the works of pioneers such as Mosher, Goertz, Vertut, Flatau and many others came designs that permitted remote manipulation of objects with a high degree of dexterity; many of these designs are still in use in the nuclear and hazardous material industries.

As the need for more distant remote manipulation arose, researchers developed designs that eliminated the

direct mechanical connection between the master and remote devices. Using motors and simple electronic sensors, it became possible to connect human hand actions to a remote manipulator via electronic signals. Within these devices, motors provided the force both to perform the task and to provide the user with the feel of doing the task.

## **Toward Computer-Generated Reality**

At some point, it was realized that if correct electrical signals could be generated by a computer, the master device could be used to make users feel as though they were performing a real task. In reality, users would simply be interacting through motors with a computer program. Early experiments were conducted by Knoll at AT&T, Kilpatrick and Brooks at The University of North Carolina at Chapel Hill, and Wilson at The University of California - San Diego. They demonstrated that the sense of touching simple shapes could indeed be evoked by programming computers to control electromechanical master devices.

These seminal efforts at building haptic virtual realities proved the concept. But, they lacked the compute power to build virtual objects of any complexity and the mechanical performance to provide convincing fidelity. Consequently, these early ideas percolated on the back burner awaiting the right technical threshold and need to arise.

With the advent of sufficient compute power to enable real-time 3D graphics came the birth of virtual reality. Early visitors to virtual worlds were forced to use joysticks and keyboards to navigate through computer-generated environments. When sensor-laden gloves such as the VPL Data Glove and the Virtex CyberGlove became available, hand gestures could be used to command motion and actions in virtual worlds. Yet, without the input of mechanical power, these gloves left users with the unsatisfying sense of waving their hands in an empty void.

Attempts were made to provide force feedback to users either by adapting tele-manipulator masters or by various powered exoskeletal devices. None of these attempts, however, crossed the threshold of performance and convenience to make pervasive haptic interaction with simulated objects a reality.

## **A New Level of Fidelity and Convenience**

In 1993, the Massachusetts Institute of Technology's Artificial Intelligence Laboratory constructed a device that offered solutions to many of the problems facing haptic researchers. Dubbed the "Phantom Haptic Interface," the device has stimulated a flurry of activity by researchers around the world. The new device, developed by Thomas Massie and Kenneth Salisbury, delivers precise haptic stimulation to humans at a level of fidelity and convenience previously unattainable.

Looking a bit like a miniature Luxo Lamp with a thimble on the end, this device is the first of a new class of haptic interface devices that promise to change the way we work with computers and ideas. Massie and Salisbury realized that a device built to deliver the forces that arise in "point contacts" could be used to give the sensation of fingertip interactions with a wide variety of objects. Requiring only three motors and three sensors to accomplish this, the device would provide a computationally and mechanically tractable way to enable haptic interaction with complex virtual objects.

## **Exploring New Worlds of Haptic Interaction**

While designed for a particular class of touch interactions (point contacts), the Phantom is an important first step toward enabling extensive haptic interaction with computer-generated objects. Already researchers have used the Phantom to present users with a wide variety of objects to touch and manipulate. Shapes as simple as a sphere or as complex as a space shuttle model can be touched and explored with the user's finger tip.

The sense of contact is so profound that first-time Phantom users often close their eyes as they gleefully explore newly found shapes. Users can push and bat moving masses about in a game reminiscent of the early Pong game, except that they now feel the objects they strike. A demonstration of a needle biopsy procedure -- in which a long needle is inserted into a human brain -- evokes comments from doctors that the needle seems a bit "dull." This is a remarkable comment, as it indicates that the doctors are concerned

immediately with the details of the procedure rather than the fact that it is a simulation.

One Phantom researcher sent a program to Massie that was claimed to contain a wrist. Upon running the program one could feel the compliant skin surface with underlying tendons and, if you felt in the right place, a pulse (the patient appeared to have a dangerously fast heart rate due to the faster processor on which the simulation was run). Other applications provide buttons and switches that snap and slide into place as they are pushed about.

The Phantom can also be used to emulate tool interactions. You can simply remove the thimble in which you normally place your finger and replace it with specially designed tweezers. It then becomes possible to pinch and tug upon the surface of a compliant skin- like material. Other tool connectors allow users to simulate cutting and screw-driving operations.

These are but a few examples of the many demonstrations that the more than 40 Phantom users are building to explore the world of haptic interaction. As a new paradigm for human/computer interaction, the technology is going through a necessary phase of discovery and definition of basic capabilities. These capabilities are the foundation upon which sophisticated, interactive haptic worlds will be built.

## **The Potential: GUIs, Games and Training**

One can look ahead and easily identify a few areas where haptics will be useful. Surely there will be many surprise applications emerging in the future as well. The most obvious broad application is the enhancement of graphical user interfaces (GUIs such as Windows and Mac interfaces). By enabling people to feel where the buttons on their programs are, pointing and clicking takes on a whole new meaning and efficiency. Computer games could be made significantly more engaging by introducing touch interactions. While there is an enormous number of potential users in these two areas, they are cost-sensitive markets that will become accessible only after haptics can be made available at a low cost.

A nearer-term application that will tolerate the higher initial cost of the technology (and support development of lower-cost devices) is simulation for training humans to perform tasks that require sensorimotor skills. Areas that can benefit greatly from haptics include surgery and other skilled manual tasks. The Office of Naval Research is already making a significant investment in haptic technology (via basic research and SBIR initiatives), viewing it as an important component of future training systems for naval personnel.

Increasingly, humans will be interacting with computer-generated, three-dimensional visual data. The explosive proliferation of real-time 3D graphics accelerators promises to fill our computers with realistic 3D visual scenes. Users of CAD/CAM, data visualization and other engineering/scientific applications will yearn for the ability to touch and manipulate real and abstract data objects. This creates an enormous opportunity for using haptic interfaces to improve the interaction within engineering/scientific application programs.

## **Today's and Tomorrow's Enabling Technologies**

Today we can use a Pentium PC and a Phantom to display (or "render") and interact with simple haptic scenes. We have recently crossed an important threshold in haptic simulation realness by capitalizing on the design insights embodied in the Phantom and the inexpensive compute power offered by today's processors. The computer industry's aggressive development of graphics accelerators gives us the extremely fast geometric computation capabilities needed for haptic rendering. Greater computation capabilities, combined with expected advances in motor technology, further understanding of haptic psychophysics, and sensible product design, will make haptic technology an important adjunct to the way we work with computers.

The current haptic interface paradigm embodied in the Phantom focuses on the simplest of interactions -- forces at the fingertip or tool tip. There are other aspects of human haptic perception -- such as pressure distribution, temperature and high-frequency vibration -- that could enhance the quality of interaction. Whether the investment in the display technologies necessary to support these elements is warranted remains to be seen.

## **From Software to Silicon**

Even the simple application of forces to the fingertip requires significant work in developing rendering algorithms. For years graphics systems developers have worked to define efficient ways to take an object model and present its visual appearance on the screen. Many algorithms for rendering lighting effects, shading, reflection and surface texture were first developed in software and then migrated to silicon-based rendering "engines." We expect a similar trend in haptics.

Researchers are now developing rendering algorithms to present the feel of objects based on geometric and material models. How one must display (and compute) elemental sensations such as impact, friction, softness, motion and constraint must be solved first at the software algorithmic level. With time and driven by user demands, we expect a progression of haptic rendering capabilities ultimately will be encapsulated in dedicated silicon rendering engines.

*Dr. Kenneth Salisbury is a principal research scientist at MIT's Artificial Intelligence Laboratory and the co-inventor of the Phantom Haptic Interface. He serves as a technical advisor for SensAble Technologies Inc., developer of the Phantom A haptic interface device.*