Haptic Devices

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Overview of Haptics

Haptics is a recent 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. For example, the user should be able to touch a virtual object and feel a response from it. This type of feedback is called haptic feedback.

In human-computer interaction, haptic feedback means both *tactile* and *force* feedback. *Tactile*, or touch feedback is the term applied to sensations felt by the skin. Tactile feedback allows users to feel 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.

Tactile feedback, as a component of virtual reality simulations, was pioneered at MIT. In 1990 Patrick used voice coils to provide vibrations at the fingertips of a user wearing a Dextrous Hand Master Exoskeleton. Minsky and her colleagues developed the "Sandpaper" tactile joystick that mapped image texels to vibrations (1990). Commercial tactile feedback interfaces followed, namely the "Touch Master" in 1993, the CyberTouch® glove in 1995, and more recently, the "FEELit Mouse" in 1997.

Scientists have been conducting research on haptics for decades. Goertz at Argonne National Laboratories first used force feedback in a robotic tele-operation system for nuclear environments in 1954. Subsequently the group led by Brooks at the University of North Carolina at Chapel Hill adapted the same electromechanical arm to provide force feedback during virtual molecular docking (1990). Burdea and colleagues at Rutgers University developed a light and portable force feedback glove called the "Rutgers Master" in 1992. Commercial force feedback devices have subsequently appeared, such as the PHANTOM™ arm in 1993, the Impulse Engine in 1995 and the CyberGrasp® glove in 1998.

There clearly has been a resurgence of research interest and haptic interface products. In addition, research on haptic feedback has been aggressively pursued in several countries outside the U.S., notably in Japan, UK, France and Italy.

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. Most common computer interface devices, such as basic mice and joysticks, are input-only devices, meaning that they track a user's physical manipulations but provide no manual feedback. As a result, information flows in only one direction, from the peripheral to the computer. 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). 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, medical or scientific applications (e.g., PHANTOM™ device).

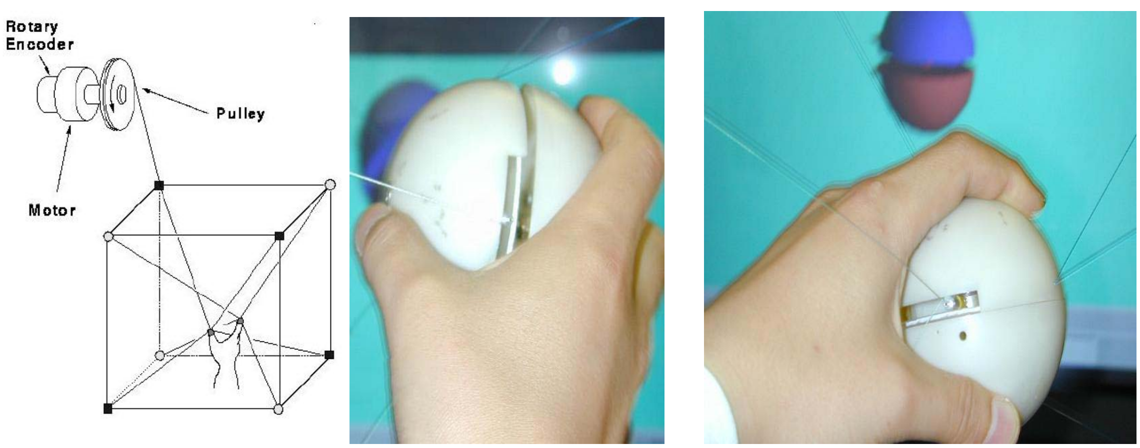
Haptic interfaces are relatively sophisticated devices. As a user manipulates the end effector, grip or handle on a haptic device, encoder output is transmitted to an interface controller at very high rates. Here the information is processed to determine the position of the end effector. The position 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. For example, when simulating the feel of a rigid wall with a force feedback joystick, motors within the joystick apply forces that simulate the feel of encountering the wall. As the user moves the joystick to penetrate the wall, the motors apply a force that resists the penetration. The farther the user penetrates the wall, the harder the motors push back to force the joystick back to the wall surface. The end result is a sensation that feels like a physical encounter with an obstacle.

The human sensorial characteristics impose much faster refresh rates for haptic feedback than for visual feedback. Computer graphics has for many years contended itself with low scene refresh rates of 20 to 30 frames/sec. In contrast, tactile sensors in the skin respond best to vibrations higher that 300 Hz. This order-of-magnitude difference between haptics and vision bandwidths requires that the haptic interface incorporate a dedicated controller. Because it is computationally expensive to convert encoder data to end effector position and translate motor torques into directional forces, a haptic device will usually have its own dedicated processor. This removes computation costs associated with haptics and the host computer can dedicate its processing power to application requirements, such as rendering high-level graphics.

General-purpose commercial haptic interfaces used today can be classified as either ground-based devices (force reflecting joysticks and linkage-based devices) or body-based devices (gloves, suits, exoskeletal devices). The most popular design on the market is a linkage-based system, which consists of a robotic arm attached to a pen (see Figure 1). The arm tracks the position of the pen and is capable of exerting a force on the tip of this pen. To meet the haptic demands required to fool one’s sense of touch, sophisticated hardware and software are required to determine the proper joint angles and torques necessary to exert a single point of force on the tip of the pen. Not only is it difficult to control force output because of the update demand, the mass of a robotic arm introduces inertial forces that must accounted for. As a result, the cost of a linkage-based force feedback device ranges from $10,000 to over $100,000.

Figure 1. ***PHANTOM™ Desktop*** **from SensAble Technologies is a popular linkage-based haptic device. The position and orientation of the pen are tracked through encoders in the robotic arm. Three degrees of force, in the *x*, *y* and *z*, direction are achieved through motors that apply torques at each joint in the robotic arm.**

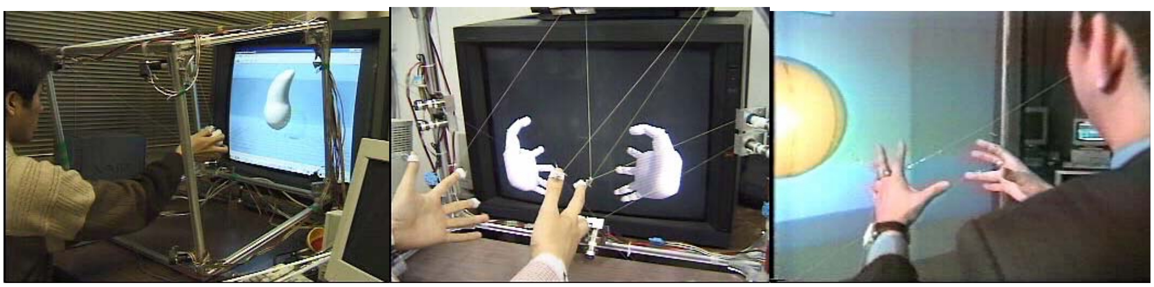
An alternative to a linkage-based device is one that is tension-based. Instead of applying force through links, cables are connected to the point of contact in order to exert a force. Encoders determine the length of each cable. From this information, the position of a "grip" can be determined. Motors are used to create tension in the cables, which results in an applied force at the grip.



(a) (b) (c)

Figure 2. (a) Schematic of a tension-based force feedback device created by Seahak Kim as part of is PhD research at the Tokyo Institute of Technology. The system provides seven degrees of force feedback (force along the x, y and z-axis; torque around the x, y and z-axis; force in the radial direction for grip). (b-c) Cables exert force on a "grip" that is positioned within the frame of the device.

A haptic device must be able to resist the force applied by a user. Just as a lever allows you to apply a large force with little effort, longer links in a robotic arm allow you to exert larger forces on the motors that control the bending of the robotic arm. Larger linkage-based systems therefore require larger motors that can exert more force. This can become very expensive and in most cases impractical, which puts a limit on the size of a linkage-based system. Because a tension-based device applies force directly to the point of contact through the tension in the cables, there is no need to compensate for the "lever effect". This removes the limitation on workspace size and the amount of force that could be applied. As a result, a tension-based device could be the size of a mouse pad or the size of a room.



(a) (b) (c)

Figure 3. Various tension based force feedback devices developed at the Precision and Intelligence Laboratory at the Tokyo Institute of Technology. (a) Six degree force feedback device with 54x54x54 cm workspace. (b) Twenty four degree of freedom device with 100x50x50 cm workspace. (c) Five degree freedom device with a 2x2x2 m workspace used within a CAVE system.

Unlike links, the cables used in a tension-based system have little mass. This essentially eliminates inertial effects and increases the accuracy of the applied force. Cables are also much safer than links in that they have little mass that can collide with a user. Cables are also unobtrusive. They do not obstruct one's view, as would one or more robotic arms. Stereoscopic 3-D projection can allow virtual objects to be placed within the frame of a tension-based device so that visualization can be co-located with the sense of touch.

Tension-based devices are only now beginning to appear in commercial markets. The low cost of these systems make them especially appealing as compared to linkage-based devices. Surgery simulation is the arena where these devices are first making an appearance, with laproscopy, trans-urethral resection of the prostate, and suturing simulation serving as some of the initial applications.