

# A Survey of Computer Haptics

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**Abstract** - Computer haptics is an emerging technology that provides force feedback and tactile sensations to users as they interact with a virtual object. Haptic hardware provides sensory feedback that simulates physical properties and forces. The monitor enables sighted users to see computer generated images and audio speakers allow users to hear sounds, the haptic device makes it possible for blind or visually impaired users to feel force feedback and textures while they manipulate virtual two and three dimensional objects. The haptic device allows the user to interact with a virtual object, such as a planet surface feature or a cell membrane, using the sense of touch. Other physical properties can also be simulated, such as textures, magnetism, viscosity, vibration, or elasticity. Science related haptic software was used with students with visual impairments, the researcher found that adding forces to the visual display enhanced users understanding of the binding energy of a drug molecule. Recently investigated the effects of integrating haptics into a school biology lesson on viruses. The students were able to interact with the viruses on a microscope slide through the sense of touch. This proved to be a huge step toward accessibility for science content that was not previously accessible to students who are blind or have low vision. Haptics have also allowed students to interact with invisible phenomena in the physical sciences.

**Key Words:** Kinesthesia, Tactile, Vibration, Virtual reality.

## 1. Introduction

It is difficult to imagine life without haptics, because it is a natural and integral part of our lives. Without haptics, we would have great difficulty grasping and manipulating objects, unable to determine many material or surface properties, and miss feeling the warmth of a loved one's hand. Thus, many of the applications of artificial haptics address scenarios where the sense of touch is lost or really diminished compared with the experience of a healthy person in the real world.

Certain highly specialized professions can use augmented haptic feedback, such as an astronaut teleoperating a robot outside the International Space Station to enable repair tasks while avoiding a dangerous human space walk, or a surgeon using a robot to perform a delicate procedure at a scale not achievable with the human hand. In such teleoperation scenarios, we often aim to give human operators a sense of telepresence such that they feel they are directly manipulating the environment with their own hands, rather than having their actions mediated by a robot and

communication/control system. A more universally experienced lack of haptics is in interactive computing. Computers, tablets, and smart phones have sensors to measure human inputs, but their outputs (displays) are limited primarily to the visual and auditory channels. Vibration feedback has made inroads as a haptic display for human computer interaction, but the quality of this interaction leaves much room for improvement, and many other promising haptic feedback Modalities have yet to be implemented in commercial systems.

## 2. History of Haptics

In the early 20th century, psychophysicists introduced the word haptics (from the Greek haptesthai meaning to touch) to label the subfield of their studies that addressed human touch based perception and manipulation. In the 1970s and 1980s, significant research efforts in a completely different field robotics also began to focus on manipulation and perception by touch. Initially concerned with building autonomous robots, researchers soon found that building a dexterous robotic hand was much more complex and subtle than their initial naïve hopes had suggested. In time these two communitiesone that sought to understand the human hand and one that aspired to create devices with dexterity inspired by human abilities found fertile mutual interest in topics such as sensory design and processing, grasp control and manipulation, object representation and haptic information encoding, and grammars for describing physical tasks.

In the early 1990s a new usage of the word haptics began to emerge. The confluence of several emerging technologies made virtualized haptics, or computer haptics is possible. Much like computer graphics, computer haptics enables the display of simulated objects to humans in an interactive manner. However, computer haptics uses a display technology through which objects can be physically palpated.

This new sensory display modality presents information by exerting controlled forces on the human hand through a haptic interface. These forces depend on the physics of mechanical contact. The characteristics of interest in these forces depend on the response of the sensors in the human hand and other body parts.

Although Knoll demonstrated haptic interaction with simple virtual objects at least as early as the 1960s, only recently was sufficient technology available to make haptic interaction with complex computer simulated objects possible. The

combination of high performance force controllable haptic interfaces, computational geometric modeling and collision techniques, cost effective processing and memory, and an understanding of the perceptual needs of the human haptic system allows us to assemble computer haptic systems that can display objects of sophisticated complexity and behavior. With the commercial availability of 3 degree of freedom haptic interfaces, software toolkits from several corporate and academic sources, and several commercial haptics enabled applications, the field is experiencing rapid and exciting growth.

### 3. Human Haptic Perception

Unlike the four other senses (sight, hearing, taste, and smell), the sense of touch is not localized to a specific region of the body, it is distributed across the entire body through the touch sensory organ, our skin, and in our joints, muscles, and tendons. The sense of touch is typically described as being divided into two modalities: kinesthetic and tactile. Kinesthetic sensations, such as forces and torques, are sensed in the muscles, tendons, and joints. Tactile sensations, such as pressure, shear, and vibration, are sensed by specialized sensory end organs known as mechanoreceptors that are embedded in the skin. Each type of mechanoreceptor senses and responds to a specific type of haptic stimulus.

### 4. Haptic Devices

To introduce the breadth of haptic device design and control, here considered three major categories of haptic systems: graspable, wearable, and touchable.

A haptic device is a bidirectional instrumented/actuated human machine interface, employed by the human operator to actively interact with a computer simulated virtual environment. A haptic device can be in the form of a mouse, steering wheel, finger pad, robotic handle, gripper, joystick, gloves, magnetically levitated wrist, or even motion platforms that move the entire user's body. It can be used to simulate an environment with mass, damping, friction, and stiffness properties, or it can mimic the mechanical behavior of a virtual tool interacting with its surrounding virtual environment.

Touchable systems are encountered type displays that allow the user to actively explore the entire surface. They can be purely cutaneous devices that change their tactile properties based on location, such as a surface with variable friction. Touchable devices can also be hybrid cutaneous and kinesthetic devices that change their shape, mechanical properties, and surface properties.

#### 4.1. Kinesthetic Devices

Devices Created To Aid Kinesthetic Learning. A Form Of Learning That Involves Tactile or Physical Activities Such As Movement And Touch. Kinesthesia refers to the sensation of

movement and force and is typically associated with force displacement relationships. Receptors involved include muscle spindles, which transduce muscle stretch, and Golgi tendon organs, which sense change in muscle tension. Stimulating these receptors can produce the illusion of movement and/or force. Kinesthetic or force type haptic devices are defined by their ability to apply force about a joint such that movement (and resistance of that movement) is possible.

#### 4.2. Traditional Kinesthetic Haptic Devices

The Phantom Premium haptic device (originally commercially available from SensAble Technologies) was a milestone in the field, because it enabled three DoFs of high force and high bandwidth force feedback with very low free space impedance. Numerous other kinesthetic haptic devices, from one DoF knobs to six DoF manipulandums, have been developed, with significant research effort put toward ensuring the realism and stability of virtual environments rendered via programmed force displacement relationships.

Traditional kinesthetic devices designed using rigid links are no longer considered at the forefront of novel haptic device design, in large part because many of the research problems have been solved and the relatively high cost benefit ratio has lacked commercial potential. Yet there are some novel designs and new rendering approaches worth briefly reviewing here. One design concept to consider is the choice of control formulation: admittance versus impedance control. Admittance control devices can apply much larger forces to the human operator for applications such as rehabilitation, albeit with differing control challenges from impedance devices. Alternatively, one can design devices that mechanically resist movement in controllable directions; cobots are a great example of this. Improvements to rendering techniques and better understanding of human perception and cognition in the context of different haptic rendering algorithms will also continue to refine the capabilities of kinesthetic haptic devices.

#### 4.3. Low-Cost Kinesthetic Devices

Many kinesthetic devices have focused on high-DoF systems using the highest-quality motors with high force and low friction and cogging, linkages made from high-performance engineered materials such as carbon fiber, and low-friction bearings at joints. However, a new generation of kinesthetic haptics research is seeking to determine the minimal requirements for compelling haptic displays.

For example, haptic devices are being designed for use in education, where one or two DoFs can be sufficient to explain physical and mathematical phenomena in an intuitive, hands-on manner. For integration into classrooms, such devices should be inexpensive, robust, and perhaps even assembled by students or teachers. Haptics researchers are taking advantage of new and popular manufacturing techniques such as 3-D printing and layered manufacturing to make

haptic devices more accessible to non engineers. The conflicting goals of low cost and high performance generate important research questions for haptic device designers as well as those interested in the application of haptics in training environments. For example, we do not fully understand how the accuracy of perception of mechanical properties via a haptic device affects learning or understanding of a concept or task.

#### 4.4. Body-Grounded Kinesthetic Devices

Exoskeletons are typically body-grounded kinesthetic devices. How they should be designed and controlled in order to optimize performance for applications such as rehabilitation and user assistance is the subject of current research, which integrates design, control, biomechanics, and neuroscience. For example, hand-grounded devices can assist surgeons in steadying an instrument for medical tasks. An exciting design development in exoskeletons has been the use of soft robotic techniques and pneumatic actuation to make exoskeletons lighter, cheaper, and more adaptable to the human body.

#### 5. Multimodal Haptics

Kinesthesia has been successfully integrated with tactile feedback as well as other sensory modalities to produce compelling effects with less stringent requirements for the fidelity of force rendering. The force display of any kinesthetic haptic device is limited by the system's sampling rate, computational time delays, and quantization of position measurements.

Lower-fidelity kinesthetic haptic systems can also be enhanced by combining low-frequency force with high-frequency vibration feedback. In the real world, when we tap on a hard surface with a finger or even a stylus, we feel not only kinesthetic force, but also high-frequency vibrations resulting from the contact event. In a virtual environment, playing those vibrations with either the kinesthetic device motors or a separate vibro tactile motor can increase the perceived hardness of a surface.

#### 6. Skin Deformation Devices

The kinesthetic force-feedback devices described in the preceding section represent a fairly complete haptic experience because they not only display large forces but also stimulate the skin through the held tool, effectively providing tactile feedback in addition to the actively controlled kinesthetic feedback. In the last decade, researchers began to examine whether providing only the tactile component of contact forces would have advantages for the size, wear ability, and cost of haptic devices without detracting from the perception that net forces are being applied to the body. Prattichizzo et al. Called this cutaneous force feedback and acknowledged the removal of the kinesthetic forces as a form of sensory subtraction.

Skin deformation is a promising feedback modality in which a shear force is applied to the user's finger pad, similar to the skin deformation that occurs naturally during haptic interactions. This method takes advantage of the finger's increased sensitivity to shear forces compared with normal forces. In order to display shear force, a device contacts the skin, presses on it to ensure sufficient friction, and moves laterally to deform the skin in shear.

#### 6.1. Wearable Skin Deformation Devices

A large body of work has investigated the use of small, wearable, finger-grounded devices for deforming the finger pulp. Although there are many ways that these devices could be classified, one way is to distinguish between the devices that render indentation normal to the finger pad and those that provide lateral translation.

#### 7. Vibration

Haptic feedback in consumer products is usually synonymous with vibration feedback. Vibrations provide an added dimension to gaming by simulating the sensation of collisions or driving over a rough surface, the buzzing of a phone allows us to stay in contact and receive private notifications of messages even when in meetings, and vibrations have been used to simulate the feel of a button click. Similarly, much haptics research has focused on the use of vibration to display information, help the user complete a task, and add realism to virtual environments. Vibration's popularity can be explained by the widespread availability of actuators and the ease with which they can be integrated into systems. The actuators small size, light weight and low cost mean that vibration systems are easily scalable and can potentially display large amounts of information to users.

Haptic designers must understand the methods and limits of human haptic sensing to create haptic systems that effectively stimulate the mechanoreceptors to achieve the desired sensation.

##### 7.1. Information Display

Vibration was conveyed binary information using a simple on off state change. Arrays of these actuators can convey directional information, usually with one actuator used for each DoF. These arrays of factors are typically mounted directly on the body, with common locations being the hand, arm, and torso. Array size and actuator placement are limited by the ability of the user to distinguish the cues from multiple actuators. This distinguish ability is limited both by the receptive fields of the Pacinian corpuscles and by the propagation of vibration through the skin. Owing to differences in the distribution of Pacinian corpuscles in glabrous and hairy skin, arrays of actuators can be denser when mounted on the hand than when placed on other parts of the body, such as the torso or the forearm.

The vibration can be displayed to direct the user to move either away from the cue (repulsive feedback) or toward the cue (attractive feedback). Research has shown that users do not exhibit a preference for either repulsive or attractive feedback, but they may respond more quickly to attractive feedback. Error correction systems have been incorporated into handheld devices, prosthetic hands, and wearable bands in order to guide users toward desired locations or body positions. Vibration has also been used to correct user error when following trajectories for upper-arm motions and during surgery.

Finally, vibration can be used to provide information about events that occur at a distance, namely during teleoperation. With such systems, the user controls the motion of a robot remotely but is unable to feel the forces or vibrations experienced by the robot. Researchers have sought to use vibrations to convey to the user information about the interaction between the robot and its environment. This information transfer requires sensors on the robot (e.g., a force sensor or accelerometer) and an actuator on the master controller. Systems have been created to provide cues for remote surgery and for teleoperation of a robot.

## 7.2. Vibrotactile Illusions

In addition to displaying static sensations at discrete locations on the body, multiple vibration actuators can also display illusory sensations, such as motion. The key to these haptic illusions is the shape of the signals and the timing and spacing between individual actuators. Apparent tactile motion, which was first described by Burtt, is the sensation that vibration travels in a continuous motion across the skin. This illusion is created by controlling the length and delay of actuation between individual actuators in a linear array. It has been successfully implemented in a wearable navigation system and in both one-dimensional and two-dimensional hold able devices.

A second haptic illusion created with vibration is the phantom tactile sensation. In this illusion, two vibration actuators are activated simultaneously, and the user experiences a phantom vibration sensation between the two actuators. The location of the phantom vibration is dependent on the relative amplitudes of the two actuators. Israr & Poupyrev combined the apparent motion and phantom tactile sensation illusions to create smooth, two-dimensional tactile strokes with a sparse vibrotactile array using an algorithm they called the Tactile Brush.

## 8. Integration with Virtual and Augmented Reality

Head-mounted virtual-reality displays, with associated movement tracking and the development of creative virtual reality content, have recently led to significant interest in using haptics to enhance the quality and accessibility of virtual experiences. Indeed, the lack of realistic haptic feedback is a significant barrier to immersivity during object

contact and manipulation in virtual reality it is terribly disappointing to reach toward a highly compelling (graphically) rendered virtual object, see your fingers close around it, and feel nothing.

### 8.1. Encountered-Type Haptic Devices

An encountered-type haptic device produces physical environments for the user to explore directly with his or her entire hands rather than relying on the user to hold an intermediary device through which they receive haptic feedback. The active surfaces described in the preceding section fall into this category, but there is much work to be done to seamlessly integrate encountered type haptic devices with virtual reality. One of the main reasons to use an encountered-type haptic device with virtual reality is that the human user will see the graphically rendered environment, not the haptic device. This means that the haptic device does not need to have any realistic physical appearance and is required to feel right only at the point of contact.

### 8.2. Pseudohaptics

Visuo-haptic illusions seek to use haptic illusions and the overall dominance of the visual system to create haptic feedback with passive props and visual feedback. This pseudo haptic feedback can be used to render the perception of friction, stiffness, size, and weight. Researchers have also sought to combine visuo-haptic illusions with active haptic feedback systems. Pseudo haptics through visual feedback is effective in augmenting cutaneous active haptic feedback for increased stiffness rendering. Spatial manipulation with single-point, under actuated kinesthetic haptic devices has been augmented with visuo-haptic feedback to increase the perception of rotation alignment.

## 9. CONCLUSIONS

In communication technology training and entertainment increases, so does the number of potential applications of haptics. Haptics has already shown great promise in mobile communication and gaming, although the expressiveness of many commercial haptic devices has been limited. The potential impact of haptics is greatest in areas where the sense of touch is critical to the task or situation, where touch can replace visual or auditory cues (e.g., mobile communication and navigation), and where touch can enhance virtual interactions (e.g., virtual reality and gaming). One of the largest factors limiting the impact of the field of haptics has been the availability and expressiveness of hardware. Commercially available actuators designed exclusively for haptic output are limited, which leads many researchers to develop their own haptic devices using off-the-shelf components. The key to developing functional and effective haptic hardware is to focus on the perceptual capabilities of the human sense of touch during the design process. This human-centered design paradigm results in

haptic hardware that more effectively stimulates the mechanoreceptors to display the desired sensations.

Is it possible to create predictive models of human perception and cognition surrounding touch feedback, in order to decrease reliance on exhaustive human user studies? Past psychophysics studies have focused on human touch perception at a small number of locations on the body, including the hand, so it will be useful to expand our existing knowledge of touch perception to cover other body locations.

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