Haptics

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1. Introduction

Haptics refers to sensing and manipulation through touch. Since the early part of twentieth century, the term haptics has been used by psychologists for studies on the active touch of real objects by humans. In the late nineteen-eighties, when we started working on novel machines pertaining to touch, it became apparent that a new discipline was emerging that needed a name. Rather than concocting a new term, we chose to redefine haptics by enlarging its scope to include machine touch and human-machine touch interactions. Our working definition of haptics includes all aspects of information acquisition and object manipulation through touch by humans, machines, or a combination of the two; and the environments can be real, virtual or teleported. This is the sense in which substantial research and development in haptics is being pursued around the world today..

In order to organize the rapidly increasing multidisciplinary research literature, it is useful to define sub-areas of haptics. Haptics can be subdivided into three areas

1. **Human haptics** - the study of human sensing and manipulation through touch,
2. **Machine haptics –** the design, construction, and use of machines to replace or augment human touch.
3. **Computer haptics** -algorithms and software associated with generating and rendering the touch and feel of virtual objects (analogous to computer graphics). Consequently, multiple disciplines such as biomechanics, neuroscience, psychophysics, robot design and control, mathematical modeling and simulation, and software engineering converge to support haptics. Wide varieties of applications have emerged and span many areas of human needs such as product design, medical trainers, and rehabilitation.

Haptics is poised for rapid growth. Just as the primitive man forged hand tools to triumph over harsh nature, we need to develop smart devices to interface with information-rich real and virtual worlds. Given the ever-increasing quantities and types of information that surrounds us, and to which we need to respond rapidly, there is a critical need to explore new ways to interact with information. In order to be efficient in this interaction, it is essential that we utilize all of our sensorimotor capabilities. Our haptic system – with its tactile, kinesthetic, and motor capabilities together with the associated cognitive processes – presents a uniquely bi-directional information channel to our brains, yet it remains underutilized. If we add force and/or distributed tactile feedback of sufficient range, resolution and frequency bandwidth to match the capabilities of our hands and other body parts, a large number of applications open up, such as haptic aids for a blind user surfing the net or a surgical trainee perfecting his trade. Ongoing engineering revolutions in information technology and the miniaturization of sensors and actuators are bringing this dream ever closer to reality.

Virtual environments (VEs), generally referred to as virtual reality in the popular press, have caught the imagination of lay public as well as researchers working in a wide variety of disciplines. VEs are computer-generated synthetic environments with which a human user can interact to perform perceptual and motor tasks. A typical VE system consists of a helmet that can project computer-generated visual images and sounds appropriate to the gaze direction, and special gloves with which one can command a computer through hand gestures. The possibility that by wearing such devices, one could be mentally transported to and immersed in virtual worlds built solely through software is both fascinating and powerful. Applications of this technology include a large variety of human activities such as training, education, entertainment, health care, scientific visualization, telecommunication, design, manufacturing and marketing.

Virtual environment systems that engage only the visual and auditory senses of the user are limited in their capability to interact with the user. As in our interactions with the real world, engaging the haptic sensorimotor system that not only conveys the sense of touch and feel of objects, but also allows us to manipulate them, is desirable. In particular, the human hand is a versatile organ that is able to press, grasp, squeeze or stroke objects; it can explore object properties such as surface texture, shape and softness; it can manipulate tools such as a pen or a jack-hammer. Being able to touch, feel, and manipulate objects in an environment, in addition to seeing (and/or hearing) them, gives a sense of compelling immersion in the environment that is otherwise not possible. Real or virtual environments that deprive the human user of the touch and feel of objects seem deficient and seriously handicap human interaction capabilities. It is likely that a more immersive experience in a VE can be achieved by the synchronous operation of even a simple haptic interface with a visual and auditory display, rather than by large improvements in, say, the fidelity of the visual display alone.

Haptic interfaces are devices that enable manual interactions with virtual environments or teleported remote systems. They are employed for tasks that are usually performed using hands in the real world, such as manual exploration and manipulation of objects. In general, they receive motor action commands from the human user and display appropriate tactual images to the user. Such haptic interactions may or may not be accompanied by the stimulation of other sensory modalities such as vision and audition. Although computer keyboards, mice, trackballs, and even instrumented gloves available in the market can be thought of as relatively simple haptic interfaces, they can only convey the user's commands to the computer, and are unable to give a natural sense of touch and feel to the user. Recent advances in the development of force-reflecting haptic interfacehardware as well as haptic rendering software have caused considerable excitement. Theunderlying technology is becoming mature and has opened up novel and interesting research areas. However, to really enable the wide variety of known applications ofhaptics, and even more so, the applications that we cannot yet imagine, it is critical tounderstand the nature of touch interaction - how and what do we perceive, how do we manipulate, and how are these related to task performance. The challenge of haptics research then is two-fold: to gain a deep scientific understanding of our hapticsensorimotor system and to develop appropriate haptic interface technology.

In this short introductory document, we primarily provide an overview of the major subareasof haptics and refer the reader to some of our more detailed reviews (which, in turn,have substantial references to works by us and others) for a more in-depth look. In the firstsection, we provide the basics of how we feel and how to mimic that feel. The following section is a basic introduction to *human haptics*, the study of the human sensorimotorsystem relevant to manual exploration and manipulation. The subsequent section is on *machine haptics*, concerned with the electromechanical devices used as haptic interfaces. Next, the emerging field of *Computer Haptics* is defined and references to review papersthat deal with the paradigms, algorithms, and software for haptic interactions are provided..Several exciting applications of haptics, such as the development of medical simulators for training and virtual environments shared by multiple users, are described. Finally, future challenges and opportunities in haptics are briefly covered.

2. Touching Real and Virtual Objects

When a human user touches a real object directly or through a tool, forces are imposed on the user's skin. The associated sensory information, mediated by sensors in the skin, joints, tendons and muscles, is conveyed to the brain by the nervous system and leads to hapticperception. The subsequent motor commands issued by the brain activate the muscles and result in, say, hand and arm motion that modifies the touch sensory information. This sensor motor loop continues to occur during both exploration and manipulation of objects.

In order to create the sensation of touching virtual objects, we need to generate the reaction force of objects applied on the skin. Touching a real object through a tool is mimicked bythe use of a force reflecting haptic interface device. When the human user manipulates theend-effector of the haptic interface device, the position sensors on the device convey its tipposition to the computer. The models of objects in the computer calculate in real-time thetorque commands to the actuators on the haptic interface, so that appropriate reaction forces are applied on the user, leading to haptic perception of virtual objects.

3. Applications

The addition of haptics to various applications of virtual reality and teleportation opens exciting possibilities. Three example applications that have been pursued at our Touch Lab are summarized below.

• ***Medical Simulators:*** Just as flight simulators are used to train pilots, the multimodal virtual environment system we have developed is being used in developing virtual reality based needle procedures and surgical simulators that enable a medical trainee to see, touch, and manipulate realistic models of biological tissues and organs. The work involves the development of both instrumented hardware and software algorithms for real-time displays. An epidural injection simulator has already been tested by residents and experts in two hospitals. A minimally invasive surgery simulator is also being developed and includes (a) in vivo measurement of the mechanical properties tissues and organs, (b) development of a variety of real-time algorithms for the computation of tool-tissue force interactions and organ deformations, and (c) verification of the training effectiveness of the simulator. This work is reviewed in .

• ***Collaborative Haptics:*** In another project, the use of haptics to improve human computer interaction as well as human-human interactions mediated by computers is being explored. A multimodal shared virtual environment system has been developed and experiments have been performed with human subjects to study the role of haptic feedback in collaborative tasks and whether haptic communication through force feedback can facilitate a sense of being and collaborating with a remote partner. Two scenarios, one in which the partners are in close proximity and the other in which they are separated by several thousand miles (transatlantic touch with collaborators in University College, London have been demonstrated.

Given below are several more potential applications:

• ***Medicine:*** manipulating micro and macro robots for minimally invasive surgery; remote diagnosis for telemedicine; aids for the disabled such as haptic interfaces for the blind.

• ***Entertainment:*** video games and simulators that enable the user to feel and manipulate virtual solids, fluids, tools, and avatars.

• ***Education:*** giving students the feel of phenomena at nano, macro, or astronomical scales; "what if" scenarios for non-terrestrial physics; experiencing complex data sets.

• ***Industry:*** integration of haptics into CAD systems such that a designer can freely manipulate the mechanical components of an assembly in an immersive environment.

• ***Graphic Arts:*** virtual art exhibits, concert rooms, and museums in which the user can login remotely to play the musical instruments, and to touch and feel the haptic attributes of the displays; individual or co-operative virtual sculpturing across the internet.