Haptics

071011-1
2017년 가을학기
11/15/2017
박경신

Haptics?

Samsung's AnyCall Haptic2

What is Haptics?

- Haptics = Tactile + Kinestetic
  - Tactile : Perceptible to the sense of touch
  - Kinestetic : The sense that detects bodily position, weight, or movement of the muscles, tendons, and joints
  - **Haptics : Sensing and manipulating through touch**
- Human haptics
  - Psychophysics & Cognition
- Machine haptics
  - Machine design, Sensing, Communications
- Computer haptics
  - Stability, Modeling, Rendering

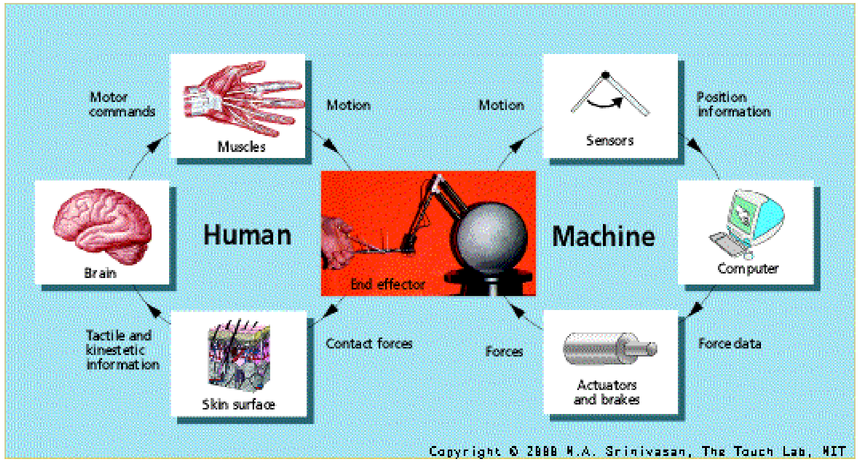
Brief Haptic History

- Early 20th century
  - Psychophysicists introduce the word "Haptics"
- 1970s and 1980s
  - Robotics manipulation and perception by touch
- Early 1990s
  - Computer Haptics simulate virtual object via physical interaction in an interactive manner
- 2000s & Recently
  - Haptic Community http://haptic.mech.northwestern.edu/
  - International Society for Haptics http://www.isfh.org/
  - Haptic devices, rendering, applications

Why use Haptics?

- Increase the information flow between computer and user
- Bidirectional flow of information and energy
  - When we push on an object, it pushes back on us
  - Fast response, accurate and efficient control
- Interact with computer in a physically direct and intuitive way

Haptic Interaction

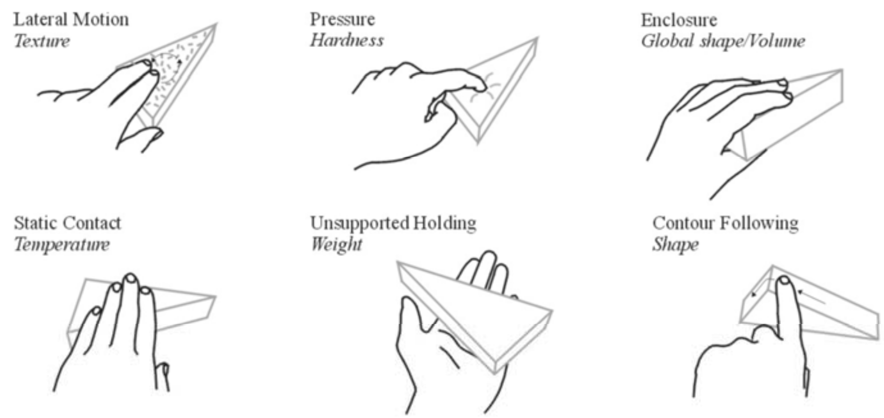


To understand human haptics, develop machine haptics, and enhance human-machine interactions
MIT Touch Lab http://touchlab.mit.edu/oldresearch/index.html

Haptic Metaphors

- Emotion
  - Feel, touching, tactful, stroke one's ego
- Haptic Exploration
  - Get a feel, poke around, scratch the surface
- Contact
  - At one's fingertips, touch base, keep in touch, on/at hand
- Constraint
  - Get/lose a grip, get/lose a grasp
- Force/Impact/Manipulation
  - Massage an ego, pushy, knock, kick, toss around, magic touch
- Surface Properties
  - Sticky situation, hot idea, abrasive personality, smooth operator

Haptic Exploration



Adapted from R.L. Klatzky, *et al.*, "Procedures for haptic object exploration vs. manipulation," Vision and action: The control of grasping, ed. M.Goodale, New Jersey: Ablex, 1990, pp. 110-127.

Human Haptics

- Why do we study “Human Haptics”?
  - To make useful haptic simulations
  - To set a limit of how good haptic simulations have to be
  - Haptic simulation can be used in psychophysical/perceptual tests

Types of Human Haptic Sensing

- Kinesthesia/Proprioception/Force
  - A sense mediated by end organs located in muscles, tendons, and joints.
  - Stimulated by body movements
  - Kinesthesia inspires **force feedback**
- Cutaneous/Tactile
  - Related to the skin
  - Cutaneous inspires **tactile feedback**

Active Touch

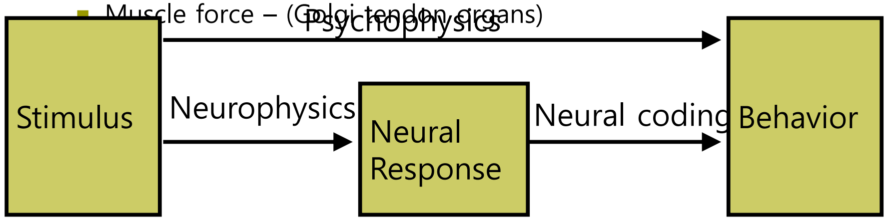
- Focus on the object
- Advantage
  - more realistic because the user can manipulate
  - Gives users a feeling of control
  - Easier to build an object model in one’s head
  - Most real tasks are active
- Disadvantage
  - Difficult to track the hand in many degrees of freedom
  - Difficult to design a transparent interface for multiple fingers
  - Interface may not be strong enough to display the forces that the person wants
- Is active touch better? In 3D, yes
- How is this important to virtual environments?

Passive Touch

- Focus on the sensation experienced
- Advantage
  - Simpler haptic interface could be developed because the user doesn’t get to move
  - Only has to output force that it is capable of
  - Some haptic cues are naturally passive, such as wind
- Disadvantage
  - Passive cues are difficult to create for most things you would want to simulate
  - Loss of control
  - Doesn’t happen often in real life

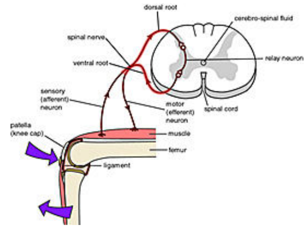
Neural Pathways in Haptic Perception

- Somatosensory Modalities
  - Touch – Spatial form, Texture, Movement, Flutter, Vibration
  - Pain – Pricking Pain, Burning Pain
  - Temperature – Cold, Warm
  - Stereognosis – (Proprioceptors)
  - Body position and movement – (Joint afferents, muscle spindles)
  - Muscle force – (Golgi tendon organs)



Neural Pathways in Haptic Perception

- Afferent nerves (sensory or receptor neurons)
  - Carry nerve impulses from receptors or sense organs into the central nervous system
- Efferent nerves (motor or effector neurons)
  - Carry nerve impulses away from the central nervous system to effectors such as muscles or glands (and also the ciliated cells of the inner ear)
- An **A**fferent connection **A**rrives and an **E**fferent connection **E**xits

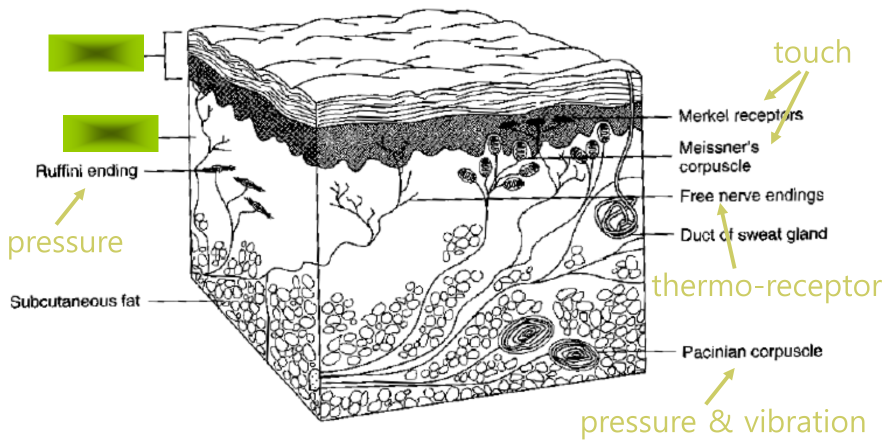


Skin

- Heaviest organ
- Prevents body fluids from escaping
- Provides information about stimuli

- Hairy skin vs. Glabrous skin
- Epidermis & Dermis

Glabrous Skin



Classification of Sensory Receptors

Receptor			Type	Characteristics
Mechano-receptor	Tactile	Touch	Merkel's disk	expended tip
			Meissner's corpuscle	encapsulated ending
			Krause's end bulb	
			Golgi-Mazzoni corpuscle	
			Hair follicle receptor	
		Pressure	Ruffini's corpuscle	
			Pacinian corpuscle	
		Fultter	Meissner's corpuscle	
		Vibration	Pacinian corpuscle	
	Position & Kinesthetic		Muscle spindle	
			Golgi tendon organ	
Thermo-receptor			Free nerve ending	uncapsulated ending
Nociceptor			Free nerve ending	uncapsulated ending

From the Skin to the Brain

- Nerve fibers
  - Receptors -> dorsal root -> spinal cord -> thalamus
- Two pathways in spine
  - Lemniscal: proprioception & touch
  - Spinothalamic: temperature & pain
- Psychophysical channels & Neural channels
  - Psychophysical channels
    - Difficult to separate channels topographically
    - Receptors are sensitive to different frequencies of vibration
    - Isolate receptors by cooling & masking
    - 4 channels in glabrous skin & 3 channels in hairy skin
  - Neural channels
    - Mirconeurography: recording electrode inserted in skin & records from a single nerve fiber

Fingertip

- Spatial resolution of about 2.5 mm
  - Multiple forces closer are sensed as one
- Sensory frequency of about 500 Hz
  - Beyond the bandwidth, not discriminate two consecutive force input signals
- Finger can comfortably apply forces
  - Maximum bandwidth at 5-10 Hz

Kinesthetic

- Kinesthesia
  - Perception of limb movement & position, Force
- Some cutaneous information is used, especially in hairy skin
- Mechanoreceptors in muscles (Muscle Mechanoreceptors)
  - Primary and secondary spindle receptors
  - Located in muscle spindles
  - Lie parallel to extrafusal muscle fibers
  - Bias: firing rates change for muscle length
  - Gain: sensitivity to changes in muscle length
  - Density not necessarily correlated with kinesthetic ability
- Golgi tendon organ

Force

- Resolution 0.06 N
- Grasping force: 400 N

What is Haptic Interfaces?

- The interfaces, to the user via the sense of touch by applying forces, vibrations, and/or motions to the user.
- Some low-end haptic devices are common in the form of game controllers.

Rumble Pak
Nintendo64 controller

DualShock
SONY PlayStation controller

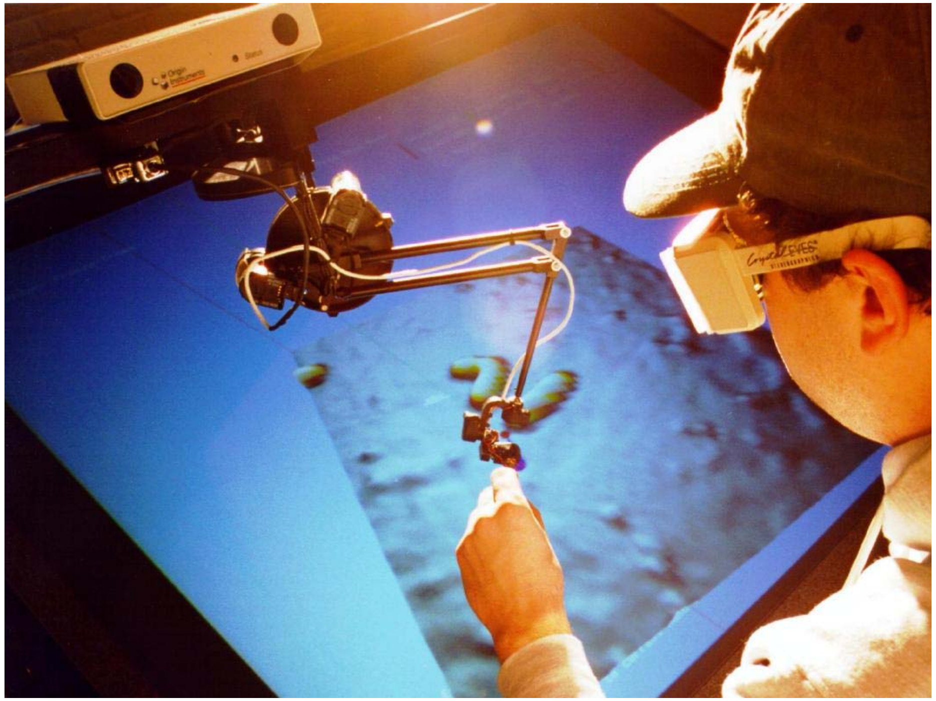
Simple rumble force-feedback
Nintendo Wiimote

Haptic Interfaces

- Grounded haptic interfaces
  - Pen-based force display
  - Hand-based force display
  - Stringed devices
  - Arm-based devices
  - Body-based devices
  - Platform devices
  - others
- Ungrounded haptic interfaces
- Tactile interfaces
  - Surface texture and geometry
  - Surface slip
  - Surface temperature

Grounded Haptic Interfaces

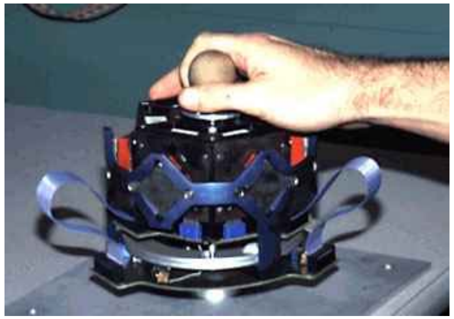
- Very similar to robots
- Need Kinematics
  - **Forward Kinematics:** based on joint angles ($\theta 1$, $\theta 2$) & lengths (l1, l2), calculate end-effectors position (x, y)
    - Absolute Forward Kinematics: sometimes done this way with haptic devices
    - Relative Forward Kinematics: usually done this way with robots, sometimes with haptic devices
  - **Inverse Kinematics:** using the end-effectors position, calculate the joint angles
- Sometimes need Dynamics



Pen-based Force Display

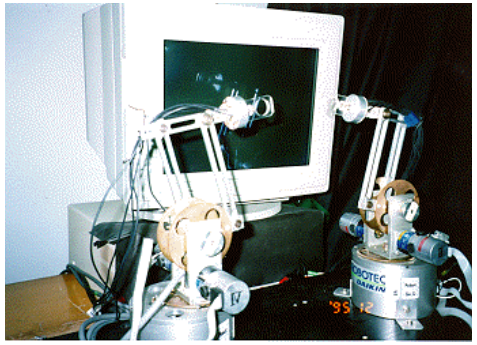
SensAble Tech. Phantom

Hand-based Force Devices



Magnetic Levitation Haptic Interface, Robotics Institute, CMU
Magic Wrist & UBC Wrist, 6-DOF, 20N, 4.5 mm motion range, less than 5 μm

Hand-based Force Devices

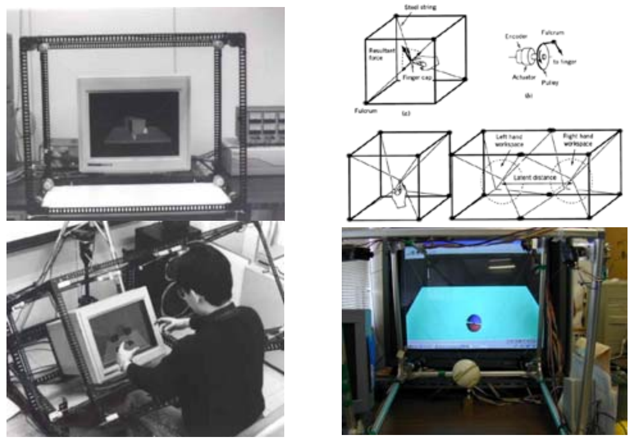


Yoshikawa's touch & force display system (Kyoto Univ.)

Hand-based Force Devices

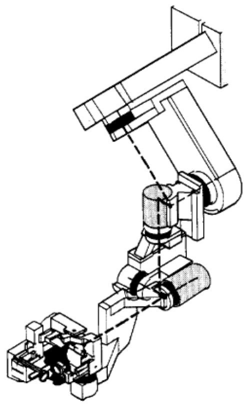
Immersion Corp., Laparoscopic Surgical Workstation

Stringed Devices



Space Interface Device for Artificial Reality (**SPIDAR**) can measure end-point in 3D space & display reflect force.

Arm-based Devices



Sarcos' Dexterous Arm, includes a human-sized slave that is commanded by a master system.

Body-based Devices

Sarcos Inc. Uniport, Biport, Treadport, Onmiport
Displays unilateral constraints, inertial forces, and slope

Sarcos Treadport

Exoskeleton (Body-based)

The BLEEX project, UC Berkeley, a self-powered exoskeleton, provides a versatile transport platform

Exoskeleton (Body-based)

Immersion Corp, Haptic workstation, two handed CyberForce, HMD or CAVE, electrically adjustable seat

Exoskeleton (Body-based)

Pneumatic Haptic Interface (Southern Methodist Univ.)

Ungrounded Haptic Interfaces

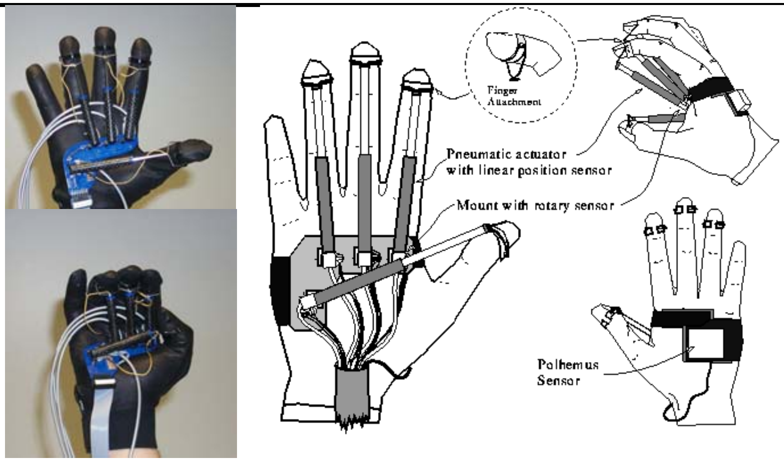
- Often simpler than grounded haptic interface (fewer degrees of freedom)
- If there are multiple DOFs, then use same kinematic equations
- Considering only force feedback (there are many other ungrounded tactile displays)

Cybergrasp

Immersion's Cyberglove

Immersion's Cybergrasp

Rutger Master II



RM-II reads hand gestures (hand-master) and displays forces (haptic-display) to four finger in real time.

Tactile Interfaces

- Simpler, lighter, more compact
- Can stand along or be integrated with force feedback systems
- Some local kinesthesia, but mostly cutaneous
- Tactile displays:
  - Surface texture and geometry
  - Surface slip
  - Surface temperature

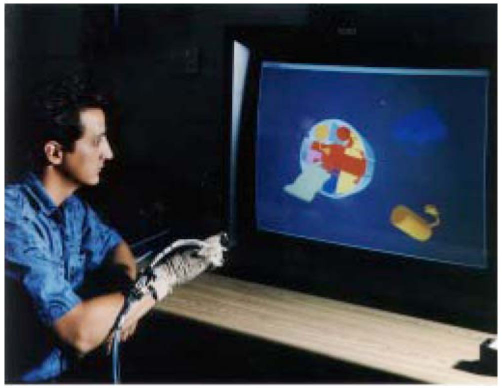
Surface Texture & Geometry Display

- Pneumatic stimulation
  - Uses compressed air to transfer energy from the power source to haptic interface
  - Simplicity, cleanliness, lower cost
  - Air jets, air rings, or air bellows (pockets)
- Vibrotactile stimulation
  - For lower frequencies and spatially resolved receptors, array type displays are necessary
  - Several different types of actuators
  - CyberTouch
- Electrotactile stimulation (electrocutaneous)
  - Uses very small currents passing through electrodes on the skin
- Functional neuromuscular stimulation

CyberTouch

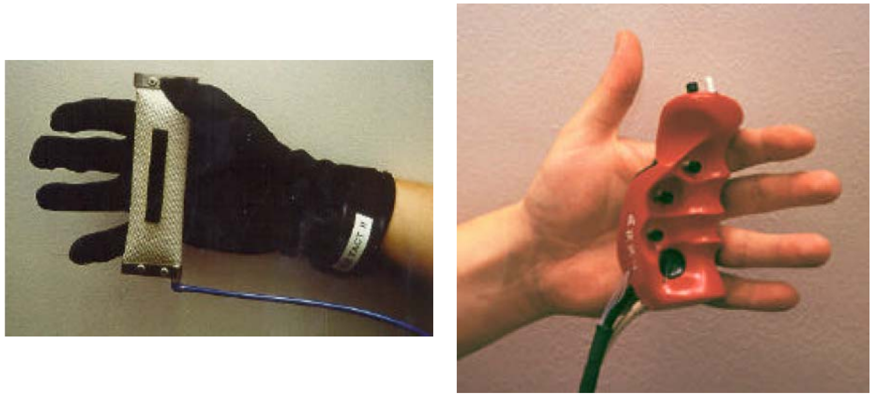
Immersion's CyberTouch (based on Cyberglove) provides complex tactile feedback patterns using 6 vibro-tactile stimulators (each finger and palm). Vibration frequency is up to 125 Hz.

Sandia's Tactile Display



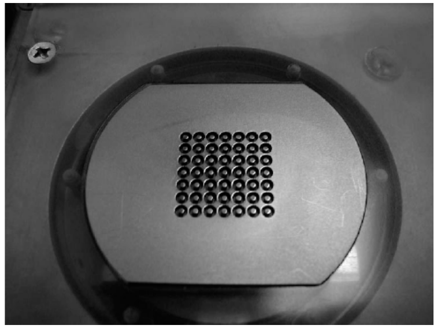
Sandia National Laboratory, Cyberglove & 6 vibrotactile feedback per fingertip, used for virtual reality

Teletact I, II, Commander



University of Salford, Tactile feedback display

Electrotactile Display

Kaczmark, Electrode array scanned by the fingertips of participants

Surface Slip Display

Johns Hopkins Univ. Haptic Exploration Lab, Tactile Haptic Slip display

- Together with force feedback, required to model grasping
- Sensory substitution not adequate - Don't want to require conscious attention
- Humans adapt to electrical stimulation, so need mechanical stimulation
- Slip actuator – rotating cylinder with controlled motion
- Simulate 2DOF sensation of the fingertip sliding across it

Temperature Display

Hokkaido University

- Objects and materials can be identified by their "thermal signature"
- Thus, some materials can be identified through static touch alone
- Peltier pump – thermoelectric heat pumps are solid-state semiconductors sandwiched between ceramic electrical insulators & easily meet the human thermal comfort zone of 13 to 46 Celsius.

Haptic Rendering

- Generate the responsive force
- Challenges:
  - Fast update (1 kHz or higher) to feel "stiff" objects, maintain a stable system, less than 10,000-polygon world model
  - Realistic haptic simulation, such as surface properties (friction, stiffness, texture), dynamic object without force discontinuity
  - Sharing force interaction over the network
- Collision detection
- Force-reflecting deformable objects
- Force model
- Force control

Collision Detection

- Collision detection between user and virtual objects:
  - Read the position of the user from the haptic display
  - See if there is a collision with objects in the virtual environment
  - If there is, calculate force
  - Send corresponding torque commands to motors, and change the virtual environment state
- Automatic detection of the imminent interaction between two objects
- Approximate collision detection using bounding boxes
- Exact collision detection can be expensive in computation
- Grasping collision detection done using vertices and lines

H-Collide library

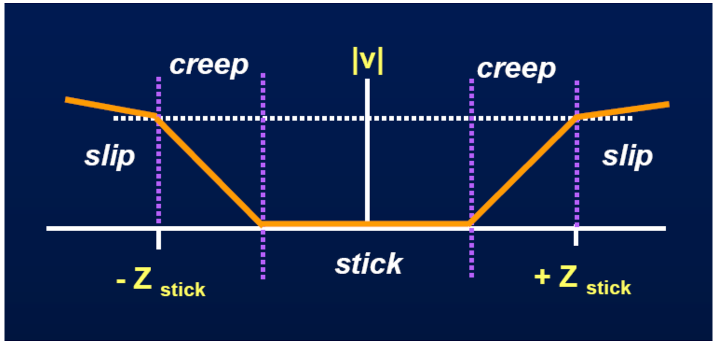
- Gregory, 1999 (Bounding box + spatial decomposition)
- Collision detection between a haptic probe and environment
- Need 1000Hz updates
- Hierarchical scene representation
- Uses frame-to-frame coherence

Force Model for geometric model

- Penalty-based method
  - Penetration depth
  - Many limitation
- Constraint-based method
  - Proxy contact point
  - Constrained by the surface
  - Limitations: Force discontinuity, hard to handle complex models

Friction Model

- Surface physics (Hayward & Armstrong 2000)
  - Stick: static friction
  - Creep: pre-sliding
  - Slip: sliding



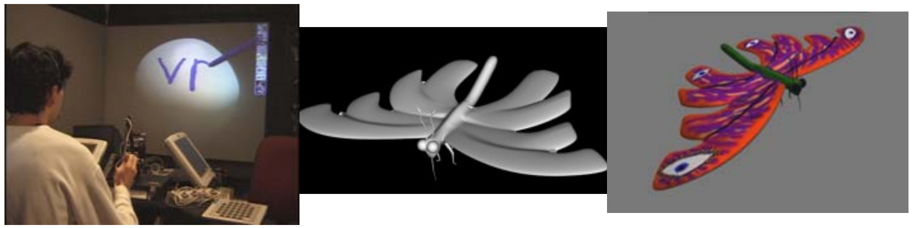
Force Control

- Damping for Walls
  - A pure spring force for a wall may seem to "active"
  - Add a dissipative term where b is the damping coefficient
  - Only damps when going into the wall
- Frictional damping
  - Friction would help, but it is difficult to implement
  - Add damping to motion parallel to surface
- Force shading
  - Analogous to Phong shading for computer graphics
  - Controlled variation in the direction of force vectors creates the illusion of non-flat shape on a nominally flat surface
- Virtual coupling
  - Decouples the haptic display control problem from the design of VE

Haptics Applications

- Entertainment
- Education and training
- Scientific visualization
- Surgical simulation
- Nanomanipulation
- Tele-operation Robot-assisted surgery
- Cooperative Manipulation

inTouch

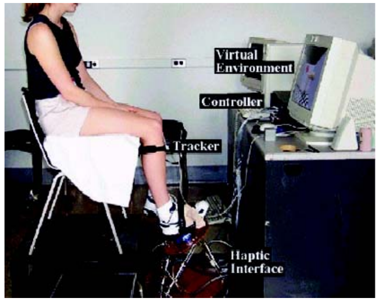


UNC, Interactive multiresolution modeling and 3D painting with a Haptic Interface provides direct sculpting model & painting on the model surface.

Cranial Implants

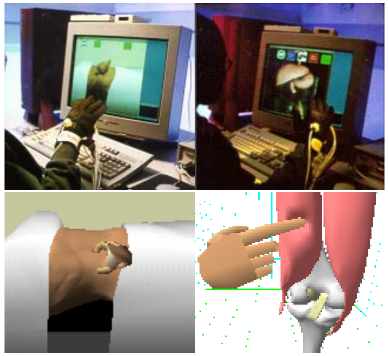
EVL, Medical sculptors and neurosurgeons create virtual 3D cranial models, based on patient CT data.

The Rutgers Ankle



Rutgers, high-technology rehabilitation interface, foot interface

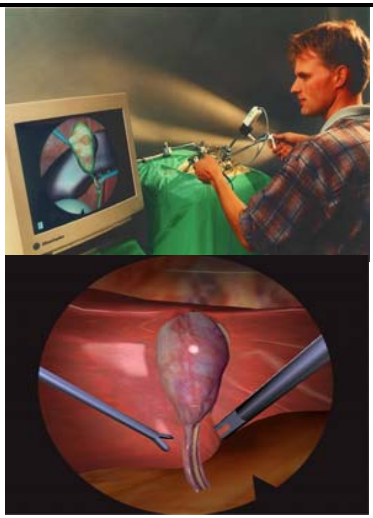
Medical Training for Tumor Detection



KAIST

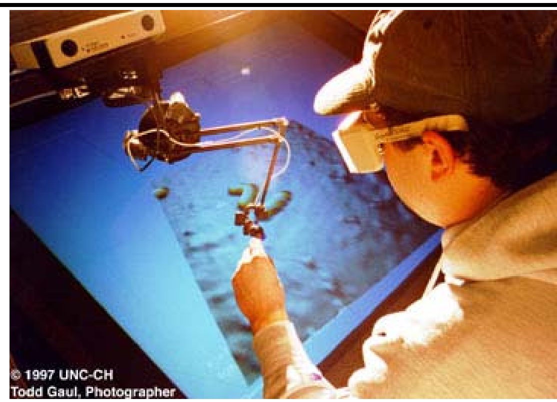
- Training simulation for **palpation** of subsurface tumors/cysts.
- People can perceive objects under skin by simply touching it.
- When direct touch liver on can identify regions of tissue that have different hardness.

Endoscopic Surgery



- Training for **Minimally Invasive Surgery (MIS),** a new kind of surgery which gets more and more common nowadays.
- A surgical operation is performed by the help of a small endoscopic camera & several long, thin, rigid instruments, through natural body openings or small artificial incisions.
- Endoscopic procedures in the human abdomen are called **laparoscopy**.

NanoManipulator



UNC, advanced visualization and control for nanomanopulation, using 3D graphics, force-feedback technology, and sub-nanometer manipulation devices, such as the Atomic Force Microscope

Robot-Assisted Surgery

Intuitive Surgical Inc. da Vinci Surgical System, consists of a surgeon console, patient-side cart, instruments and 3D endoscope and image processing equipment.

Reference

- http://www.me.jhu.edu/~allisono/courses/530.651/
- http://robot.kaist.ac.kr/~kyungku/haptics/haptics.htm
- http://touchlab.mit.edu/
- http://www.caip.rutgers.edu/vrlab/
- http://iregt1.iai.fzk.de/TRAINER/mic_def1.html
- http://www.laparoscopy.com/pictures.html
- http://cs.millersville.edu/~webster/MMVR2003lapcholey.pdf
- http://bleex.me.berkeley.edu/bleex.htm
- http://tech-www.informatik.uni-hamburg.de/lehre/ss2004/projekte/advVisConNan/
- http://sklab-www.pi.titech.ac.jp/~seahak/vr.html
- http://www.cs.utah.edu/research/areas/ve/Locomotion.html
- http://www-list.cea.fr/fr/publications/docs/si/isr_2004_khoudja.pdf
- http://www.hitl.washington.edu/scivw/scivw-ftp/publications/IDA-pdf/HAPTIC1.PDF
- http://www.rle.mit.edu/media/pr149/20.pdf