Haptic Interfaces

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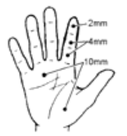
Structure of Presentation

Basic Definitions

- **Haptic**
  - Physical contact or touch
  - Interaction with both tactile and kinesthetic feedback
- **Kinesthesia** (Proprioception / force feedback /force display)
  - Perception of movement or strain from within the muscles, tendons and joints of the body
  - Example: size, shape, weight, position in space/rotation
- **Taction**
  - Sense of touch that comes from the sensitive nerve sensors at the surface of the skin.
  - Example: texture, vibration, temperature, small-scale shape or pressure distribution, wetness and so on
- **Haptic interfaces**
  - Devices which enable person-machine communication through touch.

How do we sense touch?

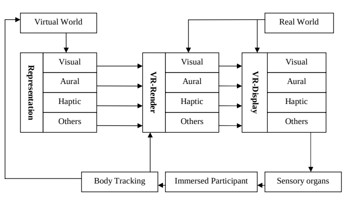
- **Tactile** feedback sensors are close to the skin. Sensitivity varies at different body part. They sense initial contact.
- **Kinesthetic/Force feedback** is sensed deeper in the body such as in muscle tendons, bones and joints.
- **Proprioceptive sensing** takes place in joints as well as the inner ear and central nervous system. Proprioceptive senses a person's position and movement.



Values for the two-point discrimination threshold at different regions of the hand

Motivation of Haptic Interfaces

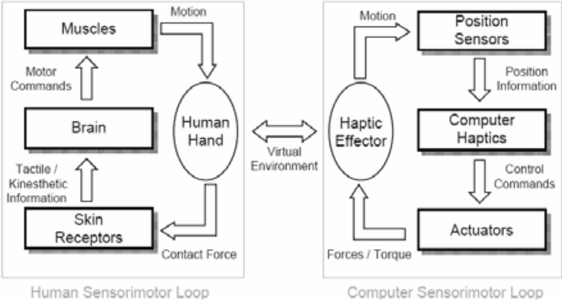
- Virtual Reality
  - Immersion, Interaction and Imagination
- Interaction methods
  - Visual Displays
  - Aural Displays
  - Haptic Displays
    - Forces
    - Tactile
    - Proprioception
    - Bi-direction



Motivation of Haptic Interfaces

- Supply huge amount of information
- Enable the active interaction with an environment
- Increases sense of presence in a VE application
- Increases human performance
- Fun!

Basic Principles of Haptic Interfaces



Basic Components for Haptic Interfaces

- **Sensors and Actuators**
  - Signal measurement
  - Force feedback
- **Electronic components** to control sensors and actuators
- **Software equations and algorithms** to create the real world
  - Mathematical model of the haptic feedback
  - Synchronization of haptic feedback and visual feedback

History of Haptic Interfaces

History of Haptic Systems Development

- 1964: First Exoskeleton device
- 1967: GROPE (University of North Carolina) – 1990 : GROPE III
- 1976: Tele-Robotics, Teleoperation (for remote manipulation of toxic or radioactive materials)
- 1994: Appearance of commercial haptic devices (Immersion, SensAble)
- +1995: Many research activities in the area haptic device and application development
- +2000: Many devices available (research and commercial) for specialized applications

History of Haptic Interfaces

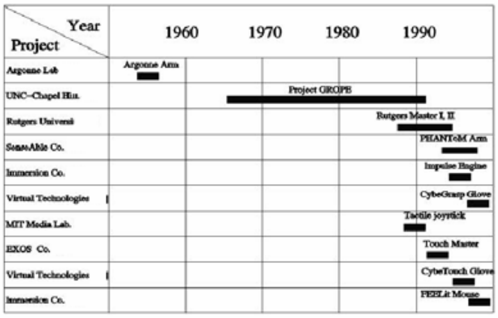


Figure 1: Abbreviated history of virtual tactile/force feedback in the USA. (adapted from [Burdea, 1996]). © John Wiley & Sons. Reprinted by permission.

Problems in Haptic Interfaces for Fidelity

- Human sense organs
  - are extremely sensitive
  - cover the whole body
  - can sense different properties of the environment
- Requires
  - Very high update rate (with a maximum over 1kHz)
  - Huge number of individual stimuli, that vary in properties of effect
    (a tactile display needs more than 1000 stimulator elements for the hand)
  - Usually of great size
  - High precision sensors and trackers
  - Powerful computational devices
  - Extremely expensive

What is enough for fidelity

"As long as certain minimum levels of force and stiffness are met, significant variations in the fidelity of the haptic simulations appear to have little effect on the subjects' ability to identify and discriminate between simulated objects."

(G. Upperman and M. O'Malley. "A Study of Performance in Haptic Environments: How much fidelity is enough?" July 2003).

- Depends on the application.
- Adaptation of the user
- Combination with other interfaces(e.g. visual) to create adequate feel of presence
- Being "suggestive" is what matters the most.

Properties of haptic displays

- Presentation properties
  - Kinesthetic cues
  - Tactile cues
  - Grounding
  - Number of display channels
  - Degrees of freedom
  - Form
  - Fidelity
  - Spatial resolution
  - Temporal resolution
  - Latency tolerance
  - Size
- Fidelity
  - Safety
  - Temperature device
  - Maximum force on finger: 40N
  - Inertia of the device

Properties of Haptic Displays

- Logistic Properties
  - User mobility
  - Interface with tracking methods
  - Environment requirements
  - Associability with other sense displays
  - Portability
  - Throughput
  - Encumbrance
  - Safety
  - Cost
- Safety
  - To user
    - Emergency stop button
    - "Drop-dead" switch
  - To device
    - malfunction

Classification of Haptic Interfaces

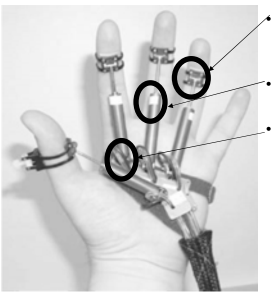
- Dimensional :
  - 2D
  - 3D
- Reference system:
  - Body based
  - Ground based
  - Un-based
- Feedback
  - Tactile
  - Kinesthetic
- Actuators
  - Electrostatic
  - Electromechanical (*Piezoelectric, Motor, SMA , micro-coil*)
  - Rheological Fluid
  - Air jet
  - Thermal
  - Hydraulic
  - Electrocutaneous
  - Pneumatic
  - Magnetic
  - Gyroscopic
  - Other

Body-based Haptic Interfaces

Rutgers Master II-ND
Rutgers University

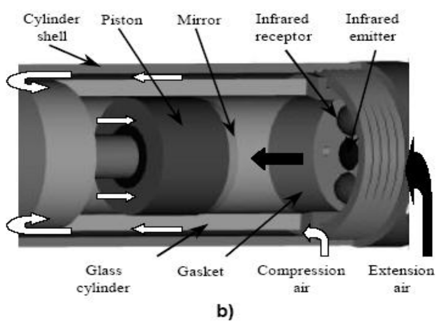
- Force-feedback glove
- Weight : 10g
- 5 degree of freedom
- 16N to each fingertips
- Pneumatic pistons

5 degree of freedom



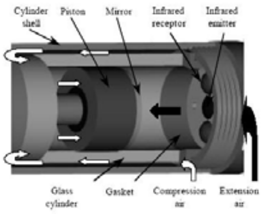
- The fingertip attachment connects to the cylinder shaft through a cylindrical joint (1 DOF)
- Each actuator is attached to the base through a spherical joint (2 DOF)
- Its cylinder shaft can both translate and rotate (2 DOF)

Pneumatic pistons



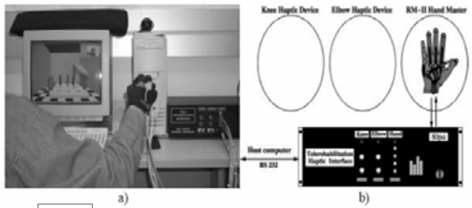
Pistons

- Pneumatic : air
- Hydraulic : fluid
- Rheological : fluid with electro-magnetical properties



Rutgers Master II-ND

- Low weight
- Portable device to simulate the grasping of virtual objects
- Designed for dexterous interaction with virtual environments.



a) b)
Telerehabilitation workstation: a) prototype developed at Rutgers;
b) The Rutgers Master II connected to the Multipurpose Haptic Control Interface

Haptic gloves

- Can not close the hands in Rutgers Master system

- In CyberGrap system
  - Can close the hands
  - Limited dynamic characteristics

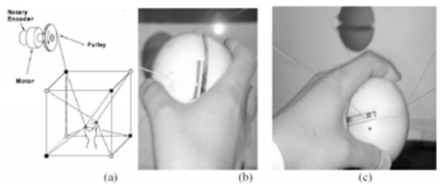
Body-based: Haptic Interfaces

- With the haptic data glove
  Pro
  - Manipulate CAD model
  - Feel the object
  - Useful for manipulating large objects without weight
  Contra
  - Restrict the workspace
  - Increase the cost and complexity of the system

- http://www.immersion.com/3d/products/cyber_force.php

Alternative solutions : Wire mechanisms

- The force is not generated by the actuators on the joints but by changing the length of the wires



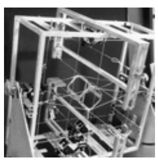
(a) (b) (c)

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.

Alternative solutions : Wire mechanisms

- No lever effect like the devices listed before
- Less limitations caused by the devices
- Allow a variety of devices, from large one to small one

- 6 DOF Tactile Stimulator Device



The Seven Degree of Freedom Hayward Haptic Hand-Controller - Mark I1

Alternative solutions: Wire mechanisms

- Due to low inertia of the cables
  - Eliminate the effect of gravity
  - Enhance the precision of the applied forces
  - Safety
- The cables do not block the user's view
  - Can place the device in front of the desk

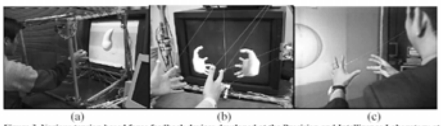


Figure 3. Various tension based force feedback devices developed at the Precision and Intelligence Laboratory at the Tokyo Institute of Technology. (a) Six degree force feedback device with 54x54x54 cm workspace. (b) Twenty four degree of freedom device with 100x50x50 cm workspace. (c) Five degree freedom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

Ground (desk)-based Haptic Interfaces

•Ground based HI are those that have a stable point in the environment (ground or desktop) as a force reference

FEELEX
University of Tsukuba

Exoskeleton device – Master arm

Southern Methodist University
Pneumatic Haptic Interface

Exoskeleton device

- Simulation of the driving experience for cockpit design optimization

PERCRO Laboratory

Ground-based Haptic Interfaces

- **Highlighted Features:**
  - Six degree-of-freedom positional sensing
  - Portable
  - Automatic workspace calibration

PHANTOM® Desktop™

Price of the Phantom®

Phantom Premium 3.0

workspace	200	liters
pos. resolution	0.02	mm
stiffness	1.0	N/mm
max. force	20	N
nom. force	3	N
tip inertia	0.15	kg
price	61,000.-	€

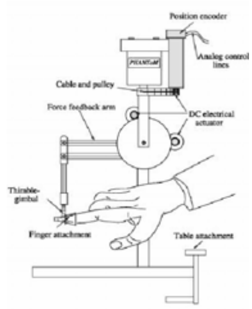
http://www.kaemart.it/touch-and-design/

PHANToM Haptic Interfaces

- Main characteristics:
  - 6 DOF
  - 3 Actuators
  - Various Models in different dimensions
- Structure
- Inconvenience of the standard model:
  - Exert force only on one finger
  - No couple
- PHANToM "Premium 3.0" decreases the couple problem

PHANToM

- Very suitable for some specific interactions
- Mediator: point, pen, virtual finger
- For more skilful handling of object virtual, it is necessary to couple at least 2 PHANToM arms (for the inch and for the index), or to use a haptic glove



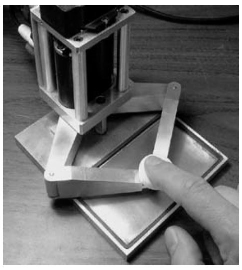
Hybrid Kinematics

Mechanical	Translation
Workspace	17 x 22 x 33 cm
Tip Inertia	125 g
Backdrive Friction	40 mN
Max Force/ Torque	2.5 N over 60 sec. 0.6 N continuous
Position Resolution	2 µm
Force Resolution	1.5 mN
Stiffness	2 N/mm

Prof. Vincent Hayward of McGill University

http://www.mpb-technologies.ca/mpbt/haptics/hand_controllers/freedom/description.html

Ground-based Haptic Interfaces



- 2DOF Haptic Devices
- Provide the feeling of real touch
- High fidelity(400Hz)
- Rehabilitation of visually handicapped persons, micro-gravity experiments

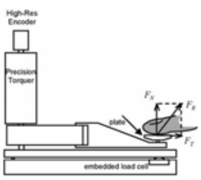
Pantograph
McGill University

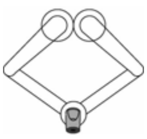
Hayward, Vincent

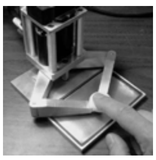
Centre for Intelligent Machines

Parallel Mechanical Structure: Pantograph

- This structure can also be used for smaller systems







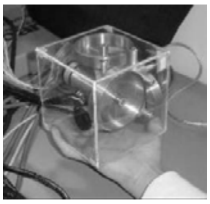
- http://www.cim.mcgill.ca/~haptic/devices/pantograph.html

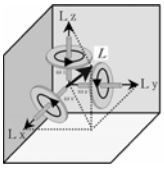
Ground-based Haptic Interfaces

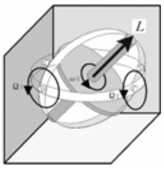
- 3 DOF
- Force-controlled
- Provides the user with a crisp haptic sensation and the power to closely simulate the weight and force found in a wide variety of human tasks

HapticMASTER
© FCS Control Systems

Un-based Haptic Interfaces: Gyro Moment Type







http://www.aist.go.jp/aist_j/new_research/nr20040521/nr20040521.html

Haptic Interface: Parallel mechanism

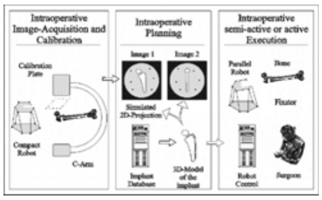
- Interest of this type of structure
  - High stiffness
  - Low inertia
  - Compact
- Other properties can be achieved through suitable mechanical design and proper control scheme

Parallel Mechanical Structure: Gough-Stewart Platform

- 6-DOF parallel mechanism with six identical kinematic chains, composed of a universal joint, a prismatic actuator, and a spherical joint.

Parallel Mechanical Structure: Gough-Stewart Platform

- Medical domain: projet Européen CRIGOS
  Compact Robot for Image Guided Orthopedic Surgery
- http://www.ame.hia.rwth-aachen.de/research/cht/indexE.html



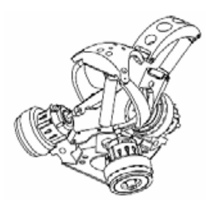
Parallel Mechanical Structure: Gough-Stewart Platform

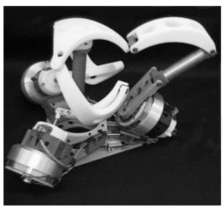
- Medical domain : Rehabilitation of ankles
(Rutgers University)

http://www.caip.rutgers.edu/vrlab/projects/ankle/system.html

Parallel Mechanical Structure: Spherical Geometry

- Laval University
  - http://wwwrobot.gmc.ulaval.ca/recherche/theme03_a.html





Parallel Mechanical Structure: Spherical Geometry

- Project **SHaDe** : Spherical Haptic Device
- The mechanism presents the particularity of having only three degrees of freedom, leading to a simpler design and a more ergonomic utilization.
- The use of the spherical geometry brings many advantages, in particular:
  - a pure rotation around a point located inside the user's hand (no translations at this point)
  - a large workspace
  - a comfortable usage and precise manipulation with arm resting.

Virtuose™ 6D Desktop

- Workspace:
  - Translation : Sphere 120 mm in diameter
  - Rotation : 35° in the3 directions at the center
- Maximum Force : 7 to 10 N
- Continuous Force : 1.4 to 3 N
- Maximum Torque: 0.3 to 0.5 Nm
- Continuous Torque: 0.06 to 0.14 Nm
- Translation Stiffness: 2500 N/m
- Rotation Stiffness: 2 N.m/rad

http://www.haption.com/index.php?lang=eng&p=2

Parallel Mechanical Structure: DELTA

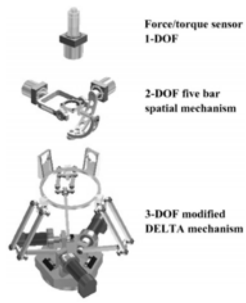
- Force dimension




http://www.forcedimension.com/fd/avs/home/products/6-dof_delta/

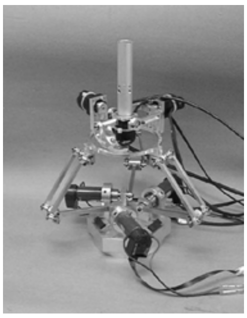
Parallel Mechanical Structure: Spherical Geometry

- Tohoku University
  - Spherical system used as complementary subsystem in a positioning system DELTA
- Advantages of this structure
  - Large work space
  - Low inertia
  - Compactness



Parallel Mechanical Structure: Spherical Geometry

- This haptic interface was in particular used for the control of the system robotized space ETS-VII
- http://www.space.mech.tohoku.ac.jp/research/haptic/haptic-e.html



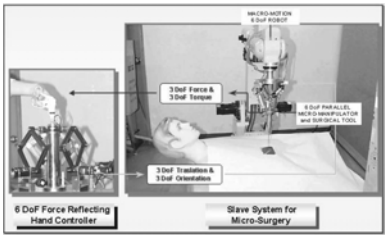
Parallel Mechanical Structure: Pantograph

- Haptic master
- Support:
  - Three sets of pantographs.

http://intron.kz.tsukuba.ac.jp/vrlab_web/hapticmaster/hapticmaster_e.html

Other parallel mechanical structures

- Robotics Lab (KAIST)
  - 3 kinematic legs composed of 5 links with 2 motors



Other parallel mechanical structure : 6 DOF Parallel Haptic Device

Haptic device

1. Singularity-free, redundant actuation architecture
2. High functional design ranging from one to six DOF
3. Unique forward / inverse solution

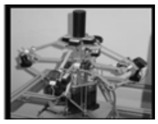


Fig. 6. Singular Configurations


Fig. 3 Photograph of Bevel Gear Set

http://robotics.hanyang.ac.kr/research.html

Comparison

Technology	Description	Advantage	Disadvantage/
Electrical Mechanisms 	Electrical Mechanical Motors	✓ easy to implement ✓tool to touch objects Provides	✓Low band-width ✓Unsuitable
Electrostatic 	Composed of a polymeric elastic dielectric that is sandwiched between compliant electrodes	✓Flexible ✓a high energy density ✓Materials are low cost ✓Suitable for large skin area ✓telemanipulation	✓Safety problem ✓Lack of related knowledge

Comparison

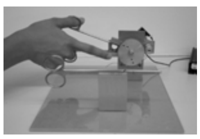
Pneumatics 	A gas is pressurized by a power plant controlled by servo-values, and delivered to rotary or linear actuators through pressurized fluid (air) lines	✓Good static force capability ✓Lighter than hydraulics ✓Easier than hydraulics	✓Relative low bandwidth ✓Low actuation stiffness ✓Low power capacity
Rheological / Hydraulics Fluid 	By the change from a state of liquid to a state of solid or near-solid	✓Low energy consumption ✓Simple mechanical design ✓Active touch. ✓Small size ✓Be able to connect with other technologies	✓Problems—related to other area problems ✓Over heating ✓Safety problem because of high voltage

Application

- Force-reflecting input devices for use with graphical user interfaces
- Games
- Multi-Media Publishing
- Arts and Creation
- Editing sounds and images
- Vehicle operation and control rooms
- Engineering & Manufacturing
- Telerobotics and teleportation
- Education and training
- Scientific Study of Touch
- Medical Use

Where to use?

- Several examples
  - *Proceedings of the 2003 Conference on New Interfaces for Musical Expression (NIME-03), Montreal, Canada*
  - New CAD maxim: Two hands are better than one
  - virtual reality training
  - main area



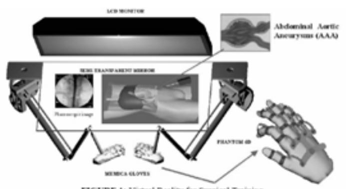


FIGURE 1: Virtual Reality for Surgical Training.

Conclusion

- Trade-off: due to different areas
- Human sensory-motor skills
- Improve communication between humans and machines.
- Linking device performance to human performance
- The more systematic study of the connection between devices and specific tasks and applications

References

- *Haptic Interfaces and Devices* Vincent Haward, Oliver R Astley, Manuel Cruz-Hernandez, Danny Grant, Gabriel Robles-De-La-Torre
- *The Rutgers Master II-ND Force Feedback Glove1* Mourad Bouzit, George Popescu, Grigore Burdea and Rares Boian Center for Advanced Information Processing
- *HW AND SW TECHNOLOGY AND COGNITIVE ERGONOMICS UPDATE* By Monica Bordegoni (Politecnico di Milano)
- *Master arms Mechanical Engineering Department*, SMU
- *Project FEELEX: Adding Haptic Surface to Graphics*, Proceeding of SIGGRAPH2001(2001) Hiroo Iwata, Hiroaki Yano, Fumitaka Nakaizumi, Ryo Kawamura

- Merci!
- Questions?