Haptic interfaces

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1. Definition, scope and history

- **Haptic**: From greek *haptikos/sense of touch* and *haptethai/to touch*
  - Include both the synthesis of *touch* and *force/torque* stimuli

- **tactile sensors**: surface texture, vibration, pressure, temperature, ...
  - Highest density on hand palm and finger tips
  - Alternate tactile regions used as sensory substitution: tongue [I 2010]

- **Kinesthetic sensors**: muscles, joints, tendons, ...
  - To determine the body posture and the nature of body interaction with the environment: exerted force/torque on contact locations
1. Definition, scope and history (2)

- A haptic device IS...
  ... a force reflecting device which allows a user to touch, feel, manipulate, create, and/or alter simulated objects in a virtual environment

  ... NOT a device which tracks movement, such as head-trackers, eye-trackers, magnetic or optical motion trackers, without providing force-reflecting feedback to the user.
1. Definition, scope and history (3)

- History
  - force feedback joystick for aircraft simulators [W]
  - in the 50s, the nuclear industry needed mechanical systems for the remote manipulation of nuclear components (Argonne USA, CEA Saclay FR).
    - Teleoperators = master / slave manipulator arm
    - The gesture performed by the user on the Master arm is reproduced on the slave arm and the force/torque reaction on the slave is felt by the user on the master arm at the level of the gripper.
    - Became electromechanical in the 60-70s.
  - Early 70s: sensor substitution/neural plasticity, Bach-y-Rita [W]
  - In the 90s minimally invasive medical training: laparoscopy
  - Games controllers: from arcade (70s) to home
Some examples of real-world haptic systems

Master-Slave system: the collision of the slave system on a solid box is reflected on the master articulated arm [video](http://www.youtube.com/watch?v=iIGy6K-vjpA)

Sensory substitution on high-density sensor region (tongue) [CBS: see with tongue with brainport] [video](http://www.youtube.com/watch?v=RaTzQVHi-C4) [video](https://www.youtube.com/watch?v=OKd56D2mvN0)
2. Haptic display characteristics [BKLP 2005]

- Haptic presentation capability
  - Tactile / kinesthetic / or both ?
  - If kinesthetic: how many points of force does it provide ?
  - What part of the body is it designed for (finger(s), wrist, feet,...)
  - How big/cumbersome ? What is the range of motion ?

- Spatial/temporal resolution
  - Spatial resolution must be much higher for finger tips vs forearm
  - Temporal resolution: 1000 Hz update rate is necessary for stability of the rendering of stiff contact (otherwise appear soft or unstable). Two distinct threads for simulation & rendering.

- Ergonomics
  - a critical requirement : Safety
  - a serious limitation : Comfort
3. Haptic display types [BKLP 2005]

Body-referenced haptic device [Utah hand]
Placed on the user body: exoskeleton with motors or cables. Need calibration to user skeleton.

Ground-referenced haptic device [Phantom]
(on desk, floor, wall, ceiling...)

Force-reflecting joystick, pen-based force feedback, stringed devices, motion platform, large articulated arm
3. Haptic display types (2)
Body-referenced haptic device:
more freedom of motion

Tradeoff due to weight

PERCRO (Pisa)

Rutgers Master II

Armeo® Power

Exoskeleton from Hocoma for rehabilitation
The concept of **haptic suit** is popular in science fiction (film «Ready Player One») but limited to vibrating units or muscular electrical stimulation (**teslasuit** below)

Electrical Muscle Stimulation replicates the small electrical stimulation produced by the brain and carried by the efferent neural signals.

Used in sport and rehabilitation ->

[电气肌肉刺激](https://en.wikipedia.org/wiki/Electrical_muscle_stimulation)
3. Haptic display types (3)

Ground-referenced haptic device: "desktop" systems

**Virtuose** from Haption (FR):
Cable system allowing human arm scale

**Da Vinci** (USA):
Master-Slave minimally invasive surgical system
(haptic visual substitution)

**Force Dimension** (CH):
High stiffness
Based on Delta Robot from EPFL
+ recent miniature system **Foldaway** from EPFL-RRL
3. Haptic display types (4)

Ground-referenced haptic device:
- Research project from UNC by Brooks team, started in 1967.
- **Goal**: help chemists to find more easily good docking position for new drugs (i.e. relative location of complex molecules at which some receptor can be exploited).
- **Results**: such task was achieved about twice as fast with haptic feedback compared to only stereo graphics display.
- Chemists have a new understanding of the receptor force field and the docking

GROPE III, 6 Degree of Freedom (DoF) Force & Torque haptic display [B 1990]
3. Haptic display types (5)


The 2 devices providing the force feedback

Laparoscopic surgical tools

The interaction must integrate a realtime deformation model of the organ to compute the correct reaction force and mesh deformation

https://www.youtube.com/watch?v=UNRIhgkfMcy
3. Haptic display types (6)

Ground-referenced haptic device exploiting a Stewart Platform are mostly used to stimulate the vestibular system sensitive to accelerations, for driving /flight simulators, arcade games and theme parks:

Stewart Platform = 6 DoFs but with limited range

Check also:
www.bluetiger.com
www.simbolrides.com

6 DoFs driving platform: KAIST (Korea)

Ferrari F1 simulator: https://www.youtube.com/watch?v=5T_tXG-89IU
3. Haptic display types (7) Research setup

Ground-referenced haptic device: Kuka robot used in MPI Tuebingen for studying human perception, cognition and action [Prof. Buelthoff]

The robot is ideal for producing acceleration stimulations and displacements over a large range

Toward RT aircraft Simulation with the MPI motion simulator, (MPI & Univ. Pisa), Niccolini, Pollini, Innocenti, & Giordano, Teufel, Buelthoff

http://www.youtube.com/watch?v=jrvnC6L9nPA&feature=related
3. Haptic display types (8)

Ground-referenced haptic device: Space Interface Device for Artificial Reality (SPIDAR) is a stringed system [Sato 1989]: a good compromise for large space interaction at low cost, lightness, and high safety.

\[
\begin{align*}
x &= \frac{(l_0^2 - l_1^2 - l_2^2 + l_3^2)}{8a} \\
y &= \frac{(l_0^2 - l_1^2 + l_2^2 - l_3^2)}{8a} \\
z &= \frac{(l_0^2 + l_1^2 - l_2^2 - l_3^2)}{8a}
\end{align*}
\]

LISA Anger & IBISC Evry [N 2009]
3. Haptic display types (9)

A bimanual SPIDAR system from Tokyo Institute of Technology, Yokohama [W 2004]

The user interacts by looking at a screen that displays virtual hands estimated from the location of the 8 finger caps.

An anatomic model of a 17 DoF hand with finger joint coupling is used to infer the virtual hand with an Inverse Kinematics algorithm.

http://www.youtube.com/watch?v=m-DS1U_INpQ
3. Haptic display types [BKLP 2005] (10)

Finger pulling device

Tactile device

CyberTouch TM: integrate small **vibrotactile** units on each finger of an Immersion CyberGlove. Each unit can be programmed to generate pulse or sustained vibrations.

CyberForce® is a force feedback armature that not only conveys 3D forces to the wrist and arm but also provides 6 DoF (degree of Freedom) wrist tracking:

- 3 DoF in translation
- + 3 DoF in orientation

Max: 60N

CyberGrasp TM: from Immersion

Each finger can be pulled from the back side of the hand to force it to open. It cannot force the hand to close.

Combination: Haptic Workstation

= 2 CyberForce & Cybergrap
4. Haptic design guidelines [BKLP 2005]

Ground-referenced
+ can produce high level of force if needed
+ don’t have to wear them
+ accurate trackers
- limited movement when using them ...
- ... or high cost (e.g. Kuka from MPI)
+ some compromise exist, e.g. SPIDAR

Body-referenced
+ more freedom of motion
+ more control for direct manipulation
- user has to bear the weight of device
- can be tedious to put on and calibrate

Tactile /electrical
+ smaller than force display
- difficult to get sensation correct
- limited to small skin area

Hybrid
+ combines force and tactile feedback
- more complex devices
5. Haptic interaction through virtual coupling

• Requested haptic control update rate: min 300 Hz up to 1 KHz – 2 KHz

• Otherwise instabilities or the haptic sensation is too soft.

• But 1 KHz /1ms is not sufficient for updating & displaying the whole state of the VR interaction
  • Difficult to prevent a visible interpenetration

• Solution: coordinate two systems [M 1996]:
  • haptic rendering updated at 1 KHz
  • simulation and graphical update at 20 Hz - 60 Hz
  • coordination through **Virtual Coupling** [LO 2006] with the concept of **proxy**, named **god object** in [Z 1995])
5. Haptic interaction through virtual coupling (2)

- Improving the **avatar** with the **proxy** \([Z\ 1995,\ TVR\ Vol3,\ LO\ 2006]\)
  - **Goal:** encapsulate the *history* of the interaction to prevent arbitrary discontinuity in the computation of the collision response (rigid objects)

The **avatar** and the **proxy** coincide when there is no collision

**collision response without proxy:**
- the avatar may sink into the object...

...and if the user pushes a bit deeper one gets closer to a different surface

The change of repulsion force can be large/not intuitive

The proxy preserves the coherence of the interaction
5. Haptic interaction through virtual coupling (3)

- Tracking the **proxy** across polygons [H2000]

  The proxy preserves the coherence of the interaction; however, some discontinuity is still possible.

- Typical complexity for N polygons [H2000]:
  - First intersection: \( \log(N) \) provided the meshes are organized with hierarchical bounding boxes or similar approach (cf. UNC GAMMA project)
  - Tracking the intersection is in \( O(1) \) because only neighbour polygons are explored.
implementation of the avatar-proxy concept
with Haptic Workstation = 2 CyberForce & Cybergrap

The proxy concept is extended to the full articulated hand [Ott et al 2008] (.avi)
5. Haptic interaction through virtual coupling (3)

• But the **proxy** induces a visual-proprioceptive discrepancy [B 2006]
  • **Translation:** what the user sees does not match exactly with the postural state elaborated by the body scheme.
  • **Example:** in case of a hand avatar: it is not displayed exactly where it should be in space. The user hand is **no more co-located** with its visual representation.

**Question:** is such visual-proprioceptive discrepancy more disturbing than seeing the correct location of the virtual hand sinking in a virtual obstacle?
5. Haptic interaction through virtual coupling (4)

- **E. Burns** et al study, at UNC [B 2006] showed that users are less sensitive to small posture mismatch than to visual sink-in, i.e. *vision* dominates *proprioception*.

- Additional study in [B 2007] regarding the *retraction* phase, when the user moves backward to prevent a collision. Compared 3 methods:
  - **rubber-band**: the proxy does not move until the avatar reaches it
    - *Velocity discrepancy*
  - **Incremental motion**: the proxy start moving backward with exactly the same quantity as the user
    - *Position discrepancy*
  - **Hybrid technique MACBETH**: the proxy makes a *scaled* movement allowing to progressively reach back the tracked user hand. The faster or slower scaling factors depend on the body-related direction.

<table>
<thead>
<tr>
<th>Real-Hand Motion Direction</th>
<th>Faster scale factor</th>
<th>Slower scale factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left</td>
<td>+0.44</td>
<td>-0.08</td>
</tr>
<tr>
<td>Right</td>
<td>+0.40</td>
<td>-0.06</td>
</tr>
<tr>
<td>Up</td>
<td>+0.51</td>
<td>-0.16</td>
</tr>
<tr>
<td>Down</td>
<td>+0.38</td>
<td>-0.27</td>
</tr>
<tr>
<td>Toward</td>
<td>+0.63</td>
<td>-0.46</td>
</tr>
<tr>
<td>Away</td>
<td>+0.69</td>
<td>0.00</td>
</tr>
</tbody>
</table>
5. From Haptic to pseudo-haptic feedback

- The **avatar-proxy** management and display is possible even without haptic device.

- **Pseudo-haptic**: Instead of synthesing a force it is possible to render the error between the **tracked user** and the **avatar-proxy** through an alternate modality (visual, audio, ...)

The error $e$ can be used to modulate the graphical display of the avatar-proxy (color, texture, special particle effects, etc...) and/or to produce a modulated sound.
On-going research

- Interaction with deformable tissues (e.g. Basdogan team)
  - Training minimally invasive surgery

[Software Development Kits]

- **Sensible** GHOST SDK / now OpenHaptics Toolkit
- **Force Dimension** Haptic SDK / **CHAI3D** open source lib
- **Haption** IPSI library for Catia TM or Virtools TM
- **Immersion** MOTIV TM SDK for tactile effects on Android mobile phones
- **ReachIn** & HAPTX Software products

- Physically-based Simulation: **Nvidia** PhysX(in Unity3D), **Bullet.org**
[References]


[BKLP 2005] 3D User Interfaces, D. Bowmann, E. Kruijff, J. LaViola, I. Poupyrev, Addison Wesley, 2005


[web References]

http://en.wikipedia.org/wiki/Haptic_technology
http://gamma.cs.unc.edu/research/collision/

Sensor substitution / Brainport: http://en.wikipedia.org/wiki/Paul_Bach-y-Rita

[I 2010] Blind soldier 'sees' with tongue device
http://www.youtube.com/watch?v=RaTzQVHi-C4

CBS: Blind Learn To See With Tongue
http://www.youtube.com/watch?v=OKd56D2mvN0

Hand Masters reference page:
http://lims.mech.northwestern.edu/projects/finger_exo/
http://www.youtube.com/watch?v=32f2UxKjydI

MPI Tuebingen: lab of Human Perception, Cognition and action
http://www.kyb.tuebingen.mpg.de/research/dep/bu.html
http://www.youtube.com/watch?v=jrvnC6L9nPA&feature=related

SPIDAR
http://www.youtube.com/watch?v=m-DS1U_INpQ
Master_Slave system:
http://www.youtube.com/watch?v=i1Gy6K-vjpA
Da Vinci demo and press article about issues with this type of interaction in surgery
http://www.youtube.com/watch?v=VJ_3GJNz4fg

Rensselaer Polytechnic bimanual surgery training
https://www.youtube.com/watch?v=UNRIhgkfMCY

Hocoma haptic rehabilitation
http://player.vimeo.com/video/26048381?title=0&byline=0&portrait=0&color=ff9933