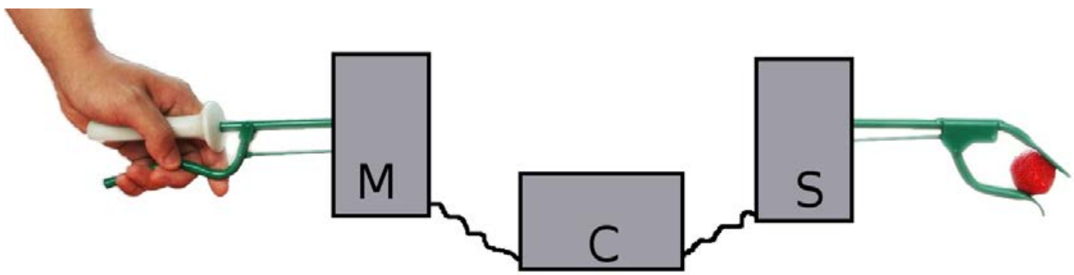
Haptic Applications (Part 1)

- Teleoperation & Haptics
- Exoskeletons & Biosignals

Feeling is believing…



Teachers

- Tricia Gibo & Jack Schorsch
- BioMechanical Engineering, Delft University of Technology

Personal Background

B.S., Mechanical Engineering (2007)

University of Southern California

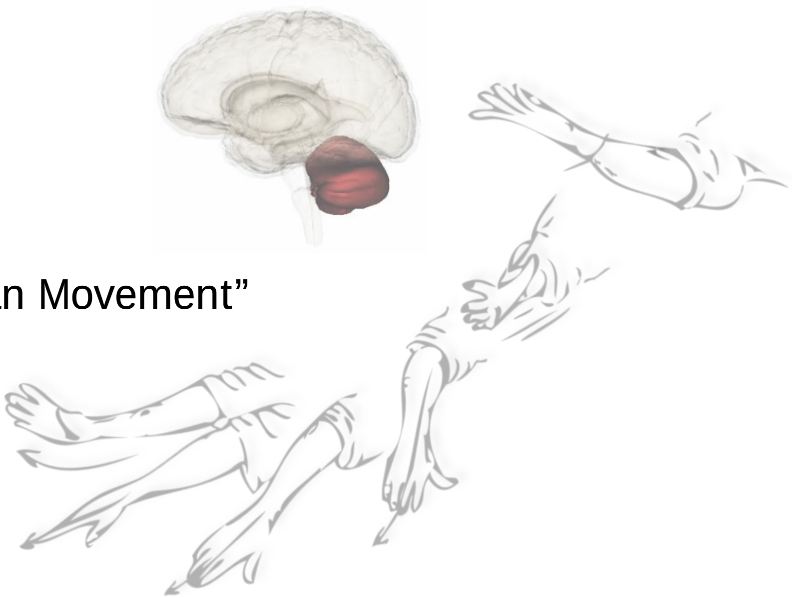
M.S., Mechanical Engineering (2009)

Johns Hopkins University

Ph.D., Mechanical Engineering (2013)

Johns Hopkins University

Stanford University (visiting student)



Thesis: “Control and Learning of Dynamics in Human Movement”

- Physical rehabilitation/assistance
- Surgical teleoperator performance

Lecture Outline

Haptic applications (Tricia)

- Short recap of previous classes
- History of haptics & some examples

- Break -

Biosignals, BMIs, and exoskeletons (Jack)

What To Take Away From This Lecture

1. **Reproduce:**
   - Characterize different types of haptic technologies/devices
   - Identify challenges of providing haptic feedback

2. **Apply:**
   - For a particular application / task, what kind of haptic feedback would be most beneficial?
   - For a particular type of haptic feedback, what kind of device would be most appropriate?

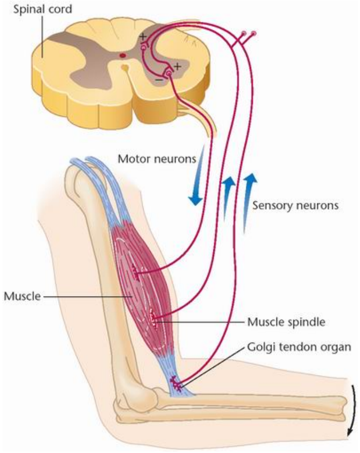
3. **Think critically about:**
   - How could lack of / errors / mismatches in haptic feedback affect perception and action?

Two Kinds of Haptic Perception

1. **Kinaesthetic / Proprioceptive:**

   force and displacement

   from tendon force, muscle stretch and stretch velocities

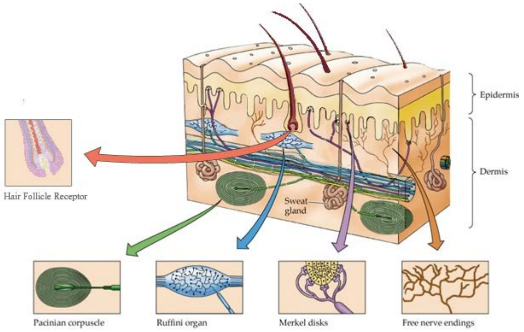


www.medicalook.com

2. **Tactile / Cutaneous:**

   mechanoreceptor: vibrations, pressure, shear stress
   thermoreceptor: temperature
   nociceptor: pain

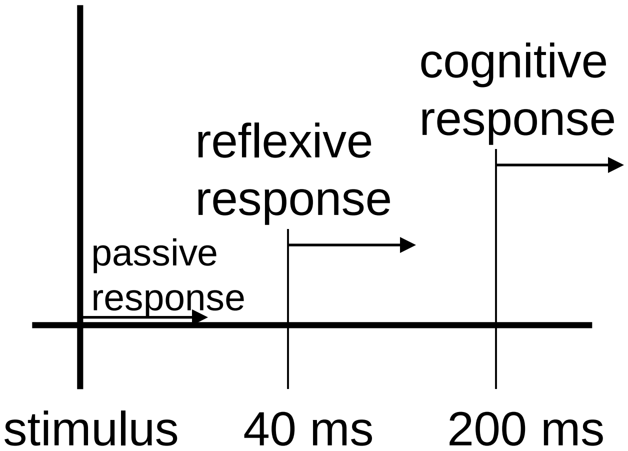
   from receptors in the skin

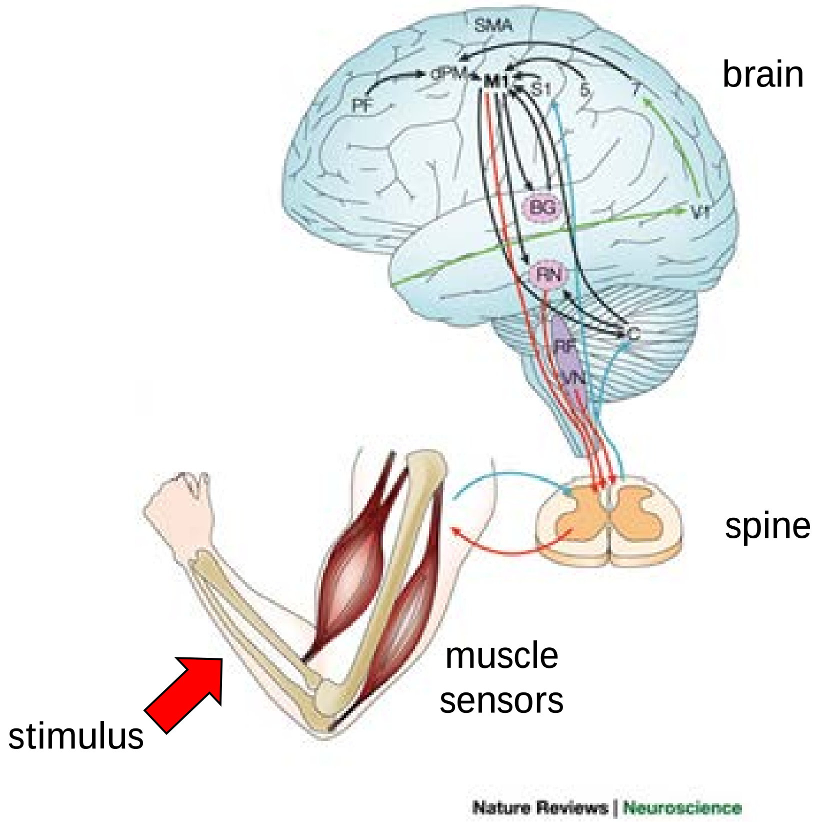


www.bdml.stanford.edu

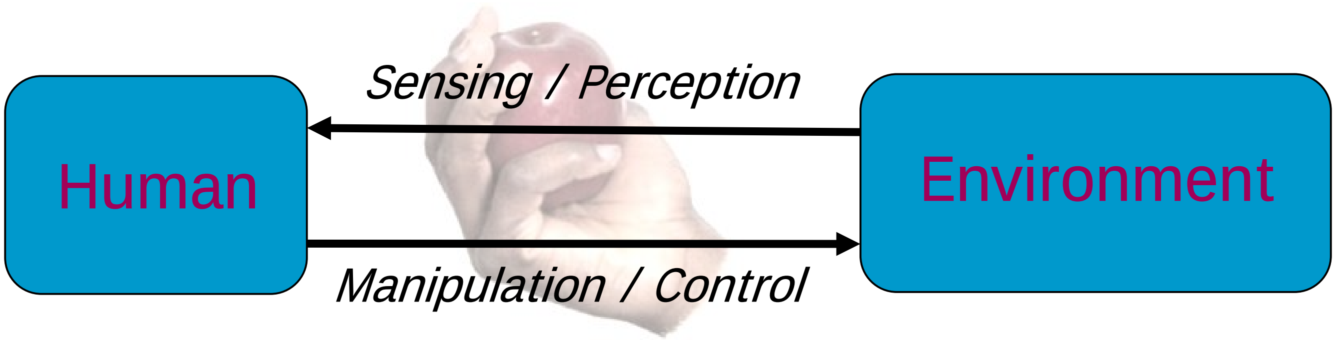
From Haptic Perception to Action

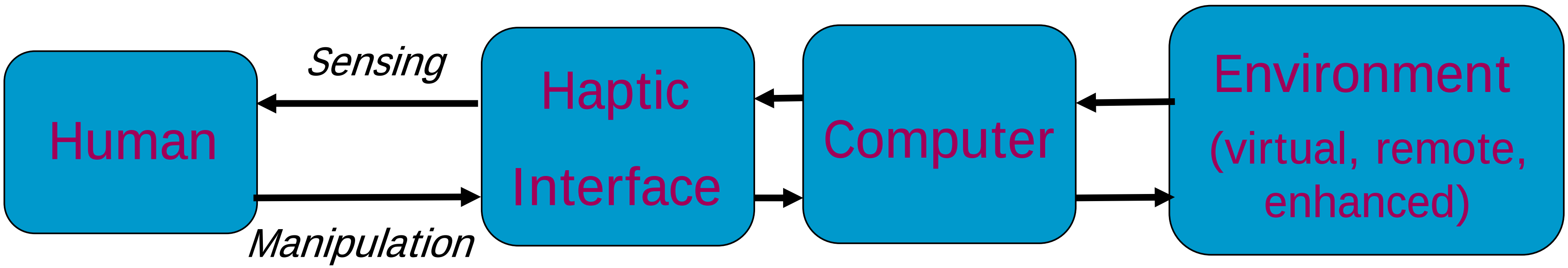
How do you respond to a force?

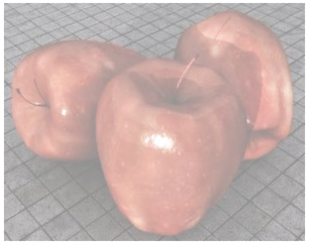


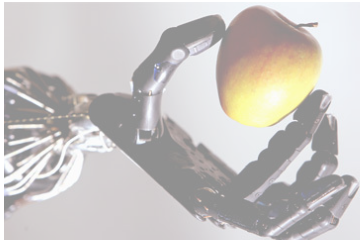


Natural vs. Engineered Haptic Interaction









History of Haptics

1. Before the industrial revolution, most ‘support systems’ were based on physical interaction
   - Windmills, hoists, levers (e.g., Leonardo da Vinci)

2. With the industrial revolution
   - Engines, dials, meters, alarms
   - First (mechanical) control systems

3. In the 20th century
   - Focus on visual and auditory systems
   - Neglect physical interaction
   - Future vision from 1934’s Huxley ‘A Brave New World’ – the feelies

4. Last decade
   - More attention on haptics

Haptic Interface Technologies: Kinaesthetic Feedback

1. Endpoint Manipulators

Impedance

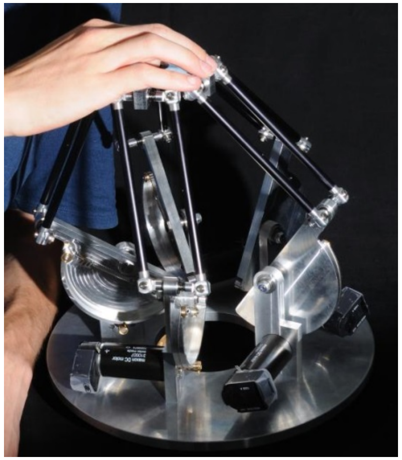
F(s) = Z(s) X(s)

Admittance

X(s) = Y(s) F(s)

Force Dimension Omega

SensAble Phantom Omni



Delft Haptics Lab PentaG

Delft NMC Lab Proprio

Moog HapticMaster

Haptic Interface Technologies: Kinaesthetic Feedback

2. Exoskeletons

ESA Eovest

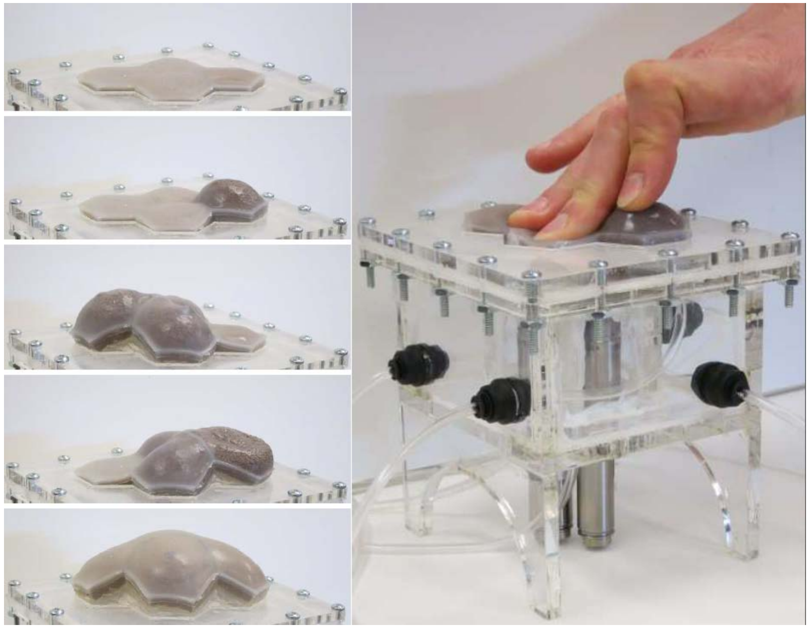
UCSC EXO-UL7

Bkin Kinarm

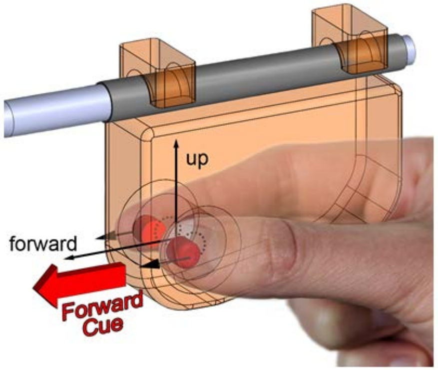
Haptic Interface Technologies: Tactile Feedback

Vibration, shear force, mechanical deformation, etc.

Deformable surface via particle jamming
(Okamura, Stanford)



Skin stretch device
(Provancher, University of Utah)



What is the Best Haptic Interface?

It depends on:

- Task requirements (workspace, degrees of freedom, force characteristics,...)
- Performance of haptic feedback device (hardware, position/force resolution, controller,...)
- Human limitations (perception,...)

General Applications for Haptics

1. Re-constructing reality
   - Teleoperation

   → Goal: restore natural haptic feedback

2. Simulating reality
   - Train difficult manual tasks
   - Test in safe environment

   → Goal: model natural haptic feedback

3. Enhancing reality
   - Games, gadgets, fun
   - Art & music
   - Communication, alerts, warnings
   - Rehabilitation
   - Shared control

   → Goal: add/augment haptic feedback

1. Re-constructing Reality: Teleoperation

Teleoperation is used when the operator cannot be in direct contact with the manipulated object/environment

Access dangerous environments:

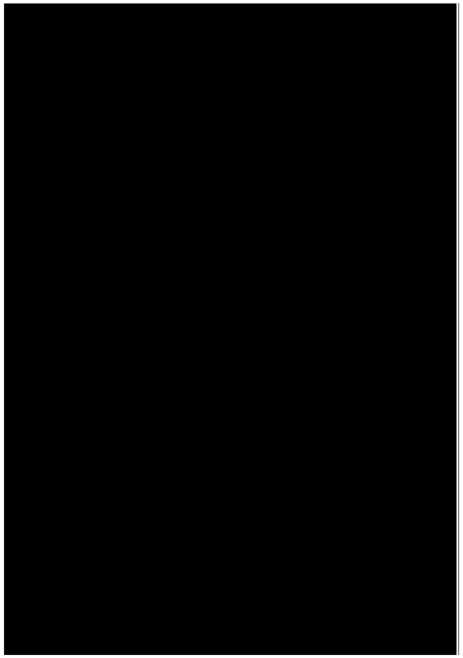
- Space
- Underwater
- Nuclear plants

Provide expertise at a distance:

- Surgery

Operate on different scales:

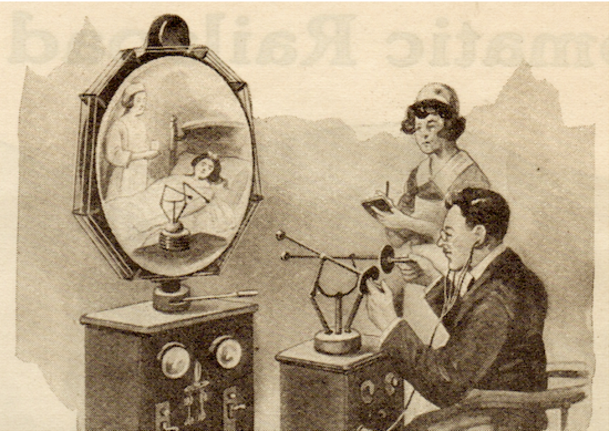
- Micro-assembly
- Excavators

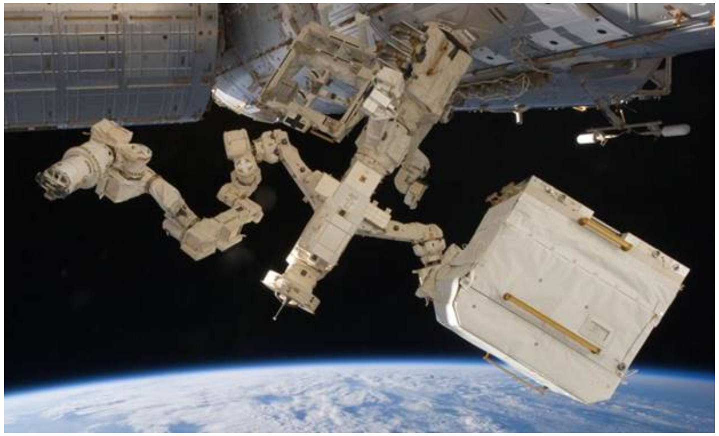


Delft Haptics Lab Munin

History of Teleoperation

- 1950 Nuclear Bomb Assembly
- 1960 Nuclear Plants
- 1970 Attempts at Space Teleoperation
- 1980 Underwater
- 1990 Mines and Explosives, Nuclear
- 2000 Surgery, Space, Enhanced Control Systems, Unmanned Aerial Vehicles, Micro-manipulation, Assembly ...

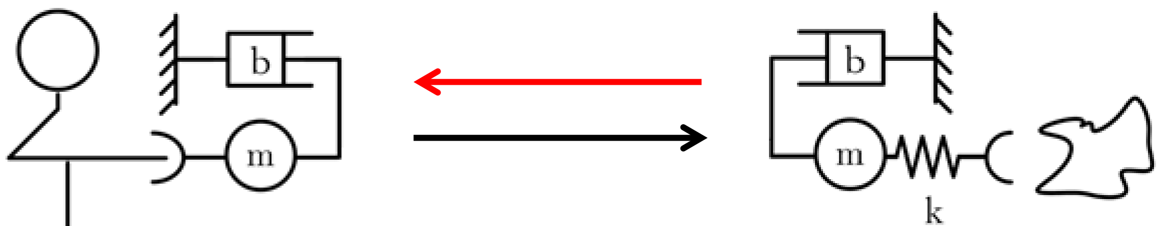




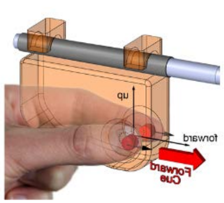
Teleoperation with Haptic Feedback

Unilateral
Unilateral vs. Bilateral

Operator – Master – Controller – Slave – Environment



Tactile



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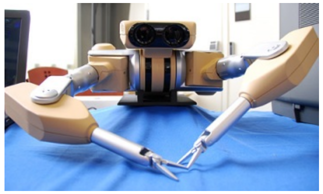
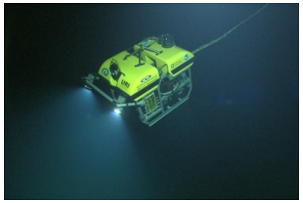


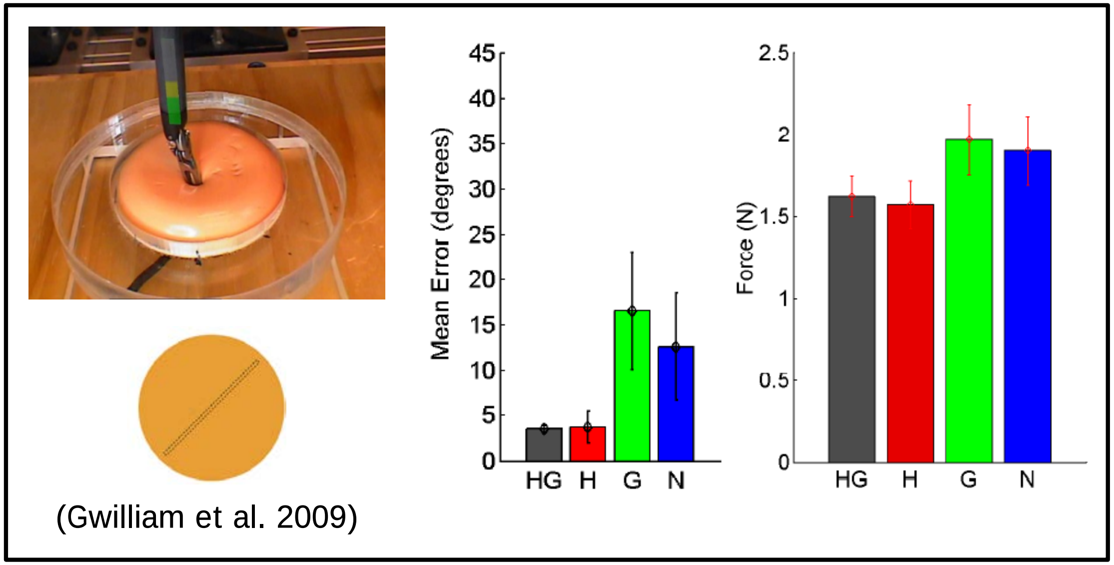
Tele*manipulation*



Motivation for Force Feedback: Surgical Example

Intuitive Surgical
da Vinci Surgical System

Current system doesn't have force feedback
How do you know how hard you are palpating organ? Pulling on suture? Grasping tissue?



How good does force feedback need to be?

Challenges of Force Feedback: Surgical Example

Add force sensors to slave instruments?

- Size
- Biocompatibility
- Sterilizability
- Cost

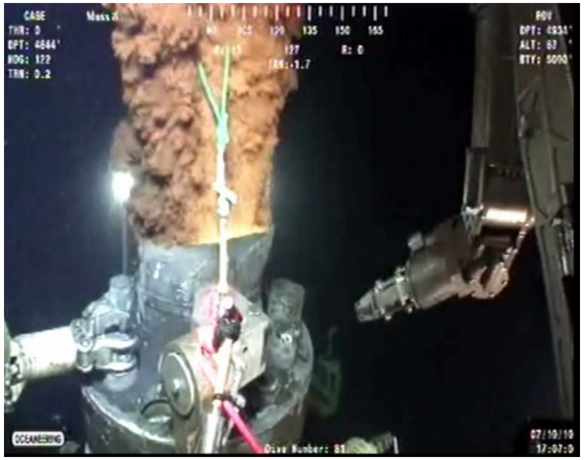
Trade-off between system stability and transparency for force feedback, due to errors in:

- Dynamic models of master and slave
- Time delays
- Environment force sensing or estimation

Now: need for high-tech tools

Still today's problem:

with current remotely operating tools, we can only realize slow and unreliable interactions in hazardous environments and difficult conditions



Deep sea: BP oil disaster

- Deep-sea (environment uncertainty)
- Nuclear fusion (high radiation)
- Space (microgravity, time-delays)
- Surgery (sensitive tissues)

Better tools save time and money !!

2. Simulating Reality

History

1930 First flight simulators
only passive mechanical feedback (springs)

now: Control loading (Moog / Fokker Control Systems)
Motion platforms
Haptic devices (Phantom, Force Dimension)

Haptic Simulation: Automotive

Racing Simulators

Motion feedback, force feedback on steering wheel

Haptic Simulation: Automotive Test

Automotive Simulators

- Simulate forces acting on cars

Haptic Simulation: Medical Training

Minimal Invasive Surgery Simulator

Simulate forces during laparoscopic and arthroscopic surgery

Simbionix

Haptic Simulation: Medical Training

Dental Simulator

Simulate drilling and contact forces

Moog

Haptic Simulation: Design

Boeing's voxmap software

Feel collisions during simulated assembly; helps you find solutions to assembly problems


BOEING

Voxmap PointShell™ (VPS) Software Library

Powerful software tools that allow haptic collision detection in complex assemblies

Overview

VPS detects and responds to virtual-object collisions at the demanding speeds of 6 degrees of freedom (DOF) haptics. Its novel technical approach yields unparalleled scalability, enough to handle even the daunting complexity of aerospace vehicles. VPS-enabled CAD applications become so powerful and intuitive that weeks worth of design analysis work are often collapsed into seconds.

VPS-enabled 6-DOF Haptic FlyThru® The user manipulates an object of interest using a SensAble Technologies PHANTOM® 6-DOF haptic interface, while VPS prevents that object from passing through neighboring objects. The user feels forces of contact as if manipulating an actual physical object.

Key Features

- Collision and proximity detection
- 6-DOF haptics and physics-based modeling
- Fast generation of motion swept volumes

Key Benefits

- Solve complex design problems faster
- Maintenance and assembly validation
- Scalable to massively large designs

Markets and Applications

- Aerospace manufacturing
- Automotive manufacturing
- Consumer product manufacturing

A Unique Business Proposition

An exclusive benefit of the Boeing technology licensing program is that companies can launch new leading-edge products without incurring R&D expenses. This is especially important to small and mid-size businesses who are striving to maximize new product introductions while minimizing development costs.

Build new business without R&D℠

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Seattle, WA 98124-2207
http://www.boeing.com/phantom/math_infosw

Contact: Howard Lohr
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Haptic Simulation: Design

Remote handling maintenance for ITER

- Validate designs for compatibility with teleoperation

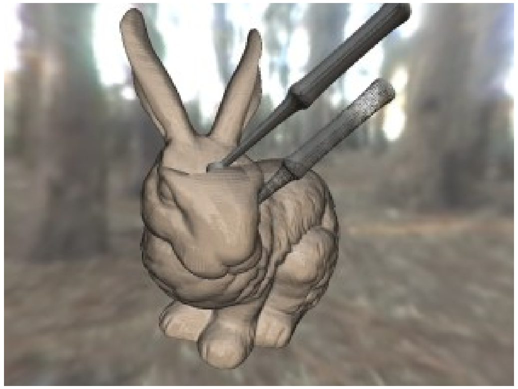
http://www.differ.nl/remote-handling-study-centre

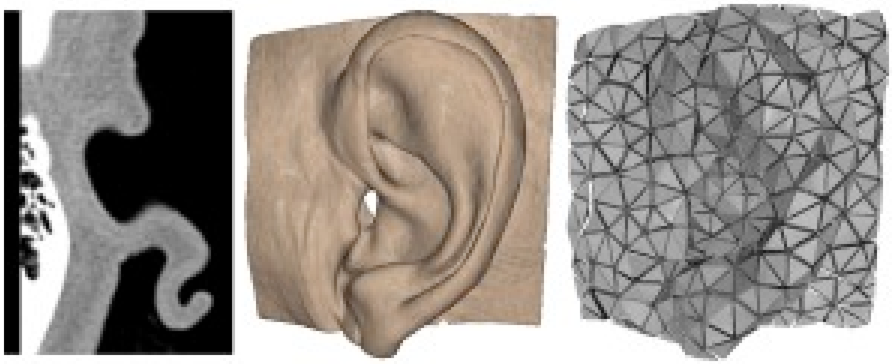
Challenges of Haptic Simulation

To ensure transfer of learning, want training situation to be as close to the actual situation as possible:

- Realistic haptic interaction
- Realistic device (non-intrusive hardware for addition of haptics)

Realism vs. computation cost





(Salisbury, Stanford)

3. Enhancing Reality: Haptic Communication

Mobile Phone Buzzers (active)

Braille (passive)

Enhancing Reality: Gaming

Steering wheel with force feedback

racing games

Joystick with force feedback

flight simulator games

shooting games

Falcon

games / simulation

Enhancing Reality: Art

Rosalyn Driscoll, sculptor

Tactile/haptic art that can be can be touched

Enhancing Reality: Music

Retractable (Music Technology Group, Barcelona)

Electronic musical instrument with a tangible table-based interface

Enhancing Reality: Improve Manual Control

Haptics as a warning (vibrations)

- Shake flight control stick near stall
- Shake seat when driving over a lane boundary
- Haptic warnings for lane-keeping

Continuous force feedback / haptic shared control

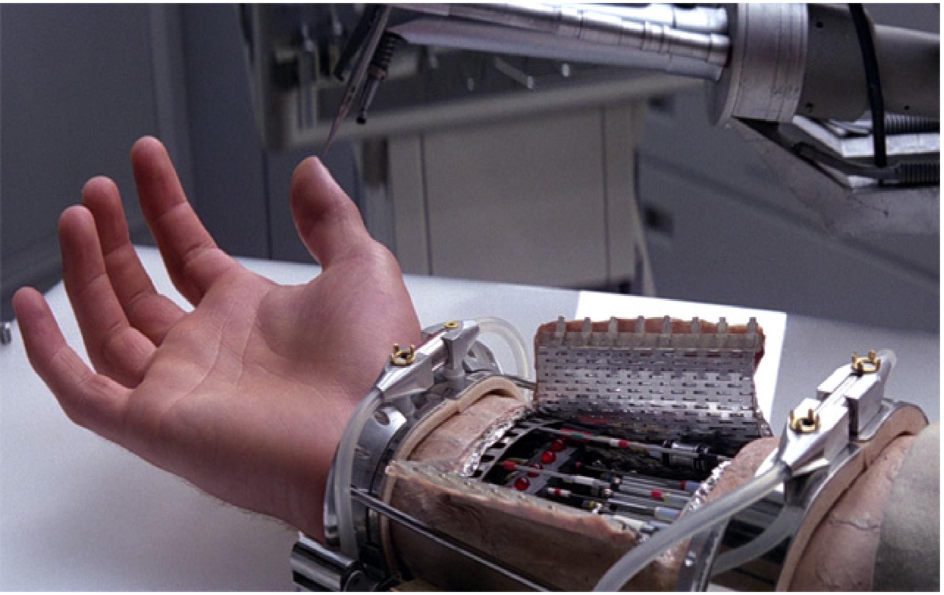
Provide additional guidance: force feedback that corresponds to desired steering/control input of an automation system

- Haptic steering wheel for lane-keeping
  Gillespie et al. (2005), MacLean (2005), Mulder & Abbink (2009)
- Haptic Gas Pedal – Nissan
  Abbink (2006), Mulder (2007)
- Control of unmanned aerial vehicles
  Lam (2008)
- Control of commercial airplanes
  Goodrich et al. (2005-2008)

Enhancing and Recreating Human Abilities

Jack F. Schorsch

- **PhD Candidate 3ME**
  - **Medical Lifting Exoskeleton**
- **Research Engineer**
  - **Myoelectric Prosthetic Upper Limbs**



(Luke Skywalker, Empire Strikes Back)

(Iron Man, DC Comics)

Haptic Applications: Telemanipulation

Evolution or Revolution?

Jeroen Wildenbeest

About me:

Oct 2011 – current	**PhD Candidate, TUD**
Nov 2010 – current	**Consultant at Heemskerk Innovative Technology B.V.**
Oct 2010	**MSc Mechanical Engineering (track BCD), TUD**

Lecture 8b – Haptic Tele-operation Applications: Revolution? -> Haptic Shared Control

Henri Boessenkool, 3ME – BioMechanical Engineering, TU Delft

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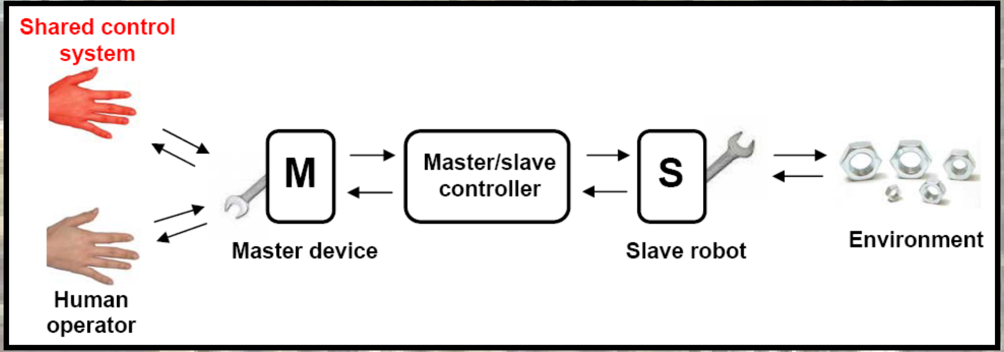

Additional Information

Haptic devices/systems have become more commonly used in the last decade

Hannaford and Okamura "Haptics" (2008)

Three main general uses:

1. Restoring reality

   Hannaford, "A design framework for teleoperators with kinaesthetic feedback" (1989)

2. Simulating reality

   Salisbury, Barbagli, and Conti, "Haptic rendering: Introductory concepts" (2004)

3. Enhancing reality

   MacLean, "Haptic interaction design for everyday interfaces" (2008)

More info on H-Haptics Project: www.h-haptics.nl

More info on Delft Haptics Lab: www.delfthapticslab.nl