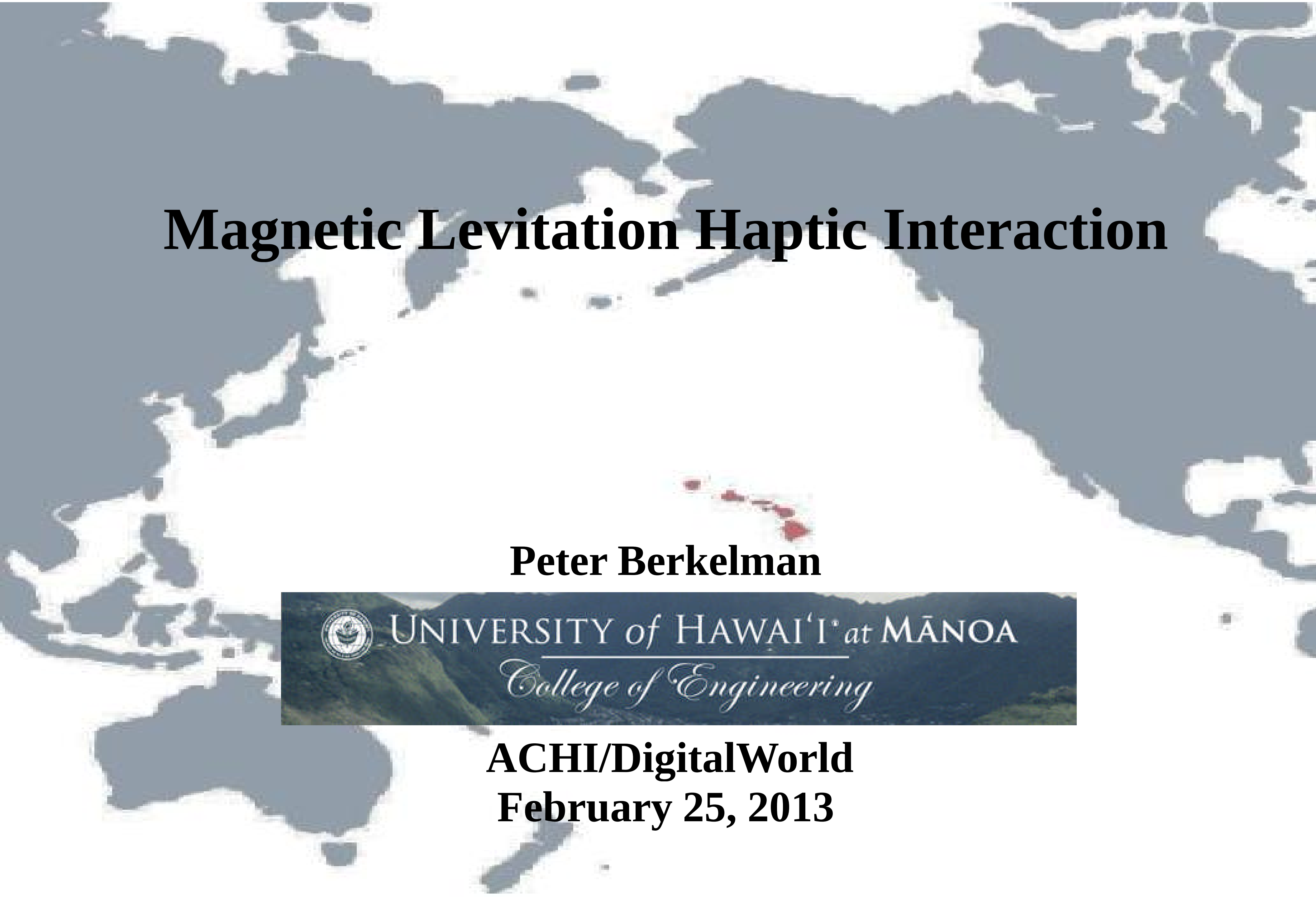
Magnetic Levitation Haptic Interaction



Peter Berkelman

UNIVERSITY of HAWAI'I at MĀNOA
College of Engineering

ACHI/DigitalWorld
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Outline:

Haptics - “Force Feedback”

Sample devices: Phantoms, Novint Falcon, Force Dimension

Inertia, friction, hysteresis/backlash in linkages & motors

Magnetic levitation alternatives: motion range, sensing, control issues

Lorentz maglev devices:

- Magic wrist, UBC 1 & 2, CMU/Butterfly, layered coils design
- Videos

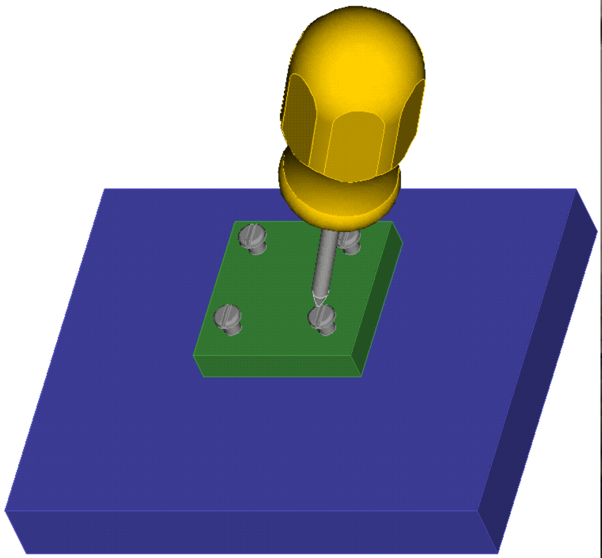
Planar maglev:

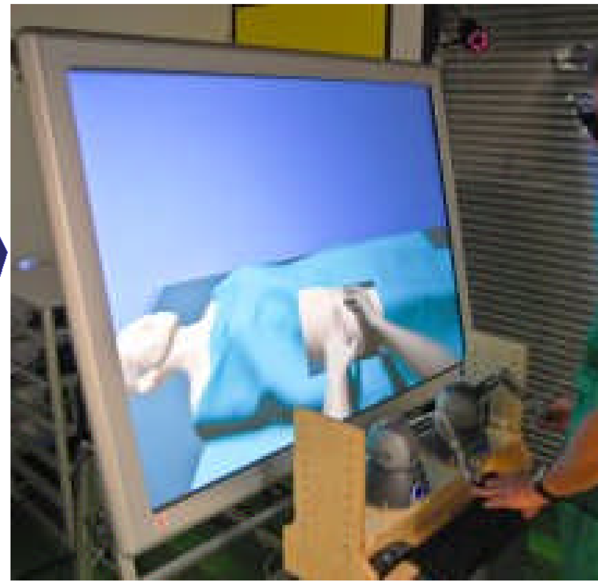
- Hawaii setup
- More videos
- Co-located display: ACHI talk

Conclusion

Haptic Interaction:

Active tactile and kinesthetic sensing and manipulation with the hand:





Haptic Interface: To physically interact with virtual or remote objects as real

Device can reproduce dynamics – force feedback

Simulation must calculate dynamics in real time for device controller

- Stiffness and damping is sufficient for static environment

Applications: CAD, medical simulations, entertainment…

Haptic Interaction (2):

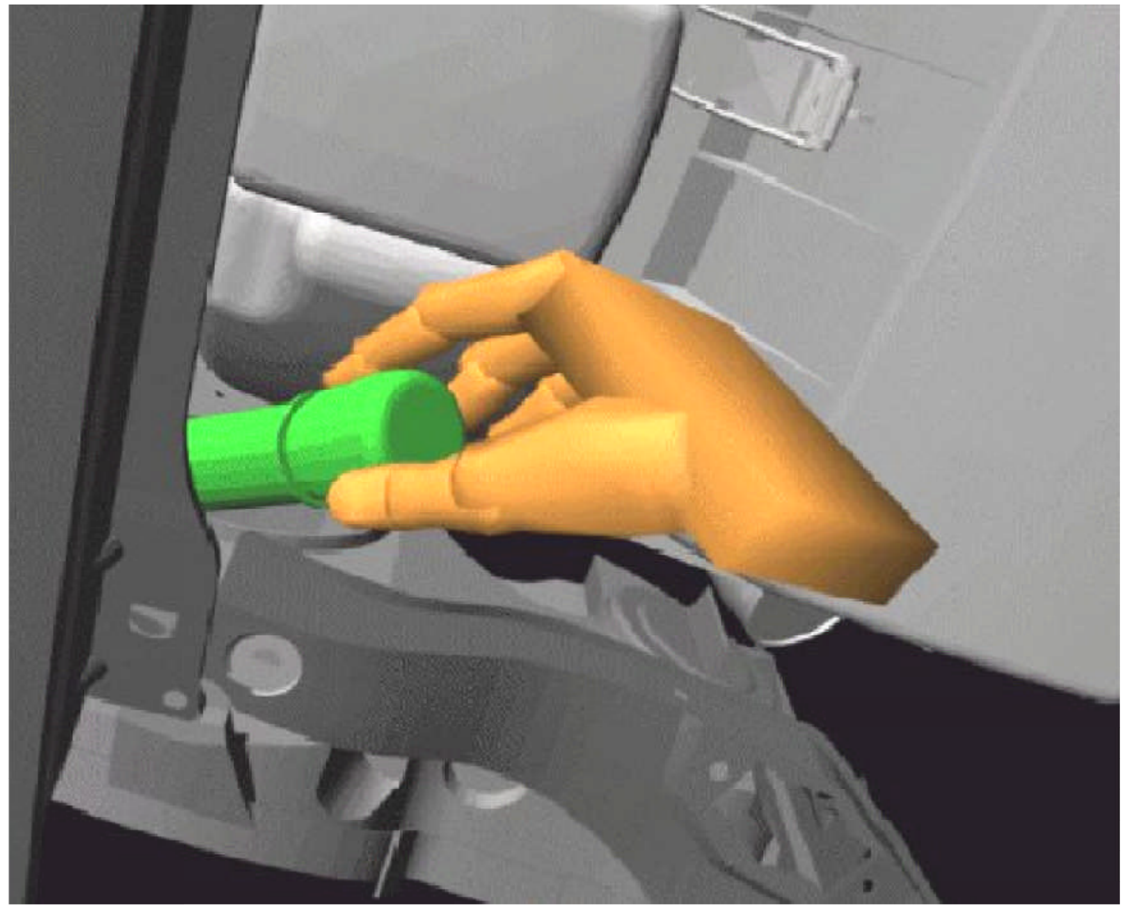
Virtual Reality:

- Incredible graphics
- But poor interactivity
- Add haptic interface?

Haptic technology is limited:

Human hand sensitivity & dexterity: µm and khz

Different approaches possible: Glove, single fingertip, rigid tool…

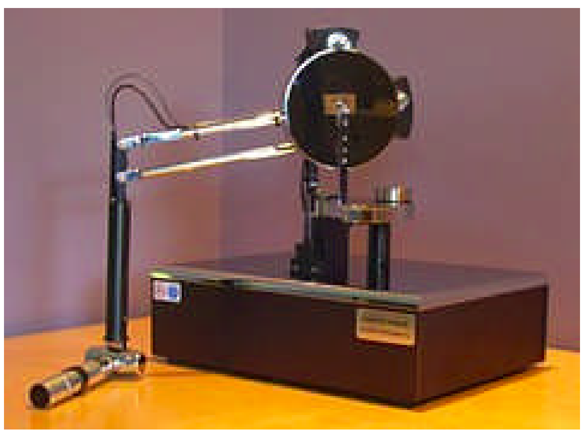


Common Haptic Interface Devices:

Phantom Omni:
Sensable/Geomagic

Force Dimension Delta

Novint Falcon



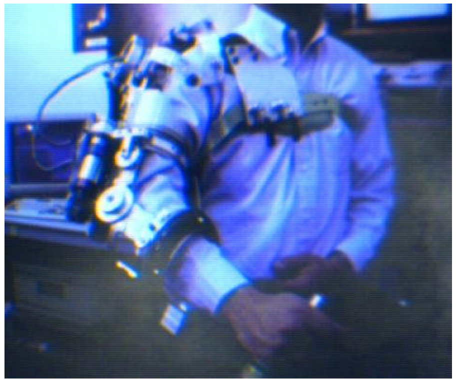
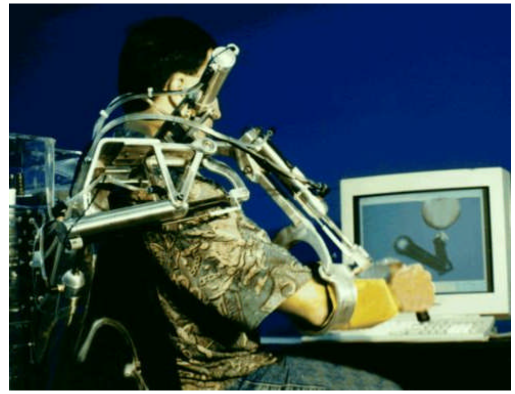
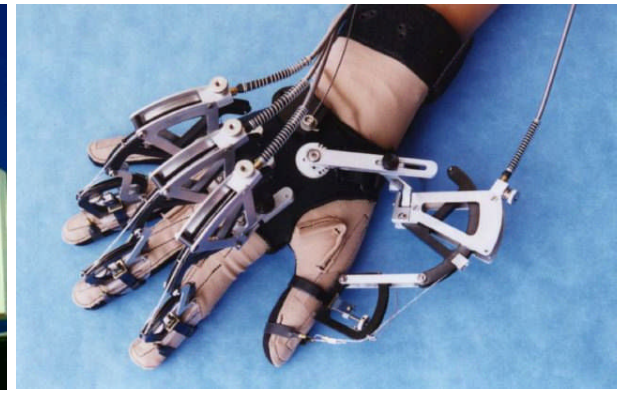
Phantom Premium 6D:
Sensable/Geomagic

Force Dimension Sigma.7

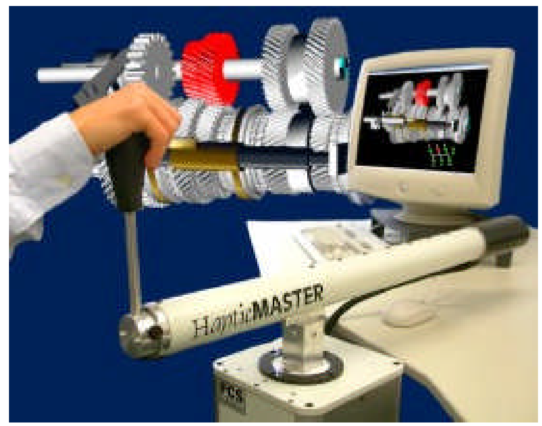
3 DOF force (point contact) and 6 DOF force and torque (rigid body contact) options

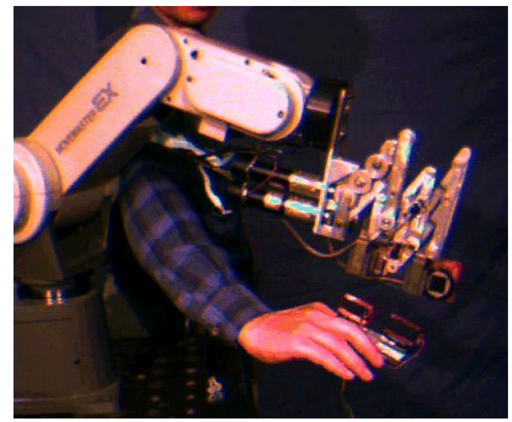
Other Haptic Devices:

Exoskeletons:

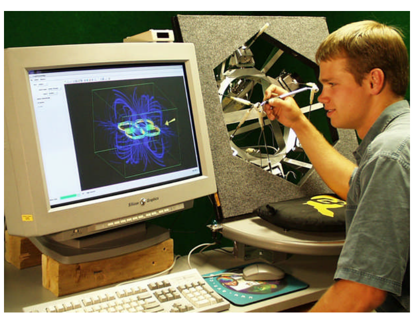
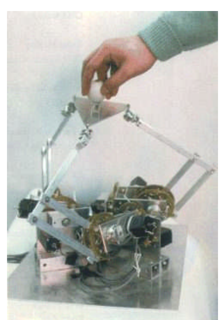




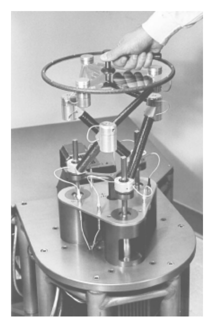
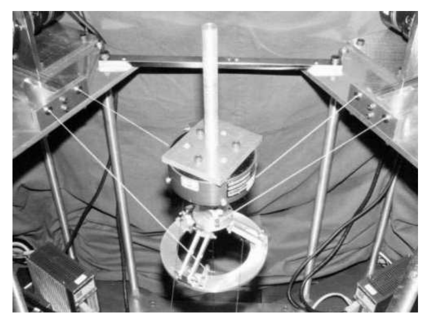
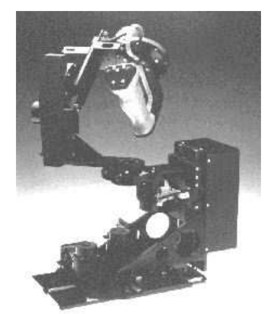
Manipulators:



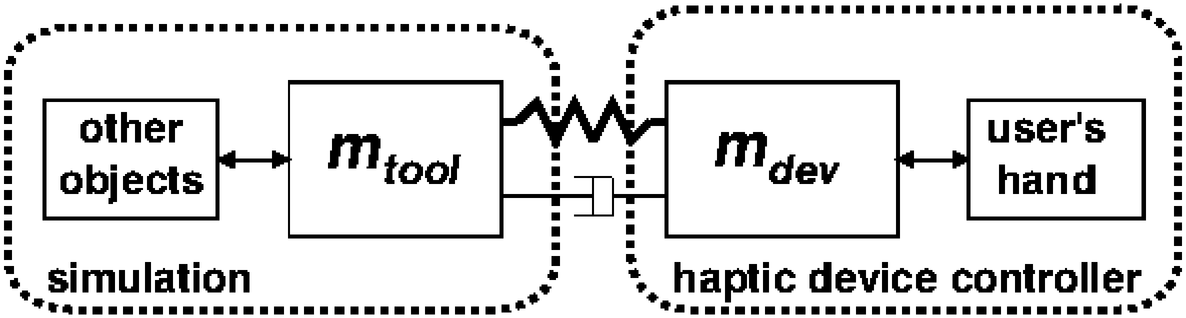
Etc:

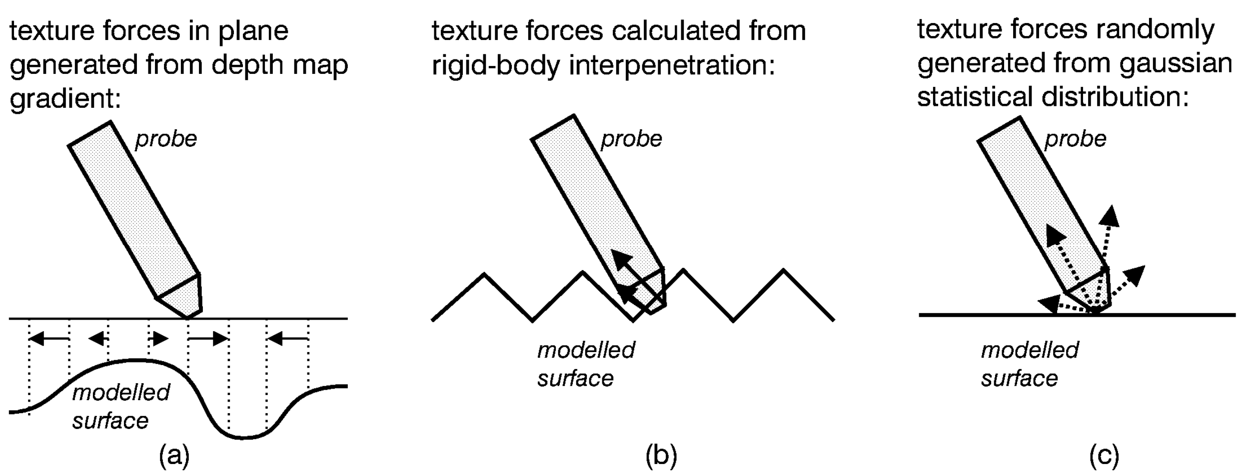




Haptic Rendering:

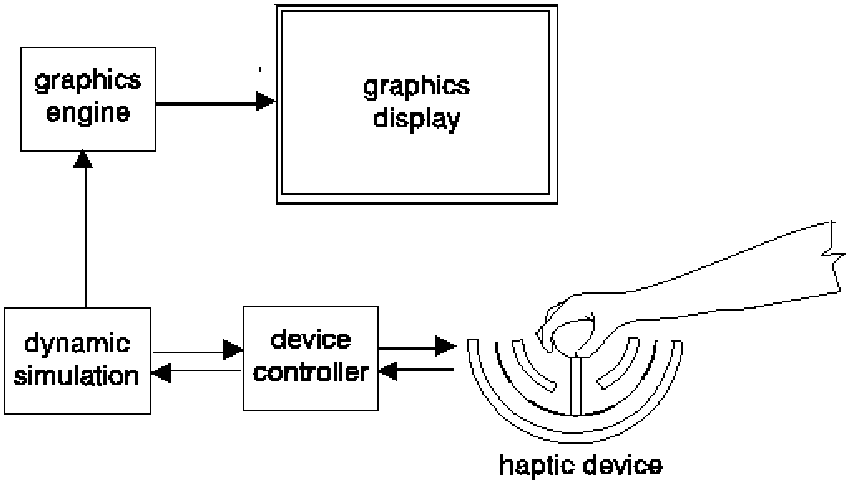
Virtual coupling is the simplest way to integrate haptic interface device with real-time simulated environment

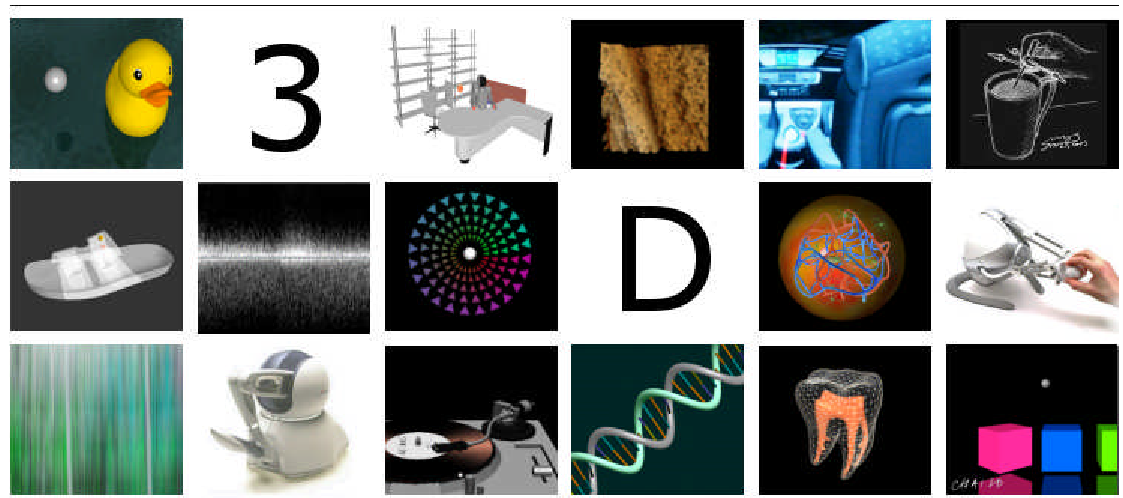


Very simple to very complex models for friction and texture haptics can be used

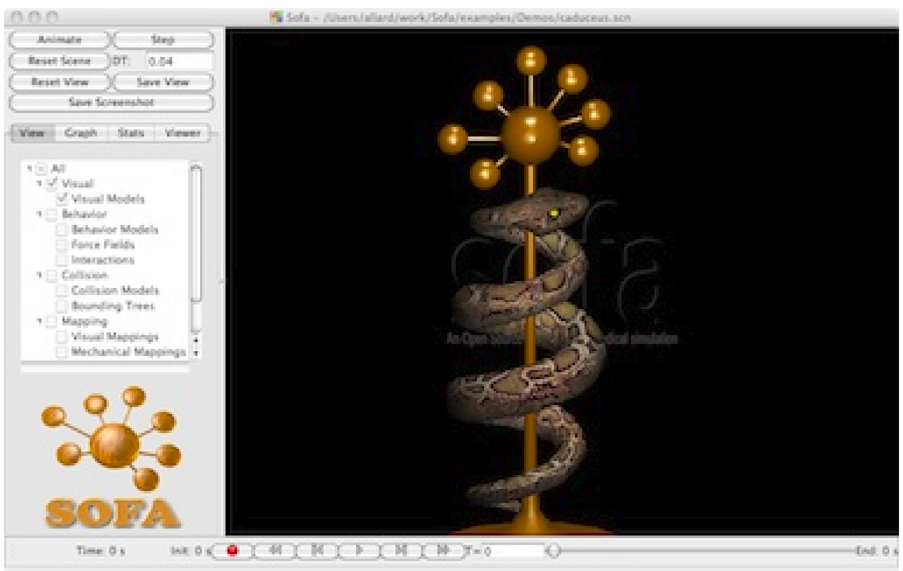


General Purpose Haptics APIs:





chai3d.org



sofa-framework.org

h3dapi.org

Maglev vs Linkages for Haptics:

Linkages:

- Friction
- Hysteresis/backlash
- Self-collision
- Bulky

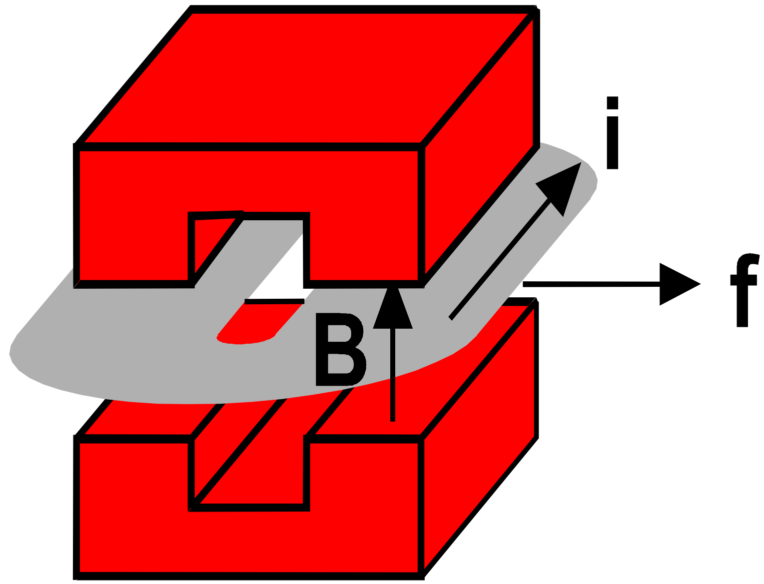
Maglev:

- Motion range
- Stability
- Position sensing
- Types

Lorentz Magnetic Levitation:

Force from current in magnetic field:

$$\mathbf{f} = -\mathbf{i}\oint \mathbf{B}\times d\mathbf{l}$$



- 6 actuators needed for levitation
- Optical position sensing

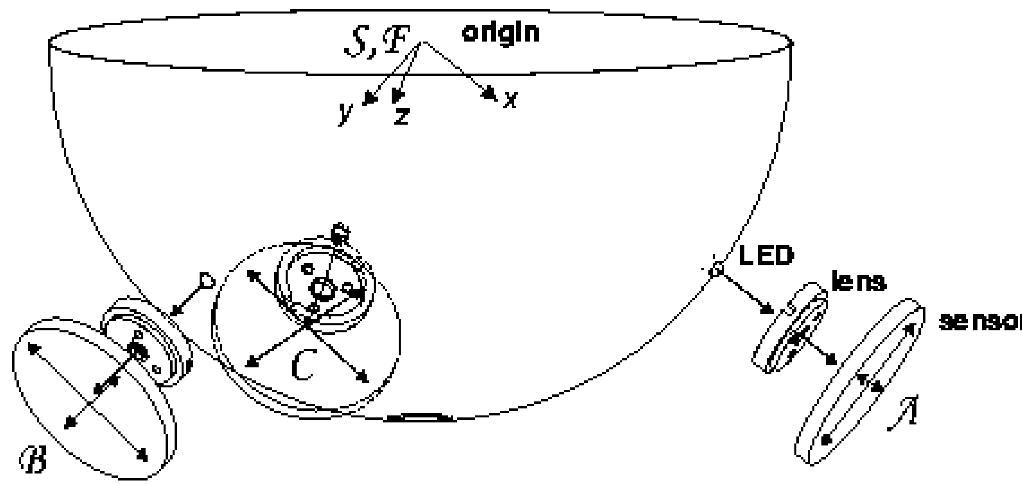
Advantages:

- Force independent of position
- Noncontact actuation & sensing
- 6 DOF with one moving part

Disadvantages:

- Limited motion range
- Expensive materials and sensors

Position sensing for maglev:



Noncontact position sensing necessary to obtain bigid body position and orientation

1000 Hz update, and 0.01 mm resolution necessary for smooth maglev and haptics

Optical position sensing methods:

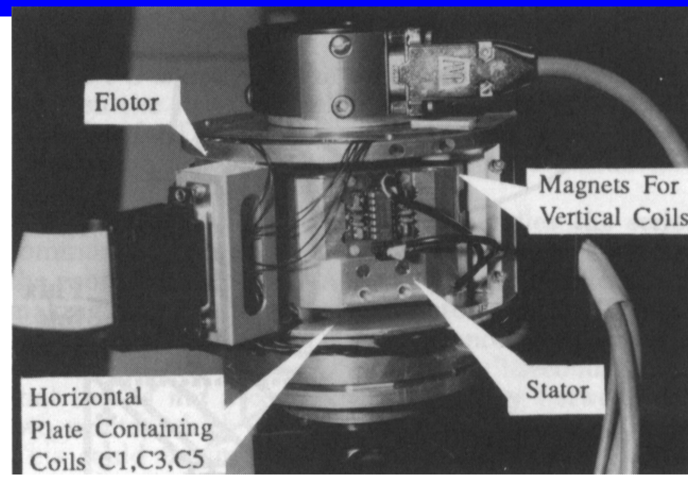
- Optical motion trackers
- Position Sensing Photodiodes

Kinematics: Nonlinear multivariable functions must be inverted to find pose from sensors

$$S_{a,x} = \frac{l_z l_l\,[n_1 n_3(1-\cos\theta) - n_2 \sin\theta] + z}{l_l\,[n_1^2 + (1-n_1^2)\cos\theta] + x + l_z - l_t} \qquad S_{a,y} = \frac{l_z l_l\,[n_1 n_2(1-\cos\theta) - n_3 \sin\theta] + y}{l_l\,[n_1^2 + (1-n_1^2)\cos\theta] + x + l_z - l_t}$$

Lorentz Force Maglev Haptic Devices:

IBM Magic Wrist, 1988



UBC Teleoperation Master, 1991

UBC Powermouse, 1997

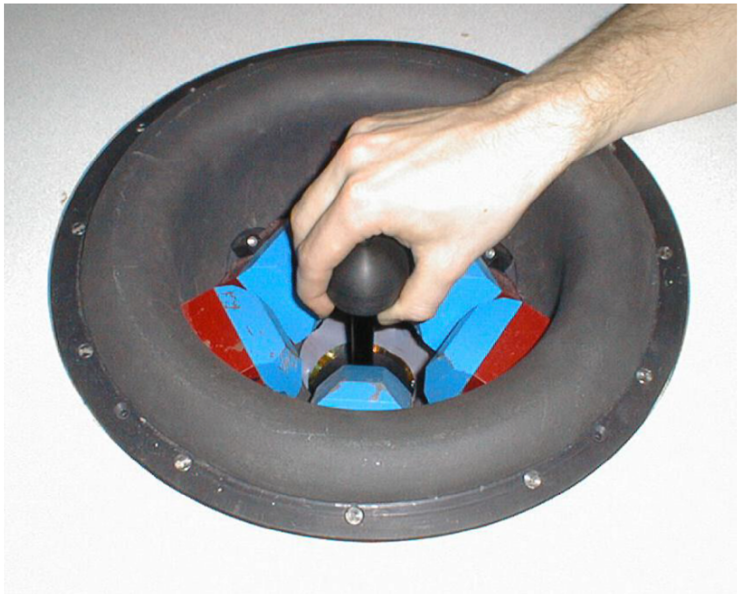
IBM and UBC wrists:

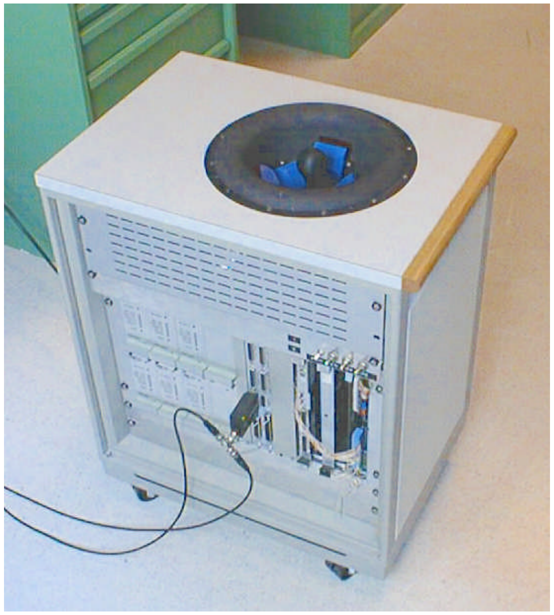
First developed as fine motion positioners carried by robot arm

Used for haptic interaction with simulated surfaces, texture, and friction

- Position bandwidths: ~50 Hz
- Position resolution: 1-2 μm
- Motion ranges under 10 mm, 10 degrees

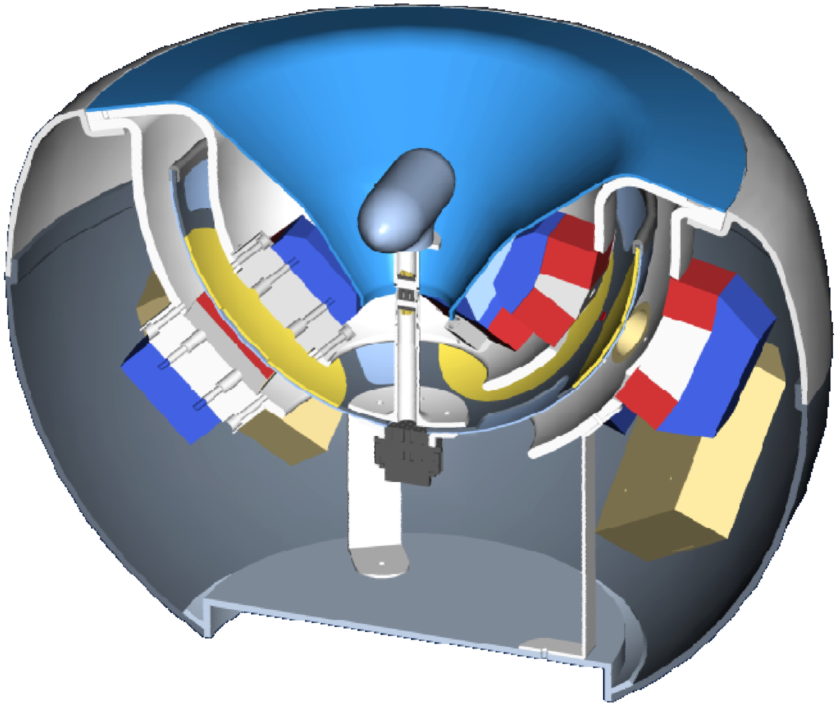
CMU Maglev Haptic Device:





Lorentz maglev device developed specifically for haptic interaction
User grasps and manipulates handle in bowl set in cabinet top

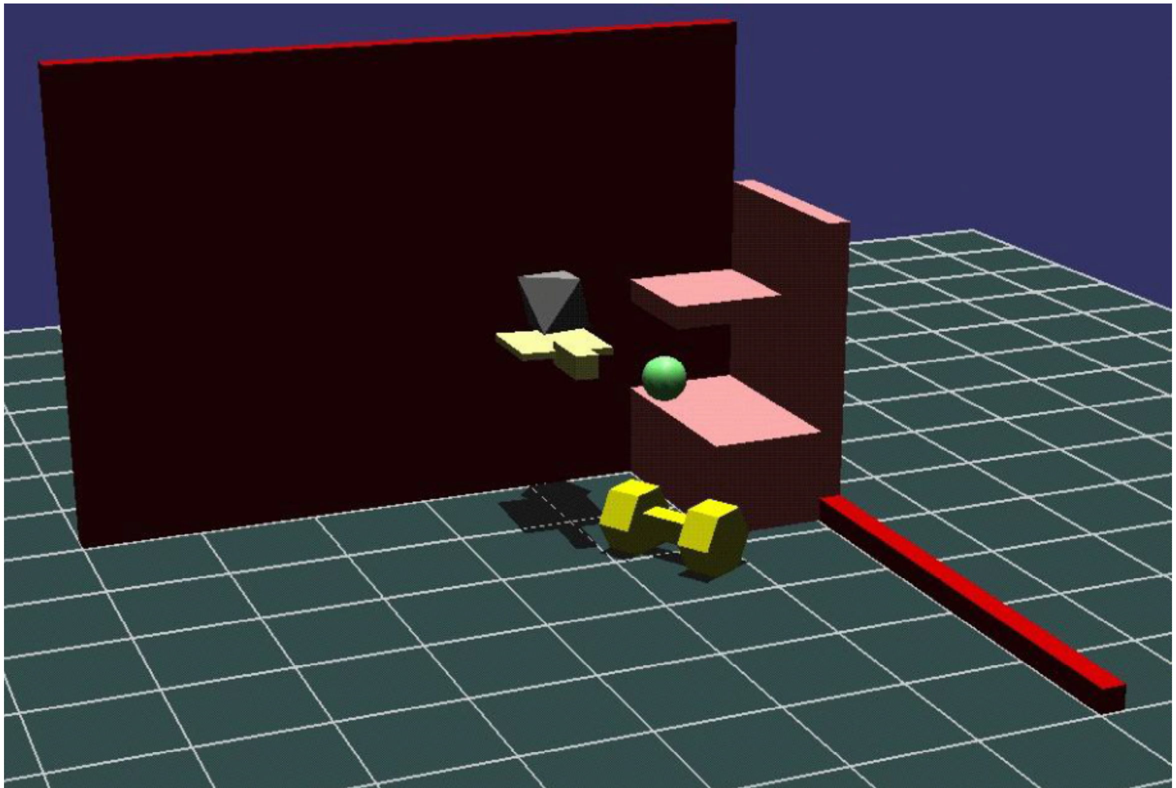
Butterfly Haptics Maglev Haptic:



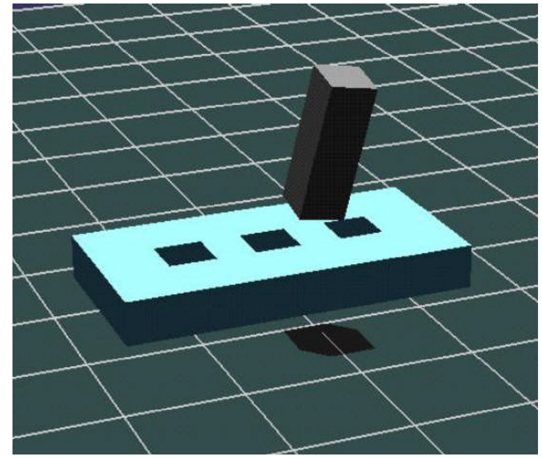
Refinement of CMU design for commercial production:

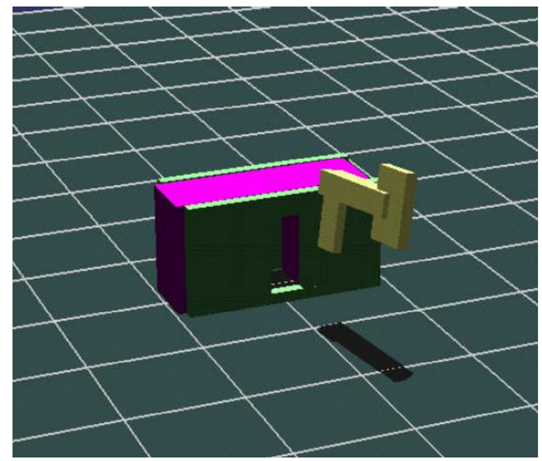
- Lighter, stiffer flotor
- Improved position sensing
- Faster control
- butterflyhaptics.com

Physical Simulation Environments:



Peg-in-Hole, Key and Lock,
Blocks World Environments

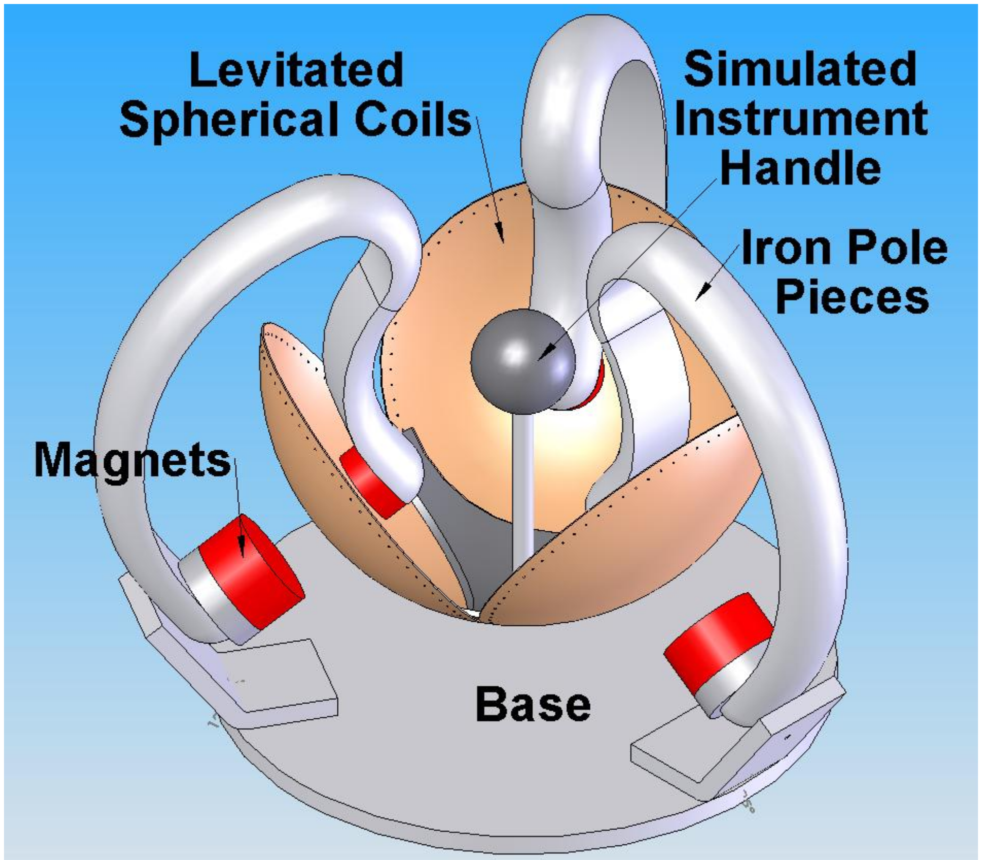




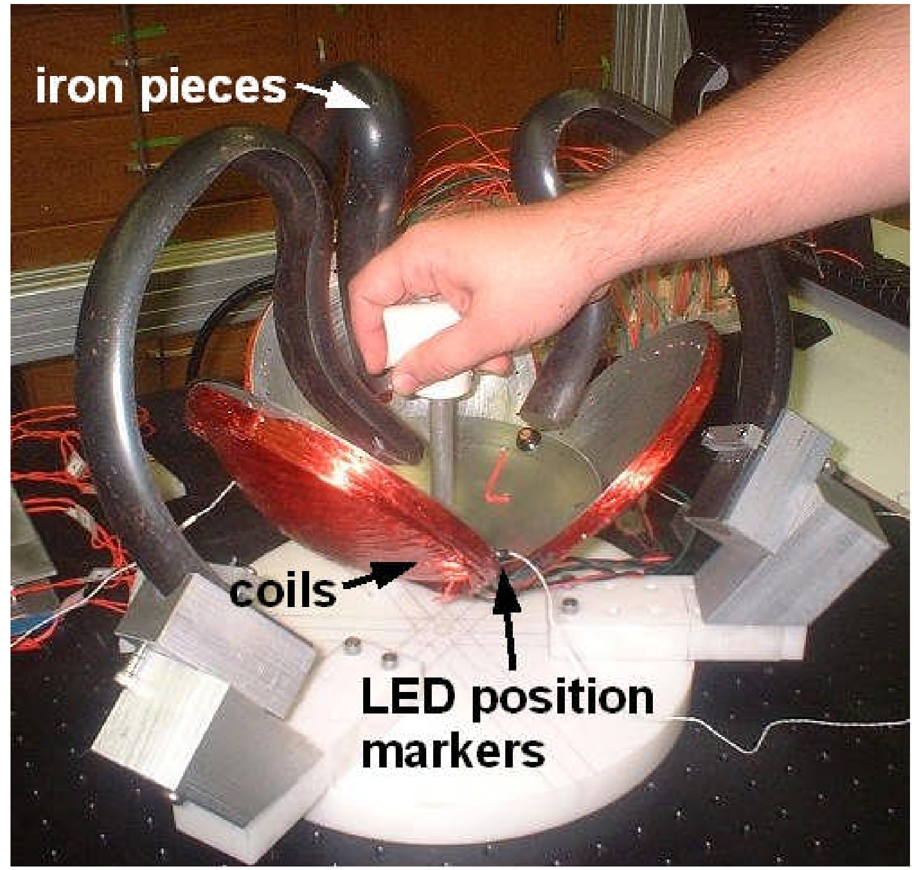
Physically based dynamic rigid body simulation on host

Simulation must be tightly coupled with haptic device controller

New Design for Increased Motion Range:



Setup for Handheld Haptic Interaction

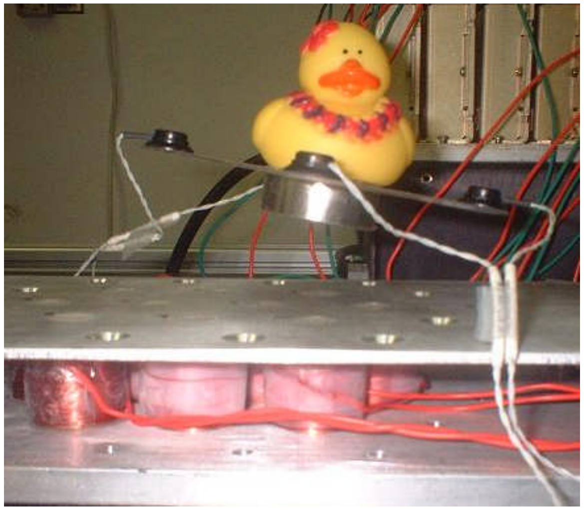


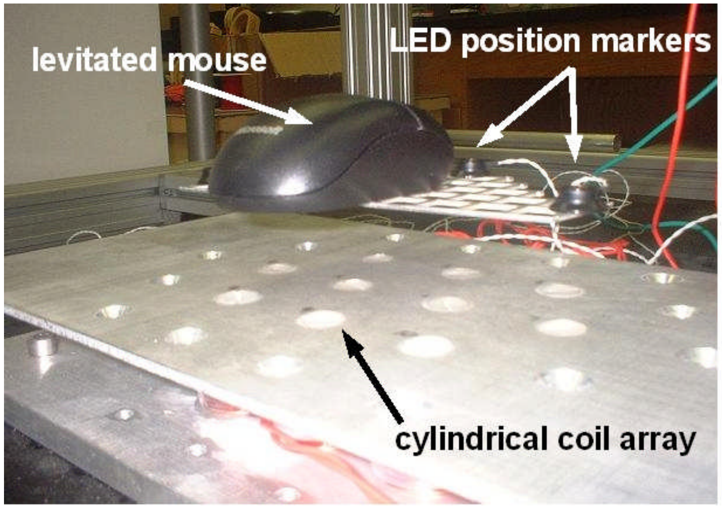
Setup for Handheld Haptic Interaction

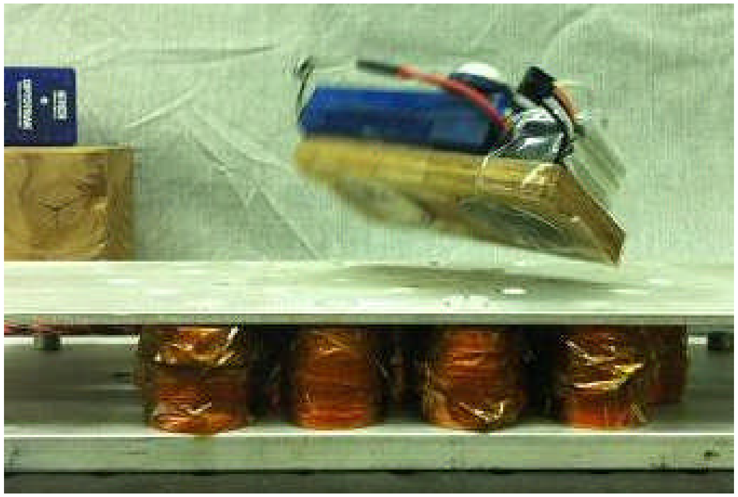
Larger coils arranged in 2 layers

Larger magnets and air gaps

Planar Coil Array Maglev System:

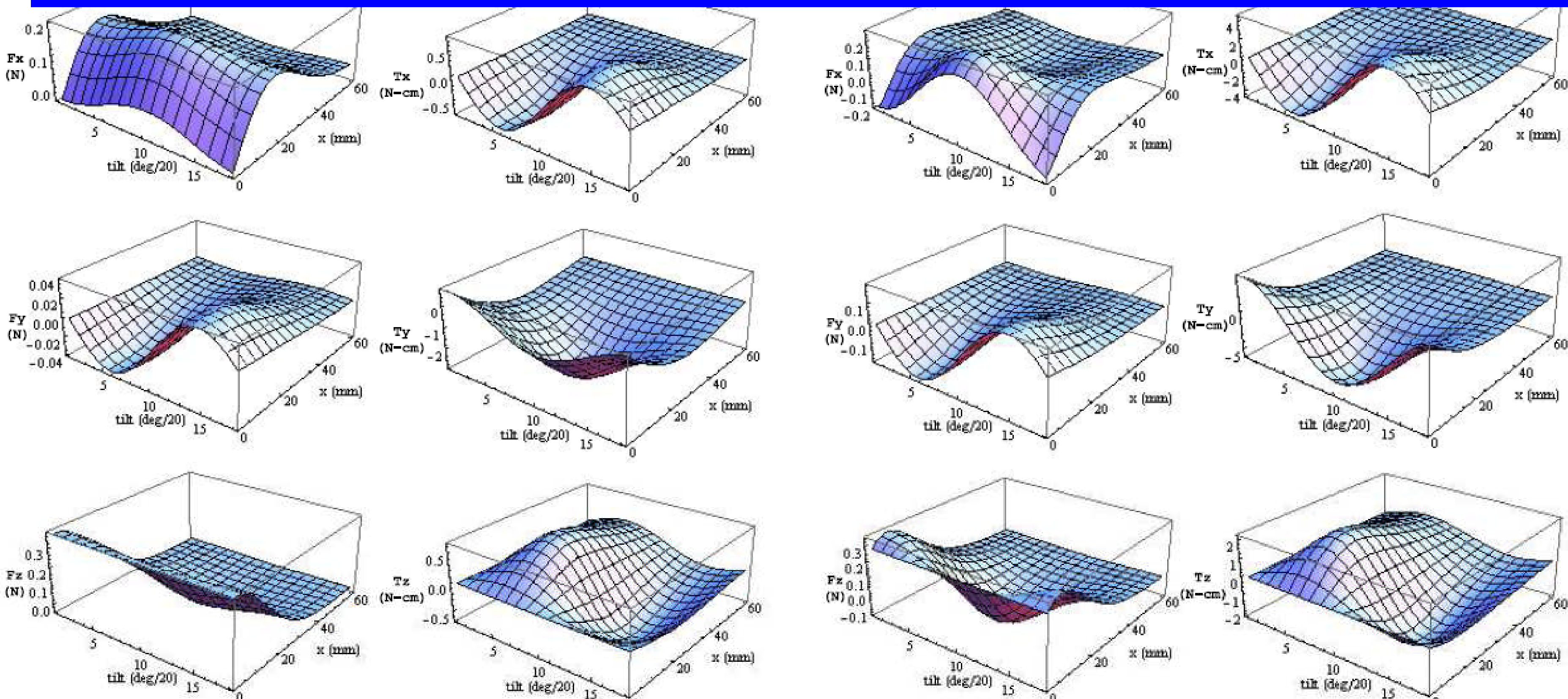






- 27-coil array generates forces and torques on magnets
- Overhead rigid-body motion tracking sensor uses infrared LEDs for position feedback control (Northern Digital OptoTrak)
- Pseudoinverse of coil current to force-torque transform matrix to calculate currents for desired forces and torques at 1000 Hz
- Usable range ~40 mm height, unlimited yaw, ±45° tilt

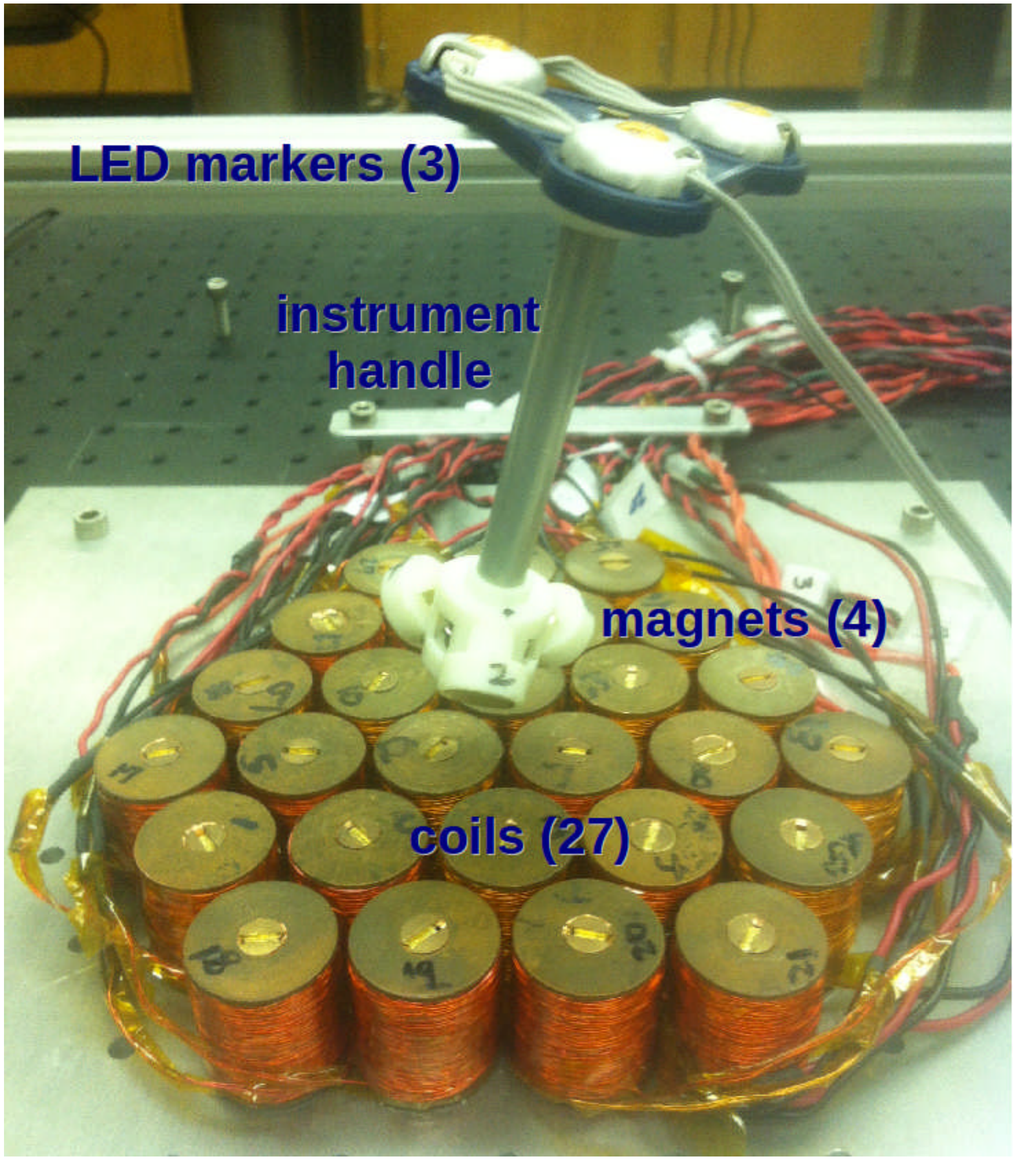
Electromagnetic Modeling:



- Calculate 3D force and torque generated per Ampere between single coil and magnet over range of positions and orientations (offline, stored in interpolated lookup table)

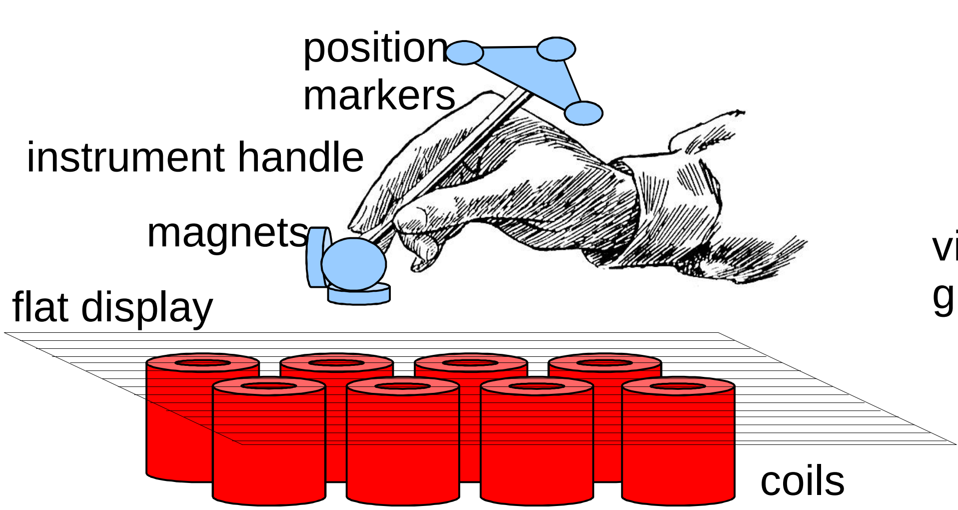
- Combine forces and torques between all coils and magnets to form current to force and torque vector transformation matrix (online)

Levitated Handle for Haptic Interaction:

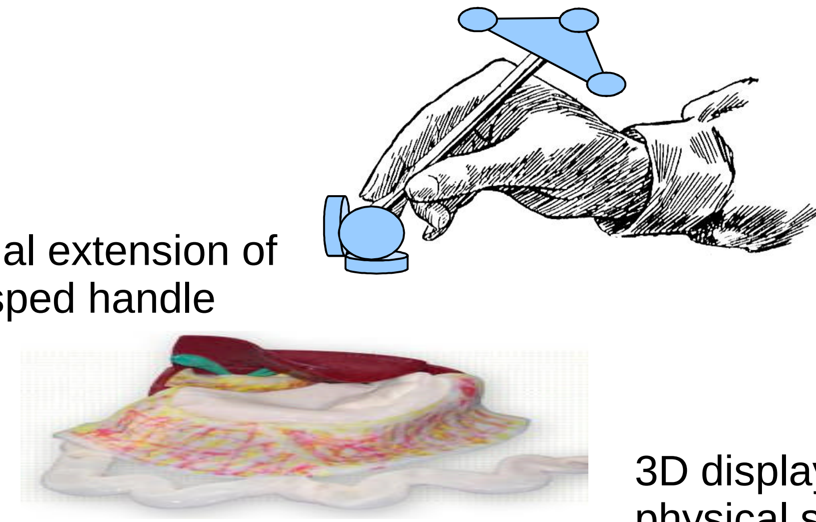


- Pen shape to be grasped by user
- LED position markers on top
- Magnets for force and torque feedback at bottom

Graphic/Maglev Haptic Co-Location:



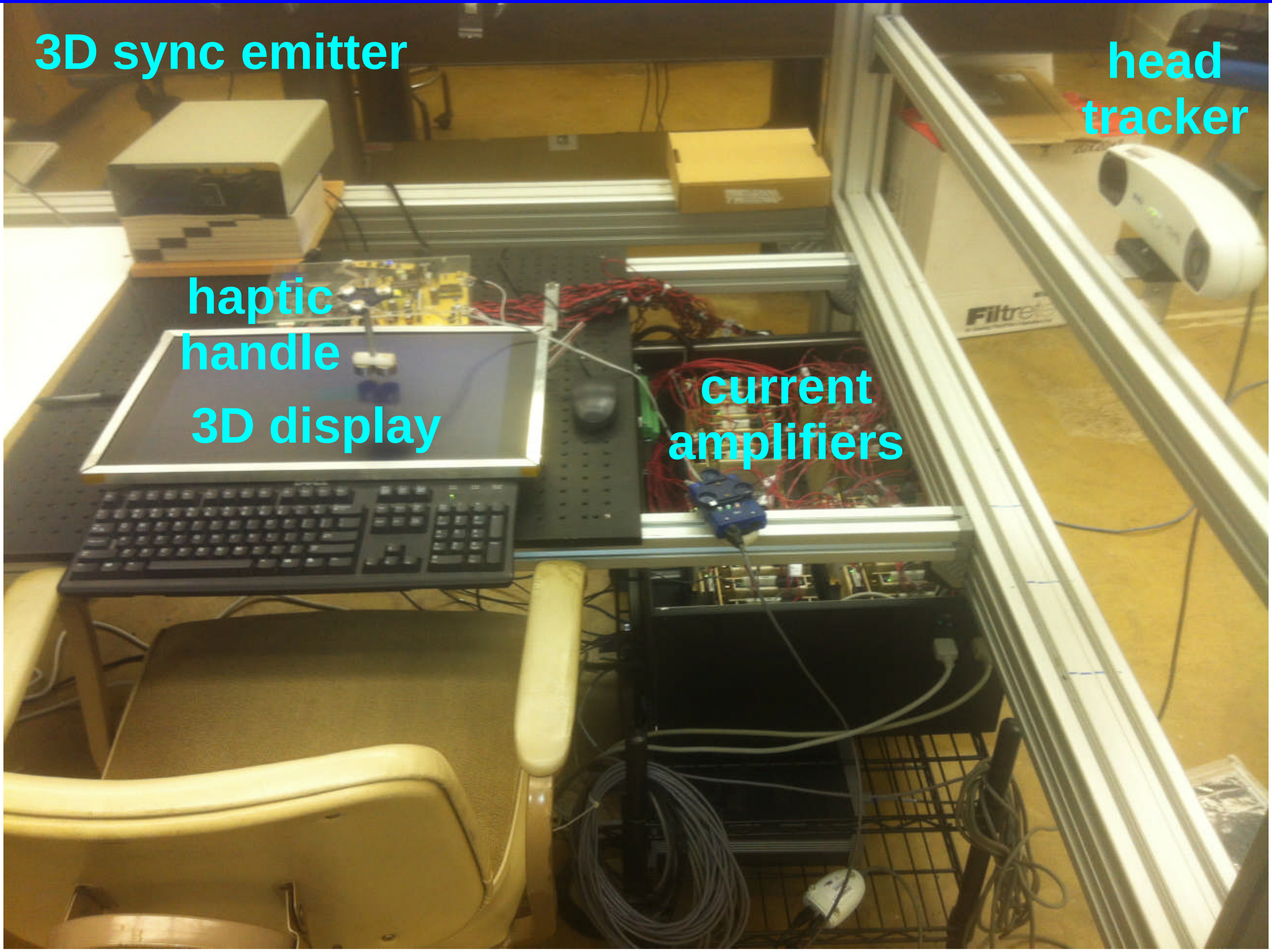
Magnetic Levitation Haptic Interface



3D Display of Virtual Environment

- Magnetic levitation system generates forces and torques on user handle through thin flat display
- 3D rendered environment at real tool tip
- Virtual tool is direct continuation of user handle

Complete System:



Head tracker on side, instrument tracker overhead, maglev coils under display

Conclusion:

Future planned work:

- Develop new position feedback systems:
  - Smaller scale
  - Magnetic?
- Magnets on fingertip and palm instead of rigid instrument
- Improve control methods
- Integrate with general APIs

Future of maglev haptics:

- Supporting technologies continually getting better
- API and simulation software getting more available and better
- Components getting cheaper