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Haptic Robotics:
Brief Overview, Literary Survey, & Initial Proposed Research

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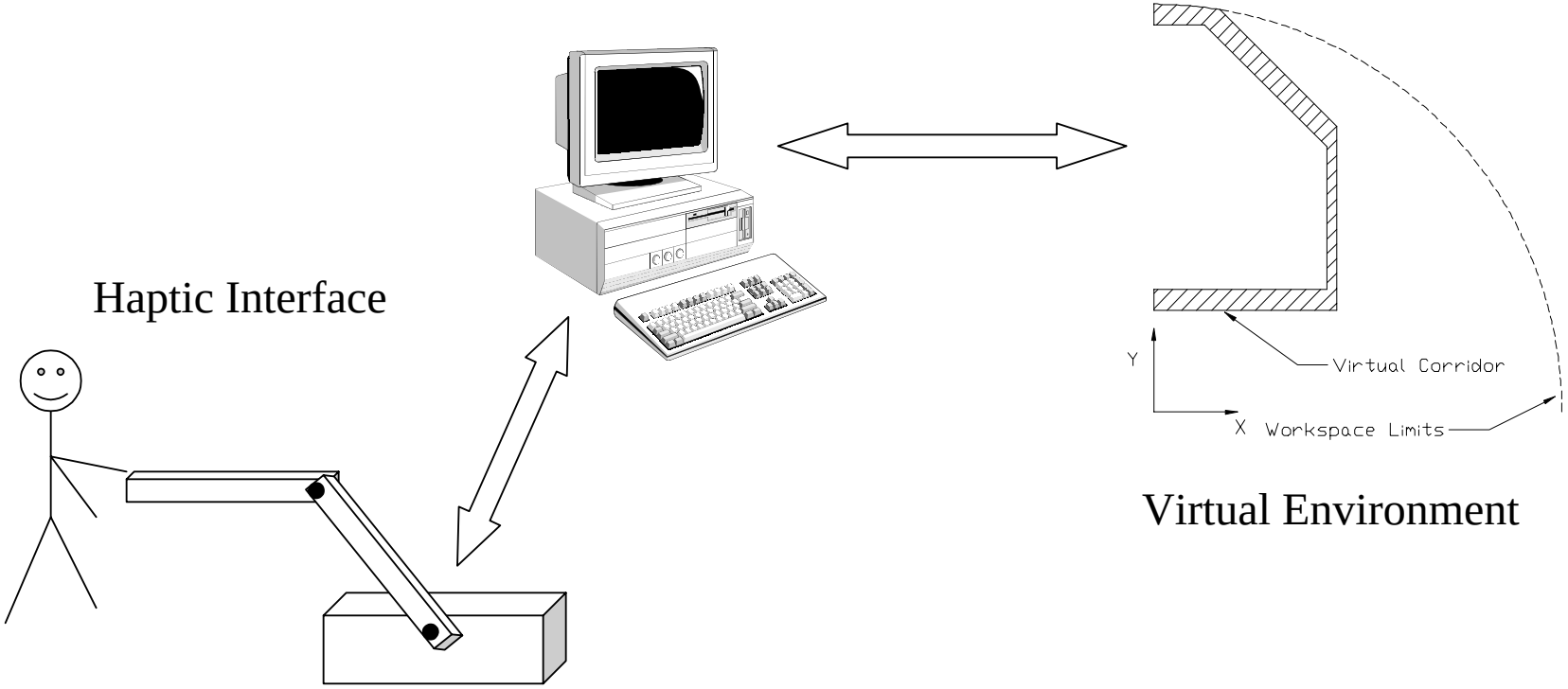
What is Haptic

- According to Mr. Webster
  - Haptic: Relating to or based on the sense of touch



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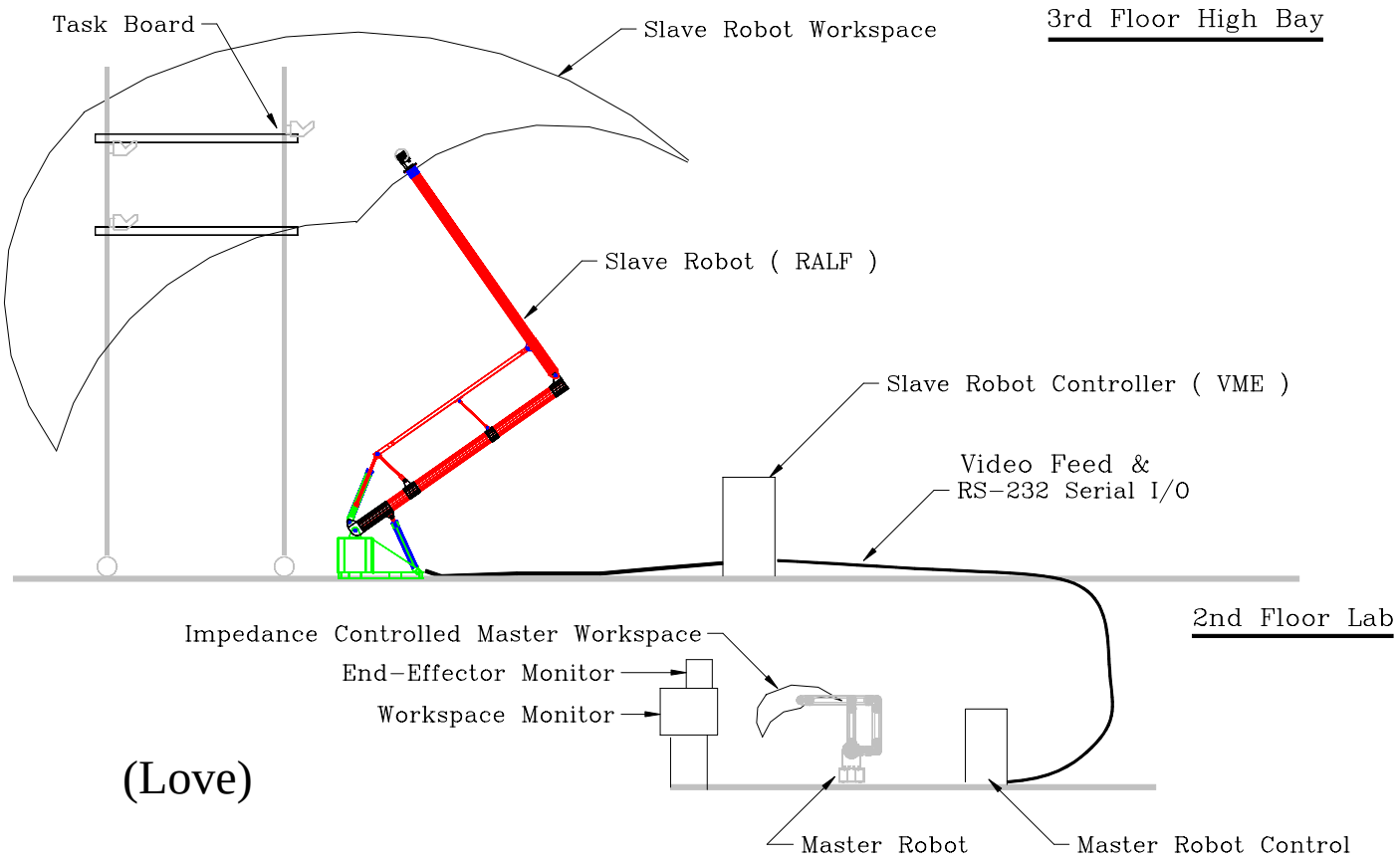
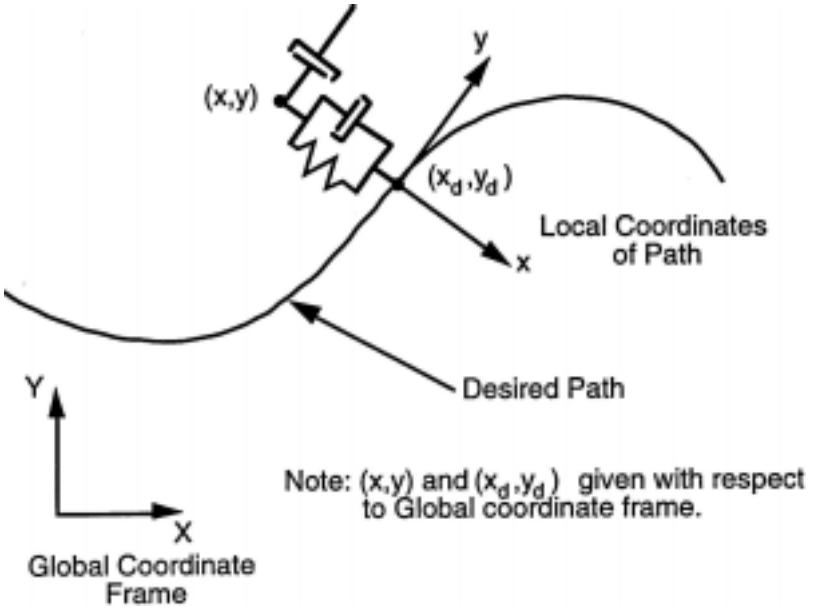
Bilateral Teleoperation



(Love)

Impedance / Admittance

- Impedance: Calculate resulting force based on position (position error)
- Admittance: Calculate resulting position (position error) based on applied force
- Apples to both haptic devices & interactions of robots with environments



(Charles)

Why Haptic?

- Uses:
  - Simulation of Virtual Environnets
    - Training, Prototype design, Rehabilitation
  - Direct Assistance to Human efforts
    - Force Scaling, Dynamic Guiding, Static Constraints
  - Teleoperation
    - Position / Force Scaling, Assistance in guiding remote equipment

- Benefits:
  - Reduced design time, Increase in achievable tasks, Decrease in task execution time, Operator safety

Haptic Devices

- Active: Add energy to the system
  - Phantom (Sensable Technologies)
  - Hurbirt (Book)
  - High Bandwidth Force Display (Hannaford, Adams)
  - Planar Pantograph (Salcudean)
  - Steady - Hand (John Hopkins)
  - Excalibur (Haptic Technologies)
- Passive: Only redirect or dissipate energy in the system
  - COBOT (Colgate, Peshkin)
  - PADyC (Troccaz)
  - PTER (Book)
  - 6 DOF “Joystick” (Crane, Goodall, Chesney)
  - PALM-V^2 (Kanade, e.t. all)

Some Key Topics in Haptics

- Unconditional stability of the interface, including effects of digital control
- Numerical simulations of interactions in virtual environments
- Human Models
- Affects of time varying delay in the control / communication loop
- Performance and effectiveness of a haptic interface
- Psychophysics
- Transparency of the haptic interface
- Development of inherently passive devices
- Design of haptic interfaces
- Identification of Environment & Adaptation of the Haptic Algorithm
- Haptic interface communication over the internet

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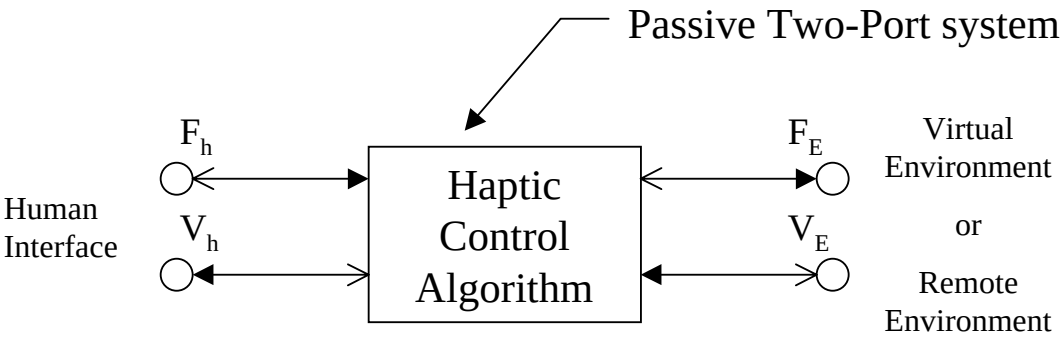
Work at IMDL

- Active
  - Love: Impedance control of master / slave for bilateral teleoperation with environment interaction by the slave.
  - Thibaut: Force magnification (direct machine / human cooperation)
  - Martin: Psychophysics for human perception of virtual environments

- Passive
  - Charles: Design, simulation, & preliminary system ID tests of PTER
  - Davis: Algorithm development & test for PTER
  - Gomes: Algorithm development & test for PTER
  - Swanson: Improved simulation of PTER, incorporating better actuator models
  - Swanson: Algorithm development & test for PTER

Unconditional Stability

- Guarantee stability via passivity theory
  - A Passive system is guaranteed stability if it interacts with passive environments

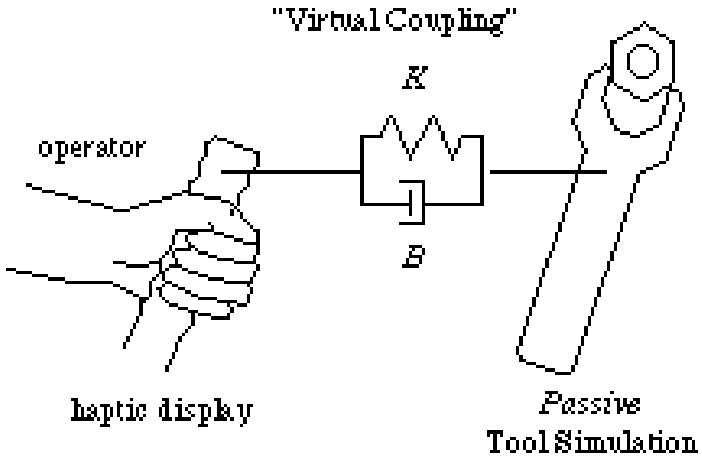


  - If the Human is Passive & Virtual / Remote Environment is passive, the entire system is passive

    $\rightarrow$ Therefore stable

Virtual Coupling

- Colgate proposed an artificial coupling between the haptic display and the virtual environment
- Analogous of adding virtual Impedance / Admittance to the haptic system
- Choose virtual stiffness (K) & Damping (B) to guarantee a passive control algorithm
- Dictates the range of achievable dynamic impedance



(Colgate)

Further Resulting Haptic Topics

- Human Model
  - Model the human as a passive system (Hogan, Mussa-Ivaldi)
  - Modeling stiffness & damping of the human
  - Psychophysics: Just Noticeable Difference
    - What is the humans resolution in both position & force sensing
    - Recognition of properties of the virtual environment

- Virtual Simulations
  - Discrete numerical simulations of passive virtual environments may not be passive
  - Collision detection & required resultant forces in virtual environments

Effectiveness of Haptic Display

- Measure of Performance with metrics
  - Achievable dynamic impedance -- “Z” Width
  - Effectiveness in assisting the operator
    - Time required to complete a given task
    - Quality in repeatability of a given task
    - Since this is a machine intended to aid humans, qualitative feedback is also important
  - Transparency -- Does the operator feel the dynamics of the simulated environment or the dynamics of the device.

Inherently Passive Devices

- Can not add energy to, or impart motion on the system

  - **PTER:** Redirect / dissipate energy through use of electromagnetic friction clutches & brakes
  - **COBOT:** Direct users input force and the devices momentum through continuos variable transmissions
  - **PADyC:** Use of one-way clutches with motors to limit joint velocities ($\omega^- < \omega < \omega^+$)
  - **PALM-V²:** Use Hydraulic cylinders to control damping forces on each link
  - **PAKY:** Central locking mechanism to hold a 6 dof arm in place
  - **6 dof "Joystick":** Uses hysteresis brakes to resist motion

Applications of Pasive Interfaces

- Many Passive haptic devices are intended as aids in the positioning of tools
  - Applications where a tool is locked in place once located (medical)
  - Concentration of giving graphical feedback over force feedback
  - Assist by supporting the majority of a payloads weight
  - Provide dynamic constraints to limit allowable motion

- Records show that only one passive haptic device was used to bilaterally teleoperate a slave
  - Chesney & Crane used the 6 dof passive joystick to bilateral teleoperate a slave for “peg in the hole” tasks

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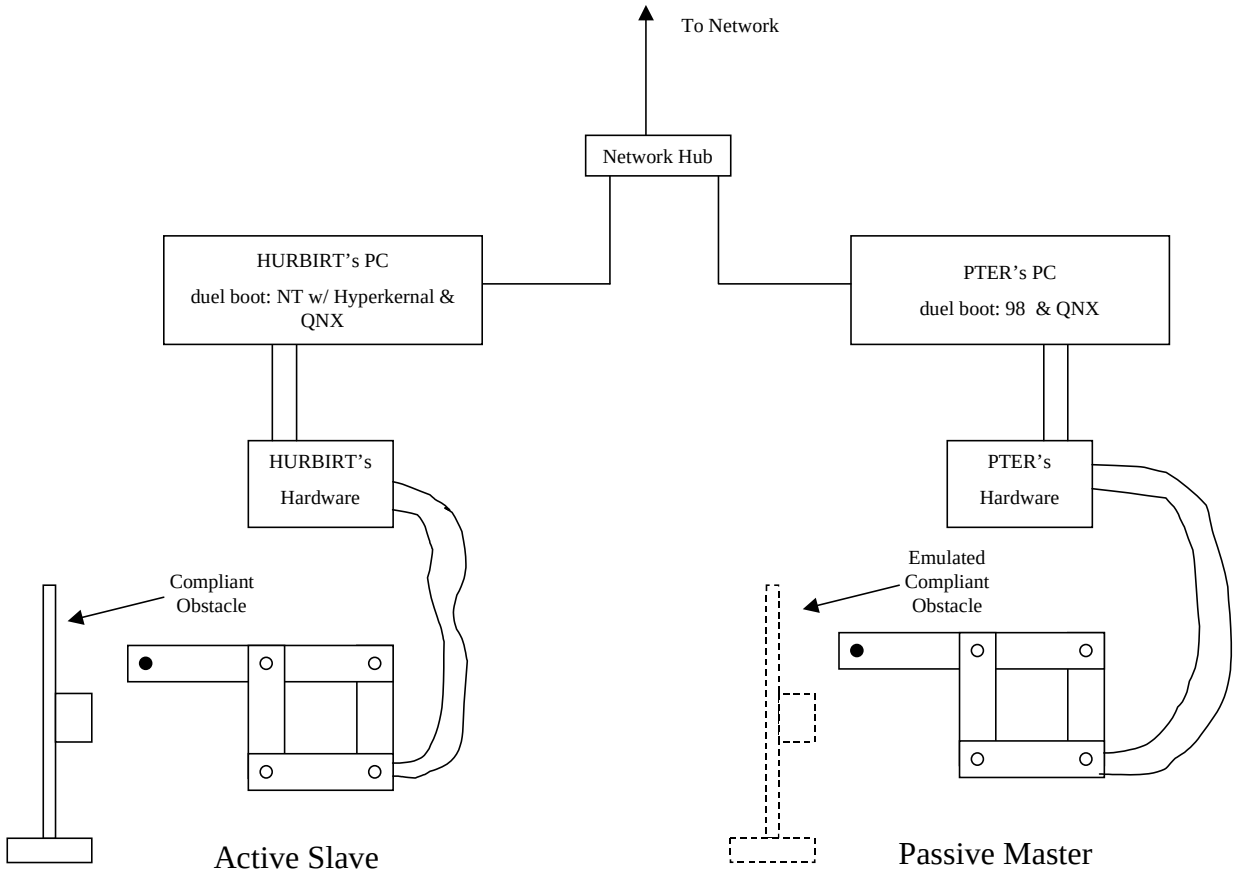
Proposed Initial Research



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Initial Deliverables

- Initial Goals to validate Hurbirt is working properly
  - Haptic feedback of virtual environments
  - Force sensing in compliant environments
  - Application of passivity theory to develop and characterize Hurbirt's control algortihms & range of dynamic impedance (i.e. Z width)

- Use PTER to teleoperate Hurbirt
  - 1. Control Hurbirt with PTER as a unilateral master
  - 2. Use PTER as a bilateral master

Hypothesized Issues

- Development of a test and metrics to compare “value added” of passive bilateral teleoperation over unilateral
- Stability of the slave when controlled by the passive master
- Communication via the internet (local)
- Force Feedback vs. Dynamic Constraint
- Modifications to PTER based on performance

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Immediate Activities

- Complete Literary Survey
  - ~33 more papers in hand to review / skim
    - Already read ~18 & skimmed ~19
  - ~35 abstracts to review
  - Follow up on Crane, Goodall, & Chesne's work
- Up to Speed on QNX & C++
  - Update Sobel to QNX & update Hurbirt's control code
- Hardware Modifications to Hurbirt
- Let Saghir finish his work with Hurbirt

Questions?

- Did you try to look up …….?
- Did you find any info regarding ……..?
- Why ……..?
- You should try ……..?