EuroHaptics2008
Workshop: Haptics Rendering

Time Domain Passivity Control for Stable Haptic Interaction

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Passivity

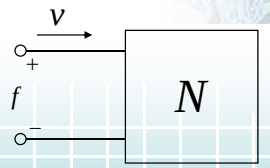
- Principle of conservation of energy:
  - *"Energy supplied BY the network can never exceed the energy which has been fed TO it"*
- Mathematical definitions

$$\int_0^t f(\tau)v(\tau)d\tau + E(0) \geq 0, \qquad \forall t \geq 0$$

Net energy supplied Initial energy storage

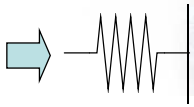
f : Force
v : Velocity

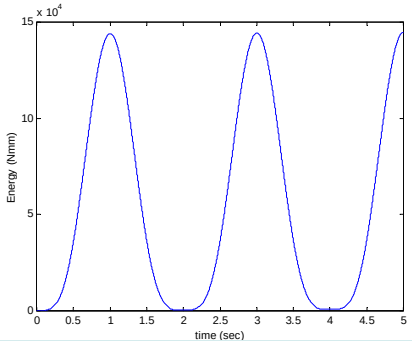
$f \cdot v > 0$
$f \cdot v < 0$

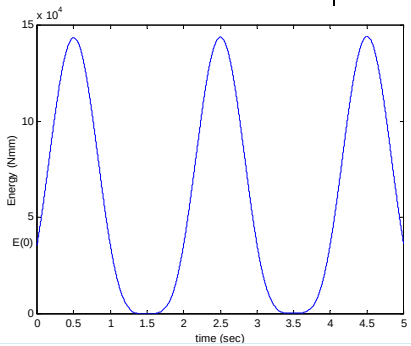


Energy Behavior of Spring

$$\int_0^t f(\tau)v(\tau)d\tau + E(0) \geq 0, \qquad \forall t \geq 0$$







Zero initial condition Initially deflected

Passivity Observer (PO) can Measure Energy Flow in Real Time

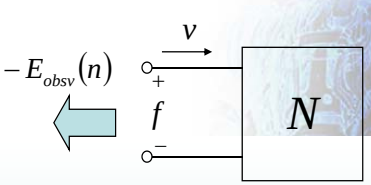
Passivity :

$$\int_0^t f(\tau)v(\tau)d\tau \geq 0, \qquad \forall t \geq 0$$

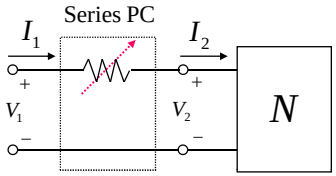
PO : $E_{obsv}(n) = \Delta T \sum_{k=0}^{n} f(k)v(k)$

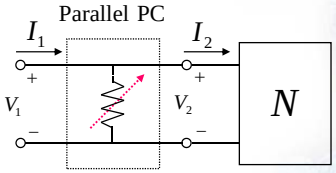
$E_{obsv}(n) \geq 0$: Passive

$E_{obsv}(n) < 0$: Active



Passivity Controller (PC) is an Adaptive Dissipation Element





Series or current conserving

Impedance causality

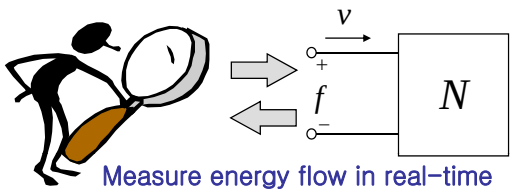
parallel or voltage conserving

Admittance causality

Time Domain Passivity Control

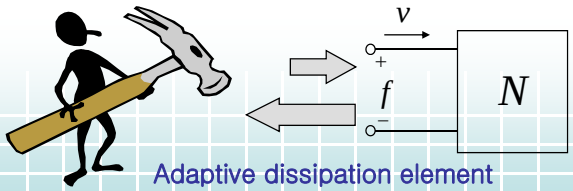
-IEEE TRA 2002-
-US Patent 2006-

❑ Passivity Observer (PO)



Measure energy flow in real-time

❑ Passivity Controller (PC)



Adaptive dissipation element

Series PC Algorithm

1) $v_1(n) = v_2(n)$ is an input

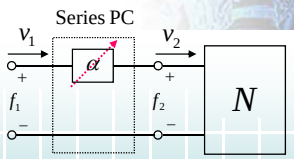
2) $f_2(n) = F_N(v_2(n))$

where $F_N(\ )$ is the output of the one-port

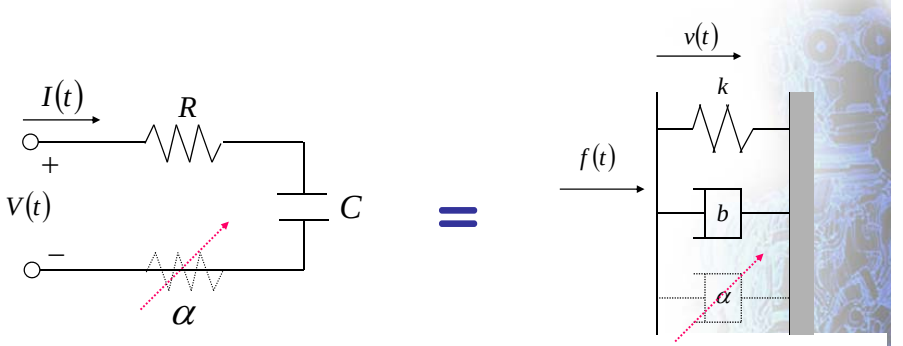
3) $E_{obsv}(n) = E_{obsv}(n-1) + [f_2(n)v_2(n) + \alpha(n-1)v_2(n-1)^2]\Delta T$

4) $$\alpha(n) = \begin{cases} -E_{obsv}(n)/\Delta T\, v_2(n)^2 & \text{if } E_{obsv}(n) < 0 \\ 0 & E_{obsv}(n) \geq 0 \end{cases}$$

5) $f_1(n) = f_2(n) + \alpha(n)\, v_2(n) \Rightarrow$ output

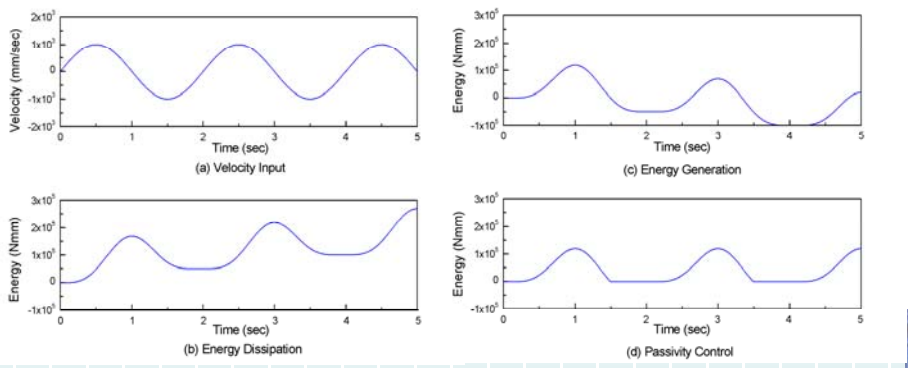


Simple Simulation of Series PC

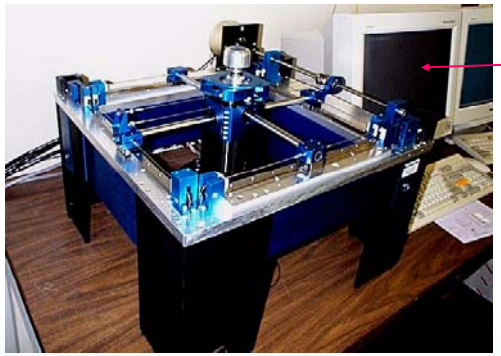


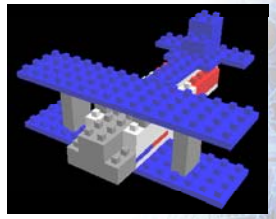
$k = 710\ N/m$
$b = 50\ Ns/m$

Simulation Results



Implemented to Excalibur Haptic Interface at University of Washington





Virtual Lego Airplane

Lego Haptic Device (LHD)

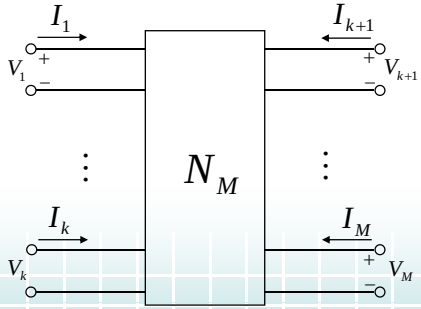
ISSUE: Maximum allowable stiffness

Haptic Interaction with a High Stiffness VE (stiffness = 90kN/m)

Extension to Multi-port Cases

- Where to place the PC ?
- What type of PC ?
- How to activate the PC ?
- How to apply teleoperation systems?

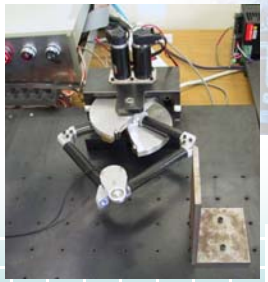
-IEEE TRA 2004-



Applied to Two-DOF Teleoperation System

- Hardware
  - Carbon fiber for increasing stiffness to mass ratio
  - Cable driven mechanism
- Software
  - QnX for RTOS, 1kHz sampling

Master

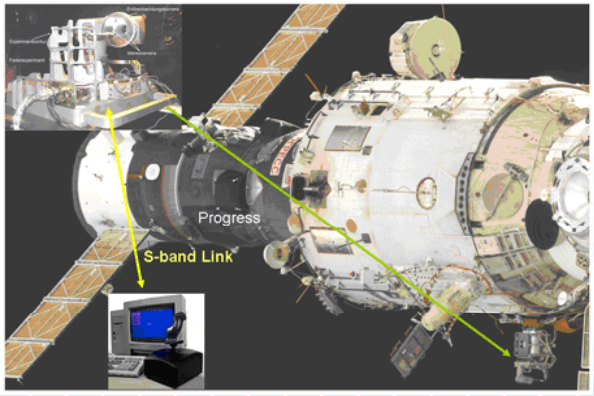


Slave

Experiment of Teleoperation

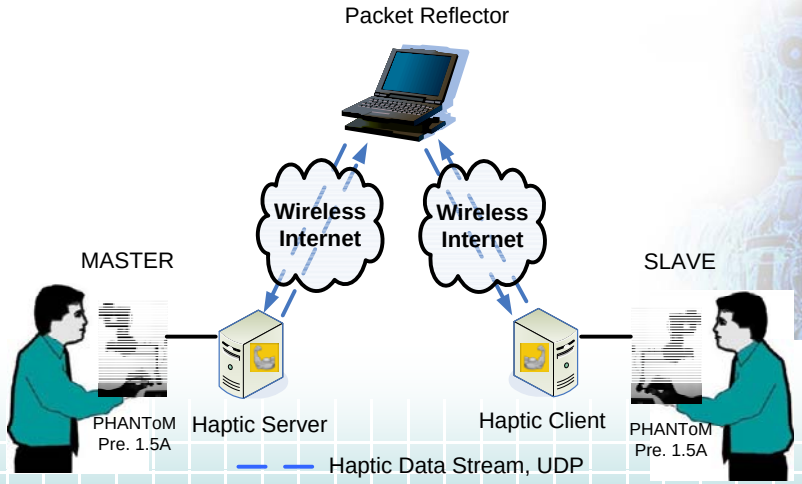
Time-delayed Teleoperation

- Ground-space bilateral control

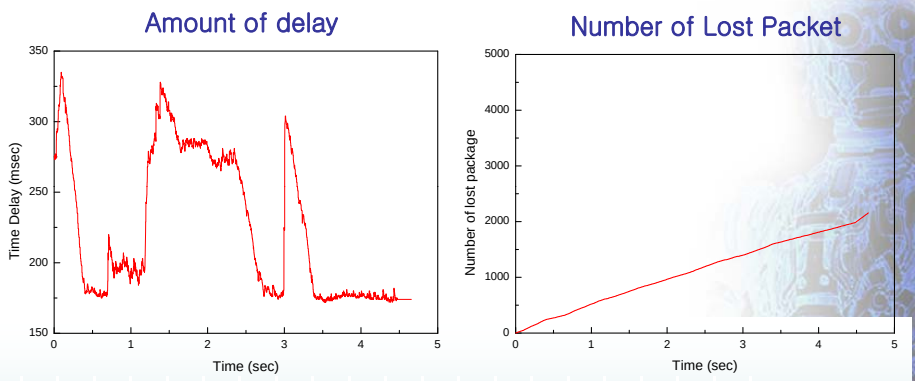


Need to consider time-delay

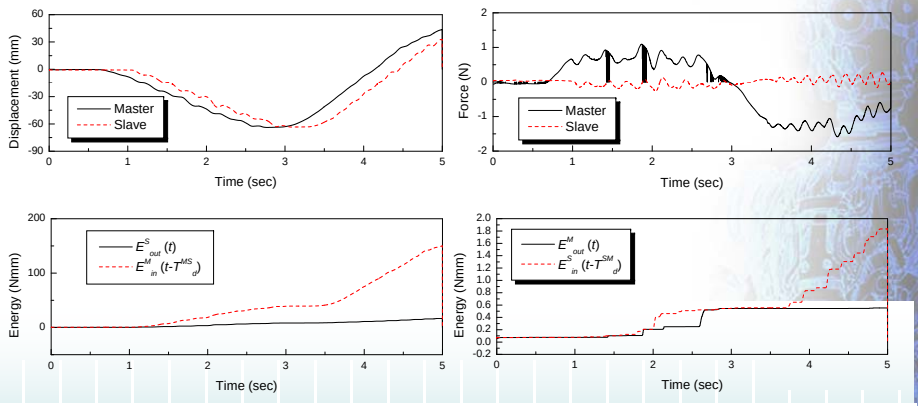
Time-varying Delay



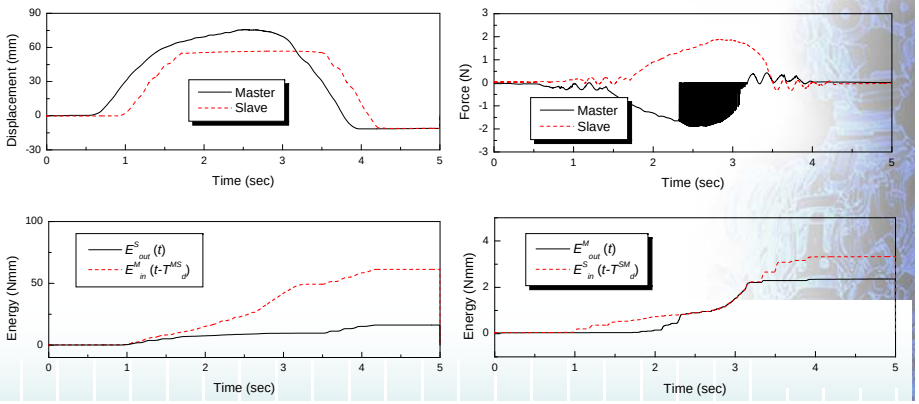
Time-varying Delay and Data Loss



Free Motion with PO/PC

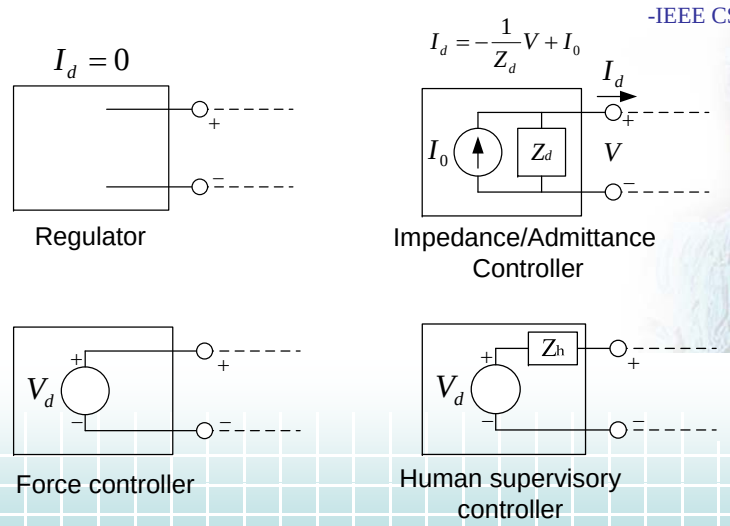


Contact Motion with PO/PC



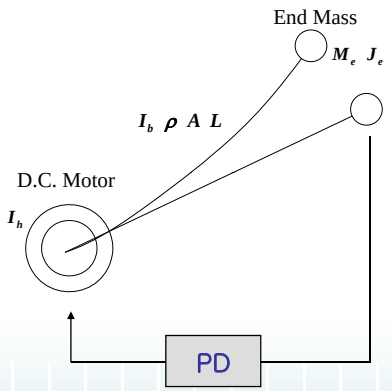
Generalization of the PO/PC Approach

-IEEE CST 2004-

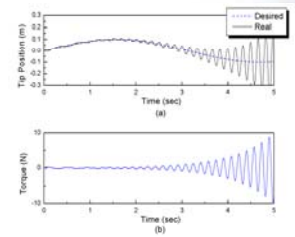


Motion Control of Single-link Flexible Manipulator with Non-collocated feedback

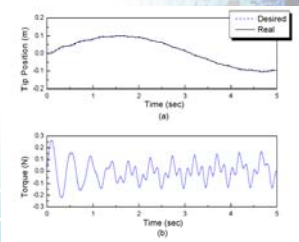
-IEEE TRO 2004-



Non-collocated Position PD-controller

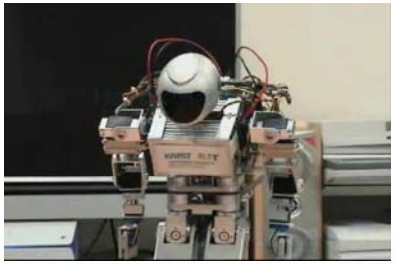


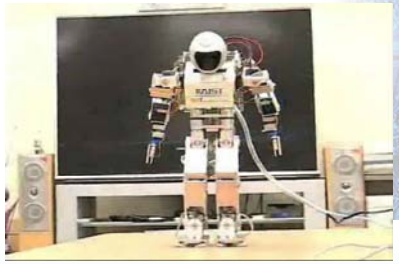
W/O the PC



W/ the PC

Stable Walking





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Thank you

Q & A

http://robot.kut.ac.kr