Haptic Systems
530-655

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Lecture 11
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Stability of Haptic Systems

- An overview of classic control
- Control problems in haptic systems
- Passivity theory
- References
An overview of classic control systems

Control objectives
- Minimum rise time
- Minimum overshoot
- Stability

Control tools
- Root locus
- Nyquist diagram
- Bode diagram

Performance factors
- Rise time
- Gain margin and Phase margin
- Bandwidth
- Steady state error
Haptic rendering systems

Plan: Robot + Human user

Controller: Virtual environment + Compensator

Control objectives
- Stability
- Transparency

Control tools
- Analytical tool
- Passivity Theory

Performance factors
- ?

Do not look at the control problem in haptic systems as a classic control problem
Haptic system for a virtual wall

**Operator:** uncertain model $\rightarrow$ **Passivity theory**

**Virtual wall:** Nonlinear model $\rightarrow$ **Nonlinear control theory**
Comparing a physical wall and a virtual wall

Interaction with a physical wall
- There is no oscillation
- The wall does not generate energy
- The wall is passive

Interaction with a virtual wall
- There might be oscillation
- The wall may generate energy
- The wall can be active
Passivity condition

Interaction with a physical wall

\[ E(t) - E(0) = \int_{0}^{t} f \cdot dx = \int_{0}^{t} f \cdot \frac{dx}{dt} \, dt = \int_{0}^{t} f \cdot v \, dt \]

\[ \int_{0}^{t} f \cdot v \, dt \geq 0 \]
Passive system properties

\[ \int_0^t f_1 \cdot v dt \geq 0 \]
\[ \int_0^t f_2 \cdot v dt \geq 0 \]

\[ \int_0^t (f \cdot v) dt = \int_0^t (f_1 + f_2) \cdot v dt = \int_0^t f_1 \cdot v dt + \int_0^t f_2 \cdot v dt \geq 0 \]

Passivity and stability

A passive system is stable
Components of a haptic system

Operator

Device

\[ v(t) \]

sample & hold

virtual wall

\[ x(t) \]

\[ \int \]
Passivity of a Virtual Wall
References:

Jean-Jacques Slotine, Weiping Li, Applied Nonlinear Control

Tomorrow

Effects of time-discretization and position
quantization on the stability of haptic systems