

Haptic Systems

530-655

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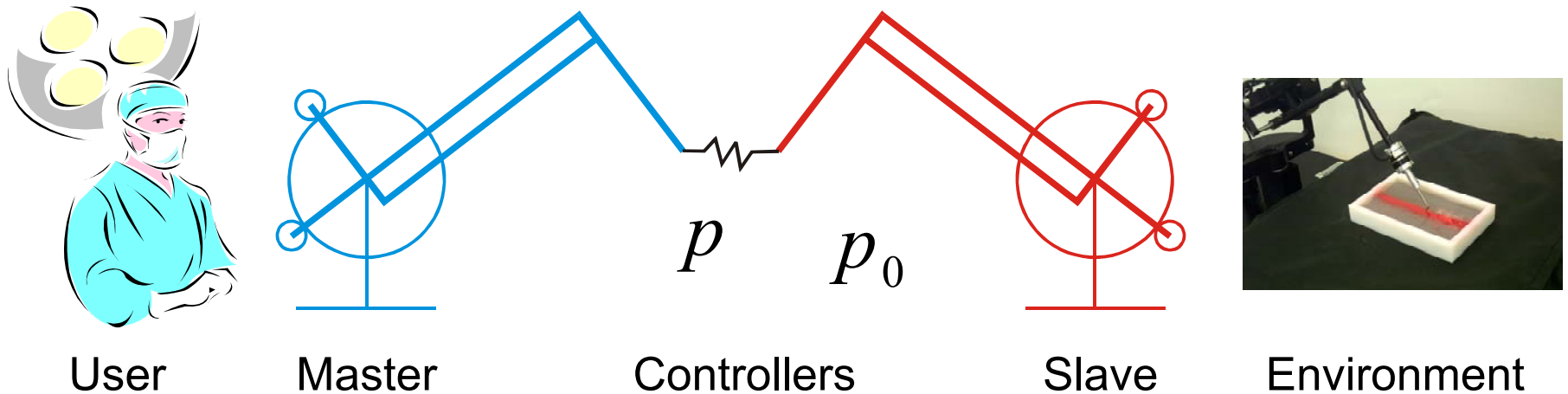
Lecture 14

27/1/06

Stability and transparency of force-feedback telemanipulation systems

- A position-position teleoperation structure
- Network model of a teleoperation system
- Transparency and stability
- References

A position-position teleoperation structure



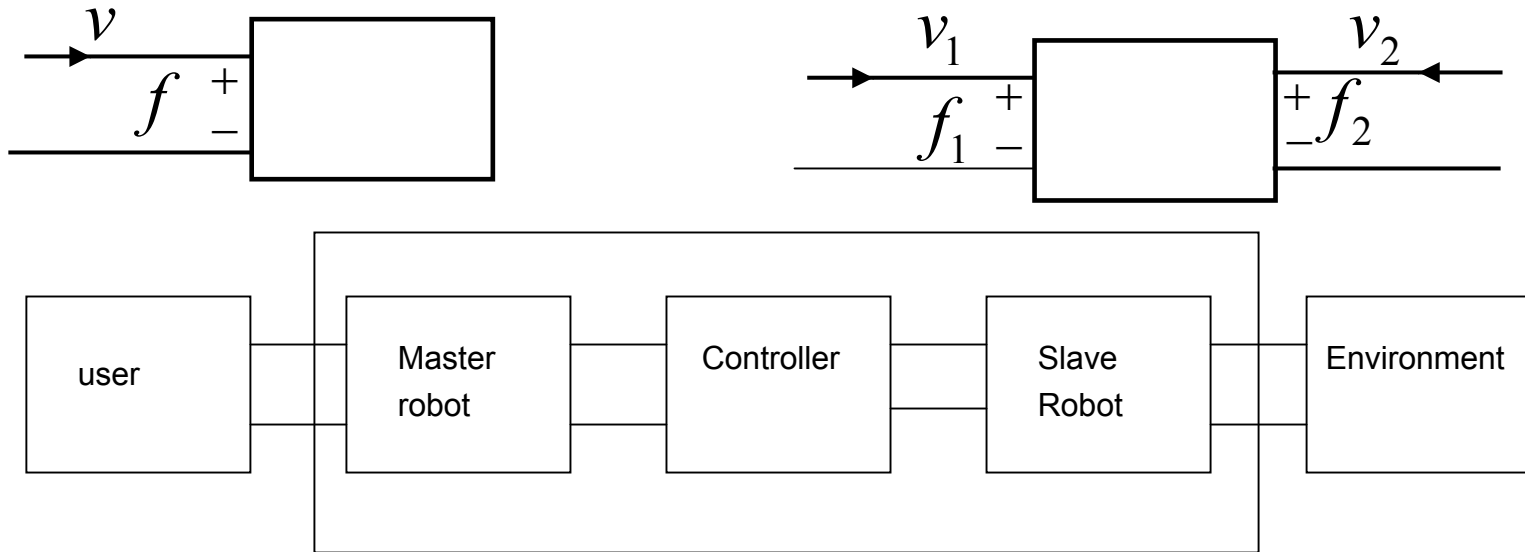
Objectives:

- Performance (Telepresence)
The users should feel that they are directly performing a task rather than controlling a robot
- Stability

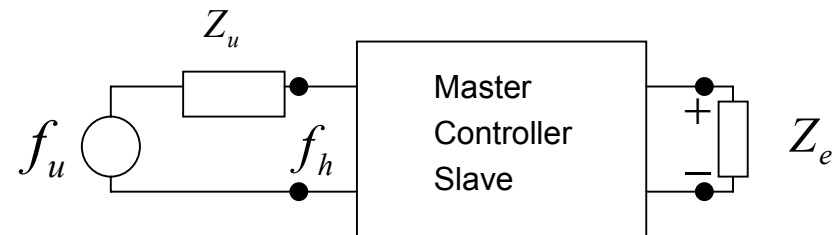
Control problems: delay, device dynamics, friction

Network model of a teleoperation system

In general, the teleoperation system behavior is smooth enough to be modeled by a linear model in a neighborhood of an operating point

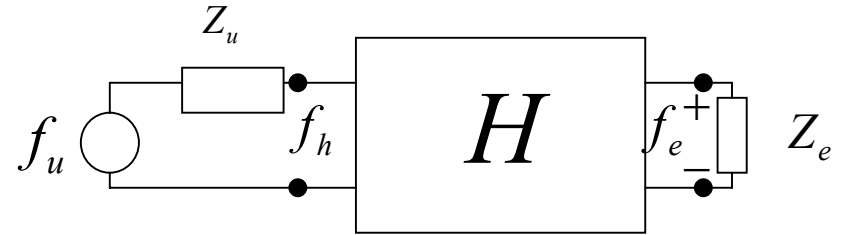


$$\begin{bmatrix} f_h \\ v_h \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} v_e \\ -f_e \end{bmatrix}$$



H Matrix

$$\begin{bmatrix} f_h \\ v_h \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} v_e \\ -f_e \end{bmatrix}$$



$$H = \begin{bmatrix} z_{in} & \text{Rev force} \\ \text{velocity} & \text{Scale} \\ \text{scale} & \frac{1}{z_{out}} \end{bmatrix}$$

Transparency

$$H = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}$$

Transparency

$$z_t = z_e$$

$$z_t = (h_{11} - h_{12}z_e)(h_{21} - h_{22}z_e)^{-1}$$

Four Channel Controller

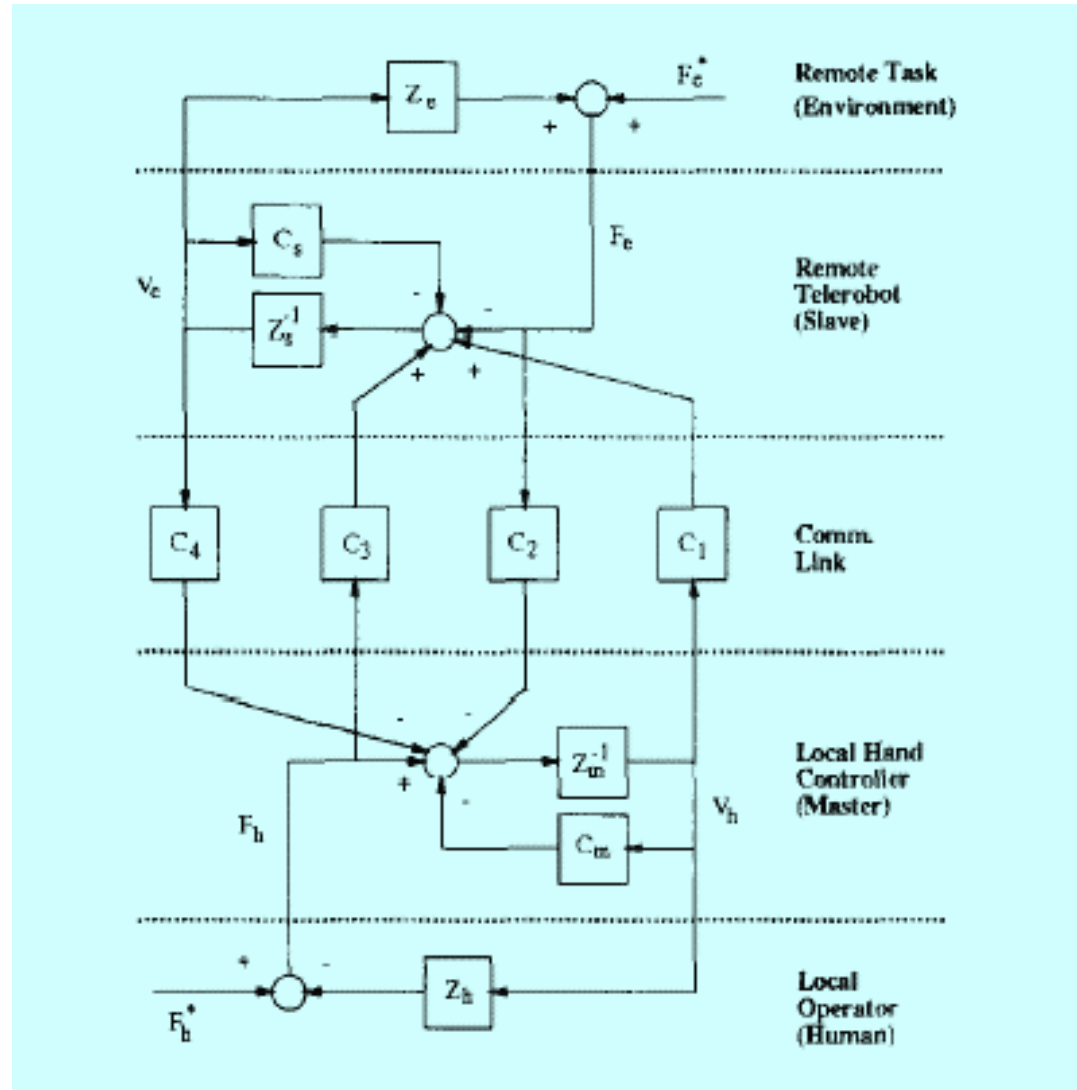
$$h_{11} = (Z_m + C_m)D(Z_s + C_s - C_3C_4) + C_4$$

$$h_{12} = -(Z_m + C_m)D(1 - C_3C_2) - C_2$$

$$h_{21} = D(1 + C_s - C_3C_4)$$

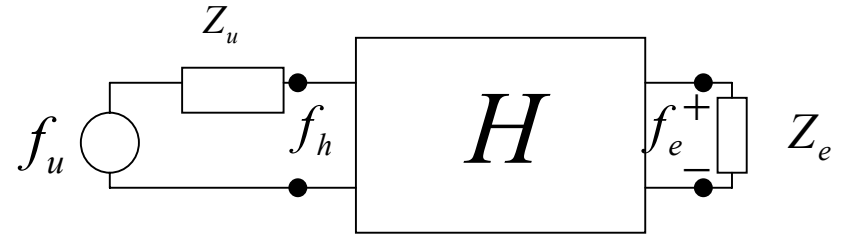
$$h_{22} = -D(1 - C_3C_2)$$

$$D = (C_1 + C_3Z_m + C_3C_m)^{-1}$$



Stability of a teleoperation system

$$\begin{bmatrix} f_h \\ v_h \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} v_e \\ -f_e \end{bmatrix}$$



Scattering operator

$$F - V = S(F + V) \quad S(s) = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} (H(s) - I)(H(s) + I)^{-1}$$

$$\sup_w \lambda^{1/2}(S^T(w)S(w)) \leq 1 \quad \text{iff the system is passive}$$

References

1. R. J. Anderson and M.W. Spong, "Bilateral control of teleoperators with time delay," IEEE Trans. Automat. Contr., vol. 34, pp. 494–501, May 1989
2. D. A. Lawrence, "Stability and transparency in bilateral teleoperation," IEEE Trans. Robot. Automat., vol. 9, no. 5, pp. 624–637, 1993.
3. A design framework for teleoperators with kinesthetic feedback B Hannaford - IEEE Transactions on Robotics and Automation, 1989
4. Colgate, J.E., Robust impedance shaping telemanipulation, IEEE Transactions on Robotics and Automation, 1993 Vol:9, Issue: 4, pp. 374-384.