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Human-machine interaction force control: using a model-referenced adaptive impedance device to control an index finger exoskeleton

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Key words: Interaction force, Adaptive control, Exoskeleton, HMI, Impedance

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Motivation

- **Disadvantages of existing methods: 1.** Most methods consider the human-machine interaction system as a linear time-invariant (LTI) system, but the parameters of the interaction system are uncertain. **2.** There is no effective strategy for hand exoskeleton interaction force control.
- **Our method:** We propose a model reference adaptive impedance control (MRAIC) method, which combines impedance control and model reference adaptive control. The former is effective for interaction force control, and the latter is effective for nonlinear systems. The method is demonstrated using an index finger exoskeleton system.

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Framework of our method

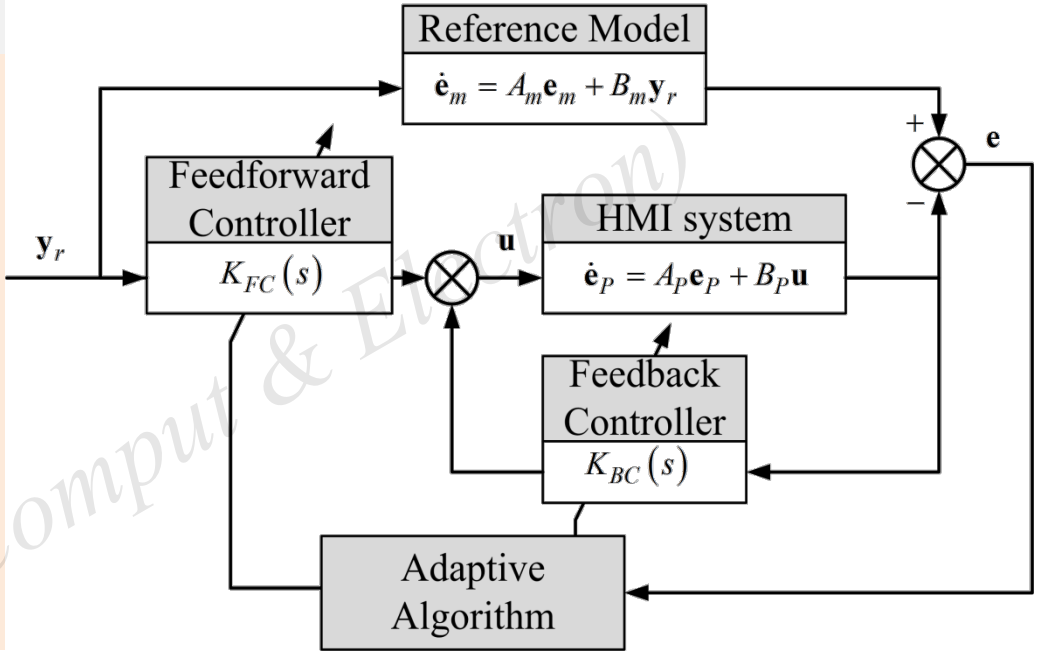
HMI system

$$\dot{\boldsymbol{e}}_P = \boldsymbol{A}_P \boldsymbol{e}_P + \boldsymbol{B}_P \boldsymbol{u}$$

$$\boldsymbol{e}_P = \begin{bmatrix} E_F \\ \dot{E}_F \end{bmatrix},$$

$$\boldsymbol{A}_P = \begin{bmatrix} 0 & 1 \\ -\dfrac{K_T + K_H}{M_T + M_H} & -\dfrac{B_T + B_H}{M_T + M_H} \end{bmatrix},$$

$$\boldsymbol{B}_P = \begin{bmatrix} 0 & \dfrac{K_T K_H}{M_T + M_H} \end{bmatrix}^{\mathrm{T}}.$$



Reference model

$$\dot{\boldsymbol{e}}_m = \boldsymbol{A}_m \boldsymbol{e}_m + \boldsymbol{B}_m \boldsymbol{y}_r$$

$$\boldsymbol{e}_m = \begin{bmatrix} E_m \\ \dot{E}_m \end{bmatrix}; \boldsymbol{A}_m = \begin{bmatrix} 0 & 1 \\ -\omega^2 & -2\xi\omega \end{bmatrix}, \boldsymbol{B}_m = \begin{bmatrix} 0 \\ \dfrac{K_T K_H}{M_T + M_H} \end{bmatrix}.$$

Control law

$$\begin{cases} \dot{\boldsymbol{K}}_B = \boldsymbol{R}_1 \boldsymbol{B}_m{}^{\mathrm{T}} \boldsymbol{P} \boldsymbol{e} \boldsymbol{e}_P{}^{\mathrm{T}} \\ \dot{\boldsymbol{K}}_F = \boldsymbol{R}_2 \boldsymbol{B}_m{}^{\mathrm{T}} \boldsymbol{P} \boldsymbol{e} \boldsymbol{y}_r{}^{\mathrm{T}} \end{cases}$$

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Summary

- **Motivation:** Design an approach for HMI force control to solve the problem that the interaction system between the human body and exoskeleton is uncertain and nonlinear.
- **Methodology:** This article presents a model reference adaptive impedance control (MRAIC) method for an index finger exoskeleton.
- **Performance:** Experiments indicated that the MRAIC scheme is effective for the nonlinear HMI problem in hand exoskeleton control, for which the PID or other linear methods do not work well. Frequency simulation shows that the system performance is optimal in the bound between 0.1 Hz and 5 Hz, which is the frequency range of human body movement.

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