LoopShaping-based Exoskeleton Control

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Outline

Motivation

Our target is to provide assistance with exoskeleton for people weak in strength. In traditional methods, we model the motion of the human lower limb as a single-pendulum, and model the effect of inertial, damping and gravity as a standard second-order ordinary differential equation.

We take the knee joint into consideration, and handle the problem in frequency domains. We believe by increasing the natural frequency of the human lower limb after coupled with exoskeleton and increasing the magnitude of the walking gait, the patients will have better walking performance.

Performance index

- We plot the integral admittance(we can regard it as angle-torque relation here) of the human lower limb and a desired admittance in the graph. Three control parameters are introduced.

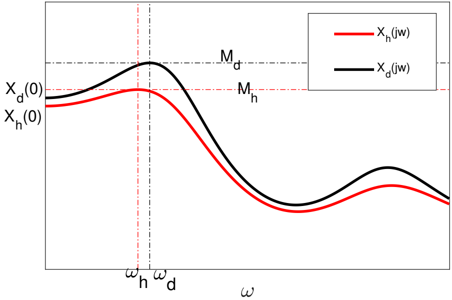

Figure: Frequency response of the unassisted human lower limb's integral admittance $X_h(jw)$ and an desired integral admittance $X_d(jw)$. The chosen control parameters are: $R_w = 1.05, R_M = 1.20, R_{CD} = 1.30$.

Loopshaping framework

- We can express the integral mechanical admittance as follows:

$$X_h = \frac{\hat{M}_{11}(s^2 + b_2 s + \hat{K}_{22}) - \hat{K}_{12}\hat{M}_{21}}{(s^2 + b_1 s + \hat{K}_{11})(s^2 + b_2 s + \hat{K}_{22}) - \hat{K}_{12}\hat{K}_{21}} \tag{1}$$

and the coupled model is:

$$Y_{couple} = \frac{\Omega_h}{\tau_h} = \frac{Y_h}{1 - Z_f Y_h} \tag{2}$$

where

$$Y_h = X_h s \tag{3}$$

so our task is then becoming control the term Z_f, which represents the assistive action of the exoskeleton.

DC gain and lead control

- We use the integral feedback compensator for DC gain to meet the static case of the coupled system, and introduce the lead controller to tune the peak of the frequency response plot.

$$Z_f = k\frac{k_{DC}}{s}\frac{s+a}{s+b} \tag{4}$$

  Because we need to meet the specific DC gain requirement, we set the constant k as $k = b/a$. So the problem comes down to find the parameter a and b, as k_{DC} can be solved directly by the target DC gain requirement.

- An cost function (target performance cost function) is introduced.

Plot results and video simulation

- In terms of the previously used human data and after the optimization, we find the parameters, thus providing the controller Z_f. The plot result is as follows:

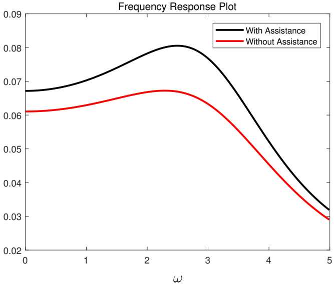

Figure: Comparison between the initial frequency response and the one after coupled with assistive exoskeleton.

- The simulation video can be found at $http://nichao.xyz/research/simulation2.avi$

Conclusion and Possible future work

- We deduce the double-pendulum model of the lower limb and thus provide the admittance transfer function between the input torque and output angle. We design an integral feedback controller as well as a lead controller. In the control design procedure, we set three control goals: frequency ratio, resonant ratio and DC gain ratio. Our control rule can exactly meet the DC gain ratio, and the rest two are met by numerical optimal solution.
- The simulation results shows the prospect of this control design approach. In future work, we would apply our method in a real lower exoskeleton and see how it works in rehabilitation. We expect this design approach will provide insight in lower limb exoskeleton control.