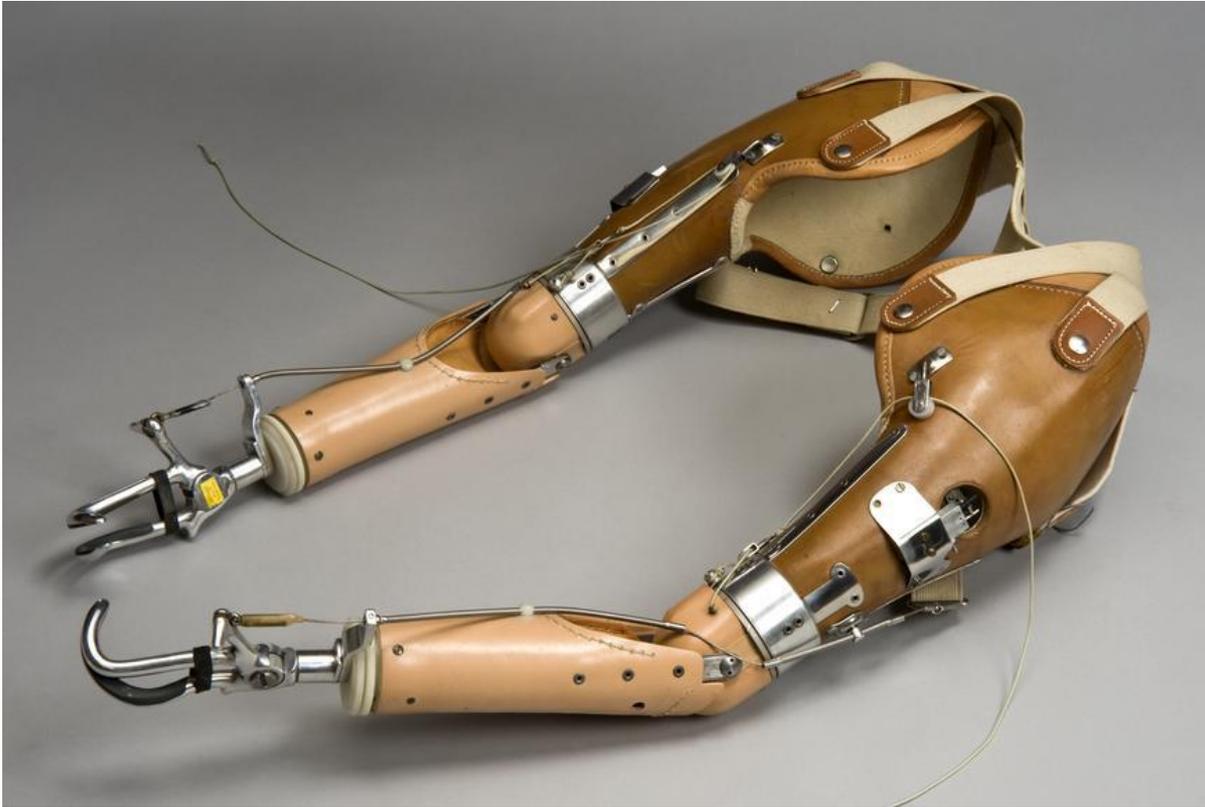


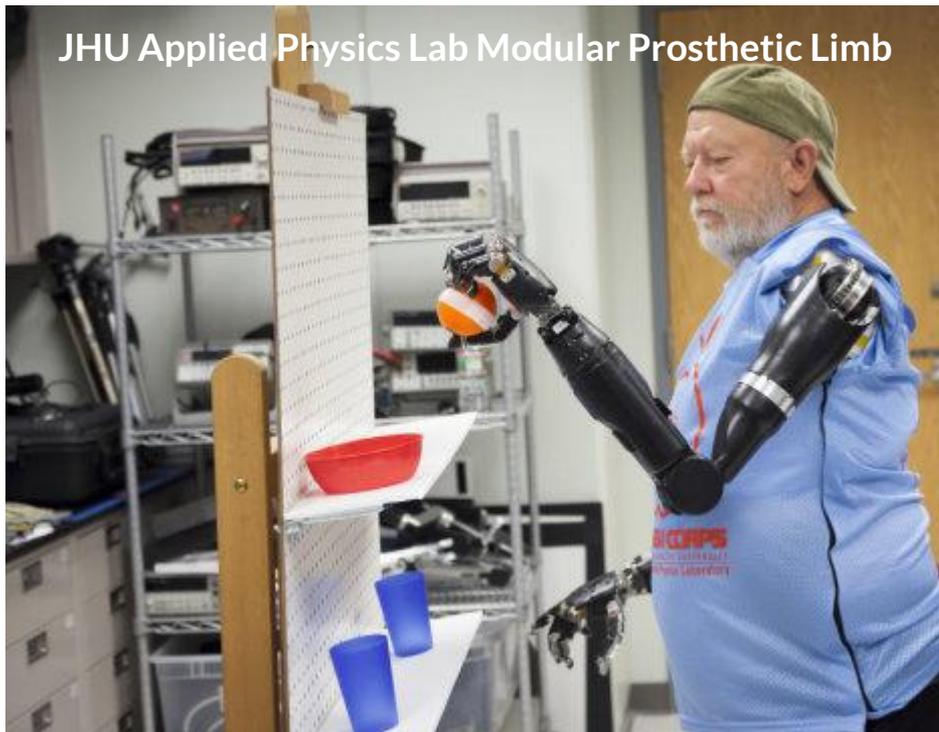
Designing Feedback Controllers for Human-Prosthetic Systems Using H-Infinity Model Matching

Julia Costacurta, Luke Osborn, Nitish Thakor, Sridevi Sarma

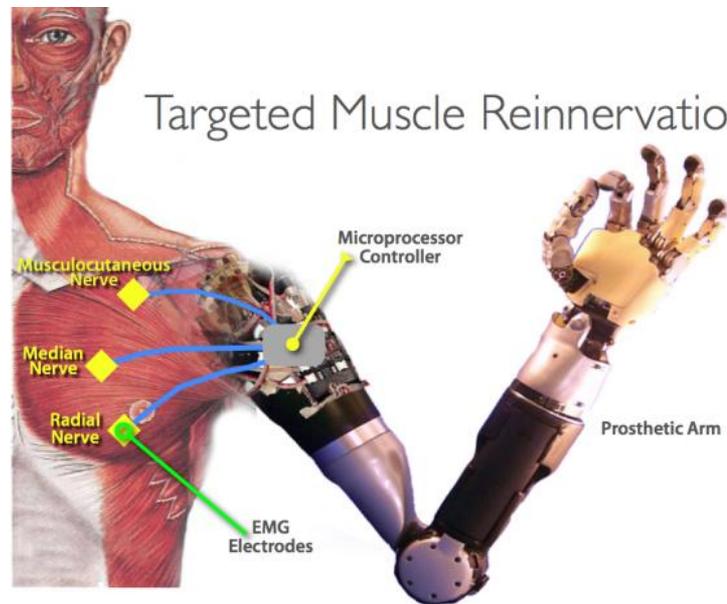




JHU Applied Physics Lab Modular Prosthetic Limb

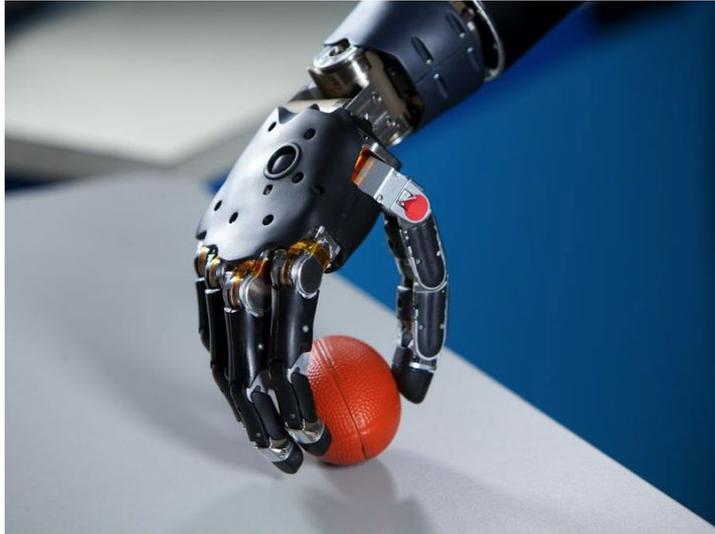


Targeted Muscle Reinnervation



Why People Abandon High-Tech Prosthetics

That Luke Skywalker prosthetic arm may strike the average user as less than sensational



(Wikimedia Commons)

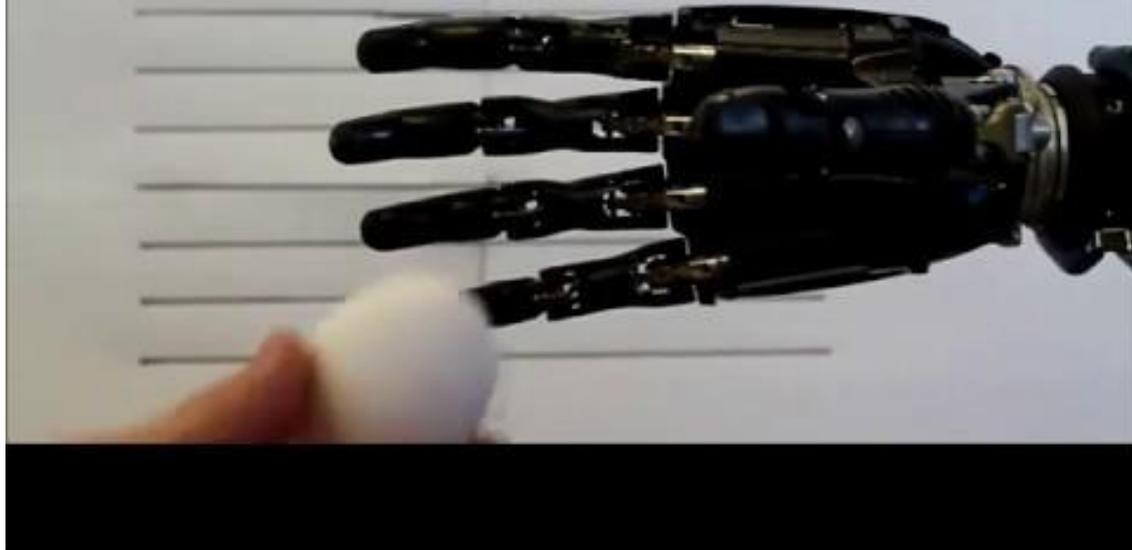
By [Patrick McGurrin](#), [Zócalo Public Square](#)

SMITHSONIAN.COM

JUNE 29, 2016

1 in 5 upper-limb prosthesis users eventually abandon their devices

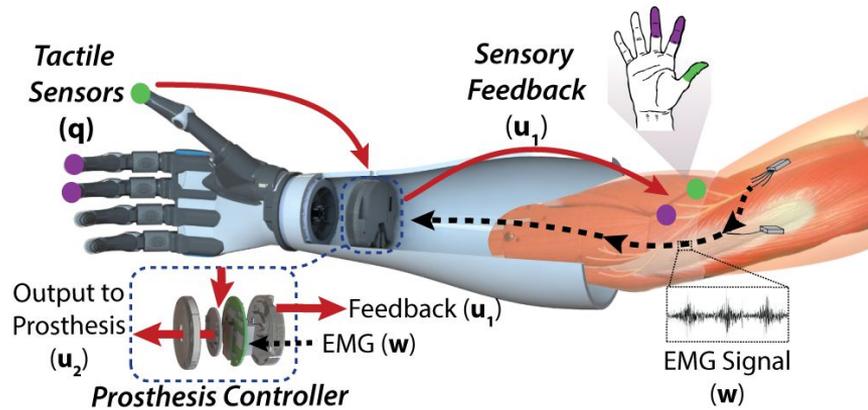
bebionic (RSL Steeper) prosthetic hand



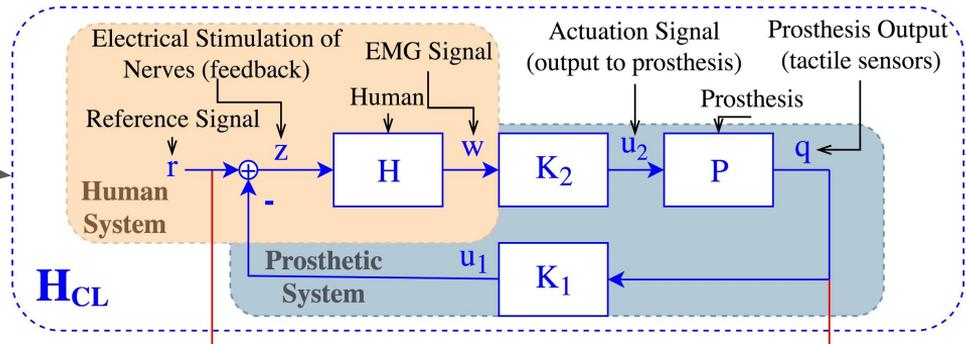
Is there is a mathematical framework that can be used to design feedback controllers which make a user feel like they're using their natural limb?

Is there is a mathematical framework that can be used to design feedback controllers, i.e. sense of touch, which make a user feel like they're using their natural limb?

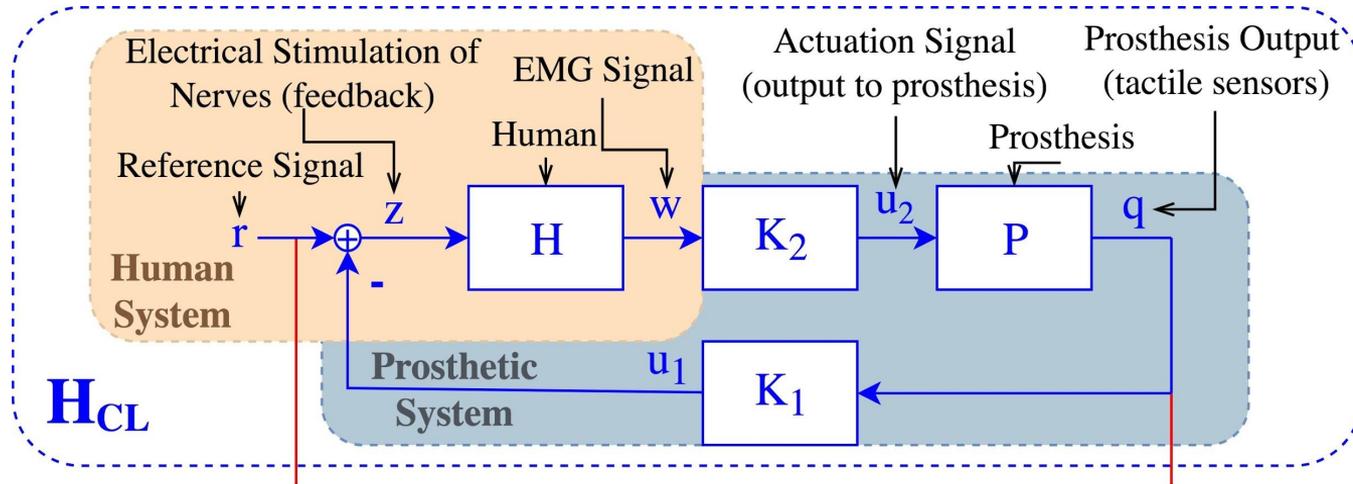
Approach: Optimal control techniques for feedback design



Conversion to Block Diagram

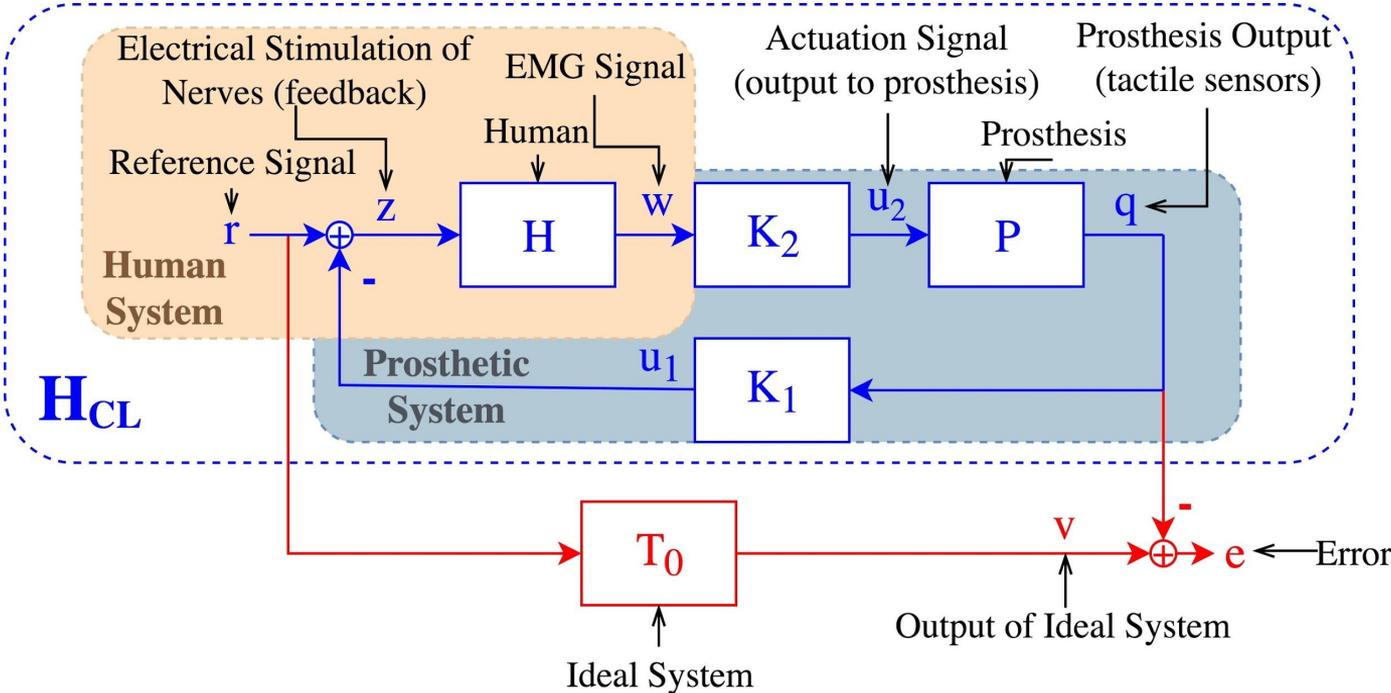


Block Diagram



- Two controllers to be designed: K_1 and K_2
- Blue system represents H_{CL} , closed-loop human-prosthesis system

Block Diagram

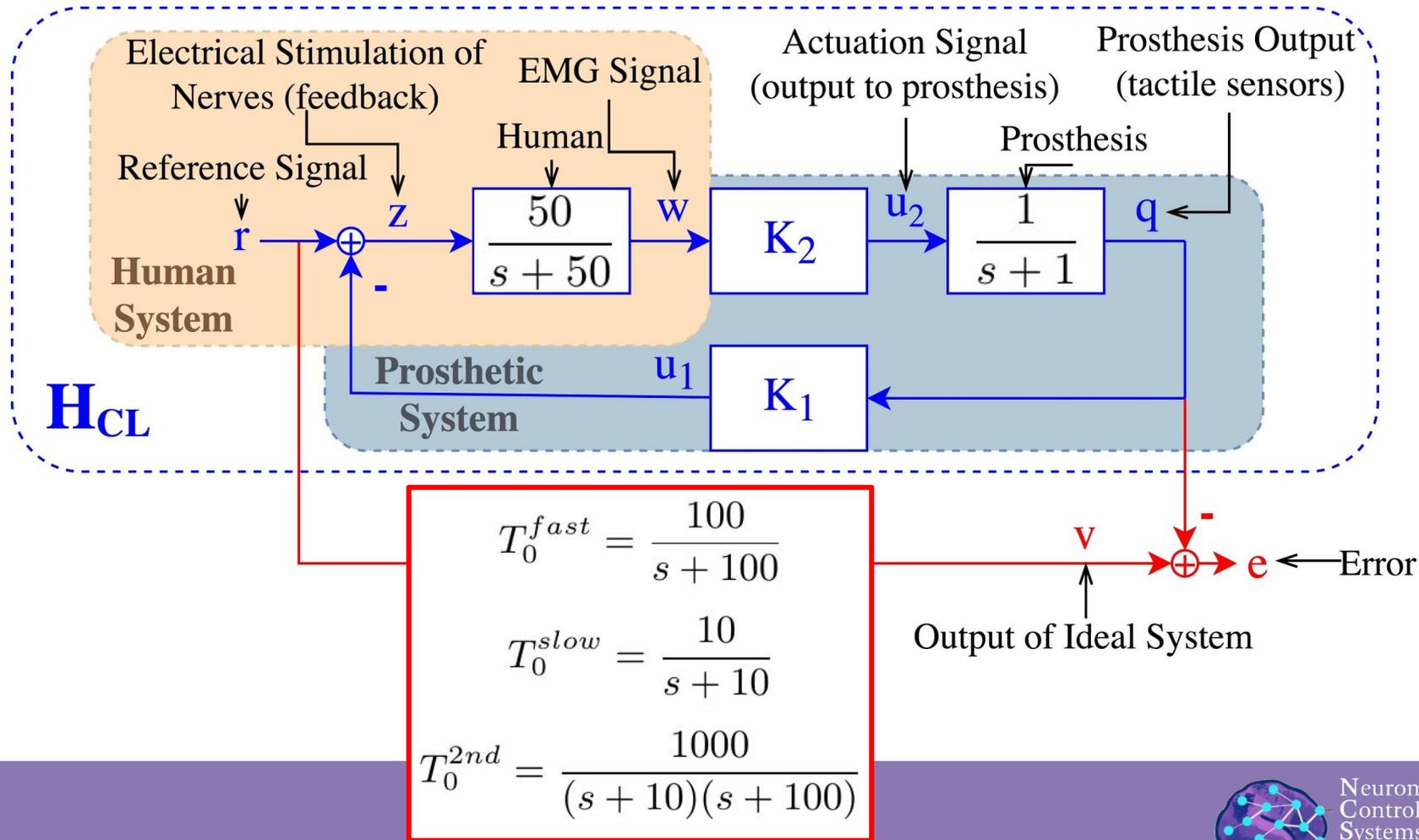


User-Prosthetic Model Matching Problem:

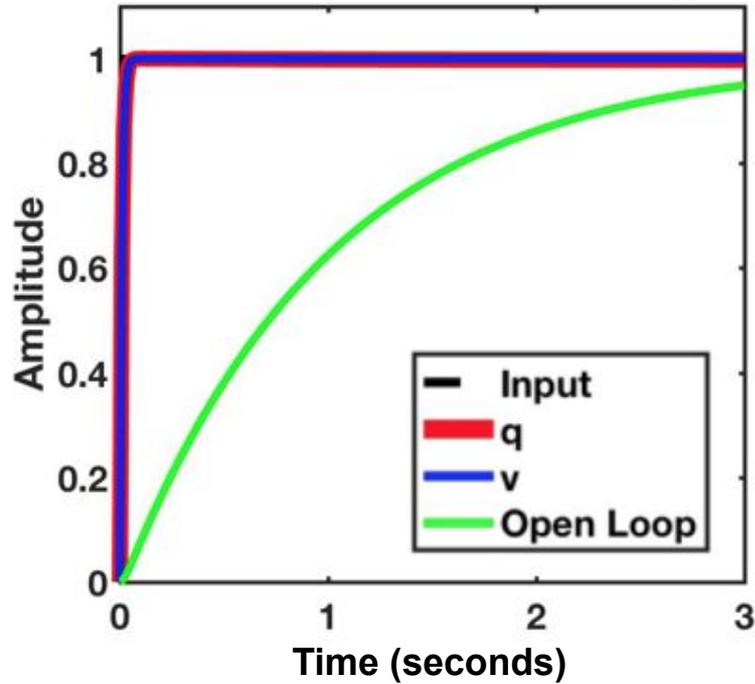
$$\min_{K_1, K_2} \|H_{CL}(K_1, K_2) - T_0\|_{H_\infty} \quad (1)$$

s.t. H_{CL} is stable.

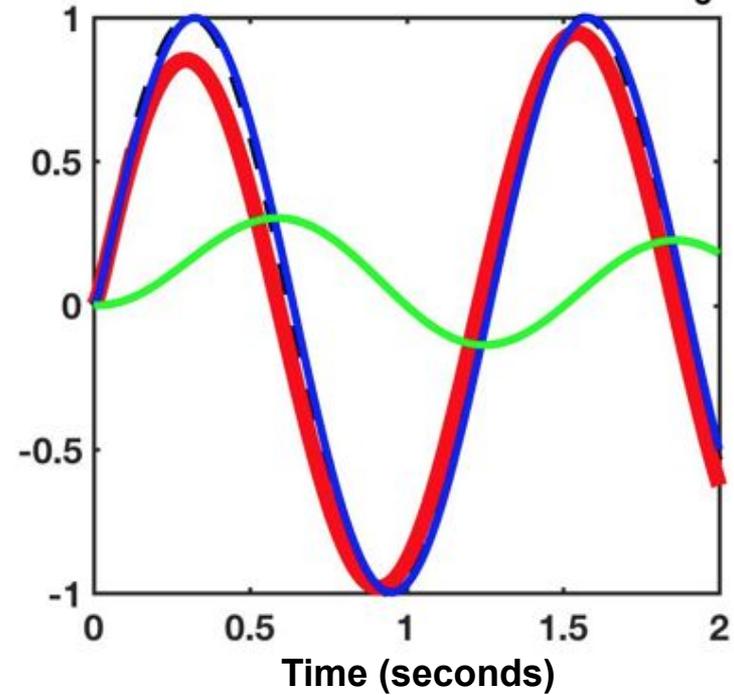
$$\|e\|_\infty = \sup_{\omega} \sigma(e(j\omega))$$



Responses to Step Input, T_0^{fast}

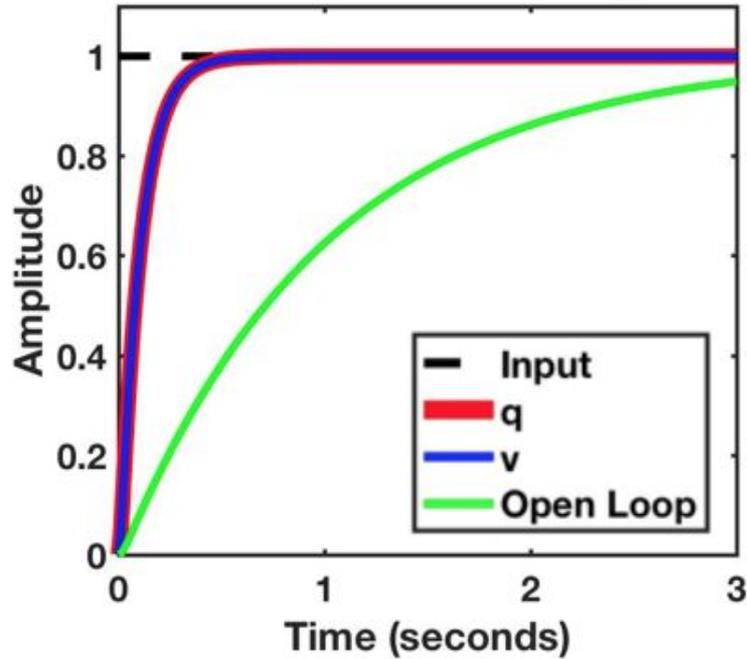


Responses to Sinusoid Input, T_0^{fast}

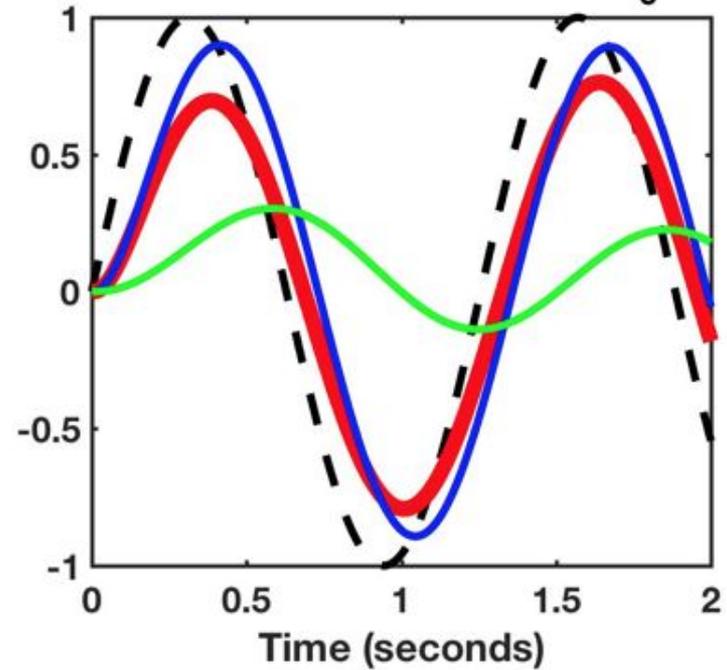


$$T_0^{fast} = \frac{100}{s + 100}$$

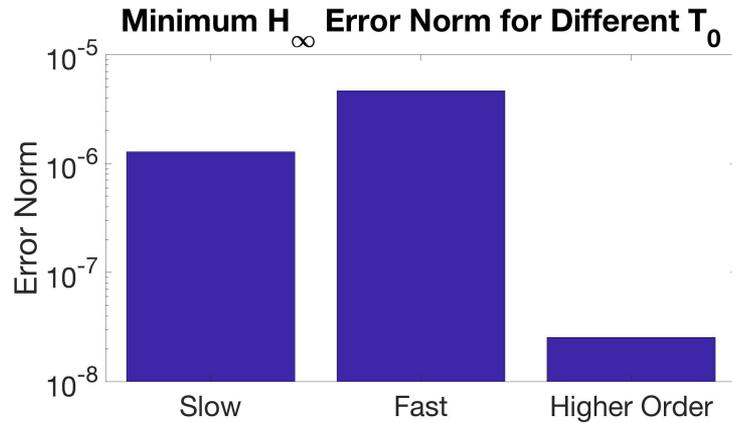
Responses to Step Input, T_0^{2nd}



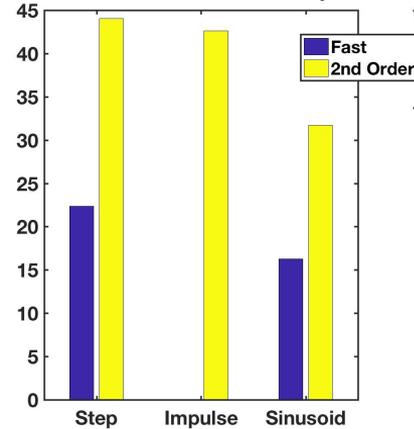
Responses to Sinusoid Input, T_0^{2nd}



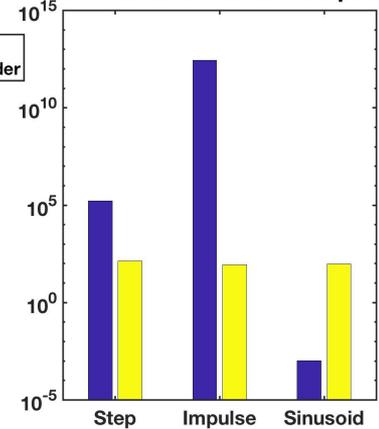
$$T_0^{2nd} = \frac{1000}{(s + 10)(s + 100)}$$



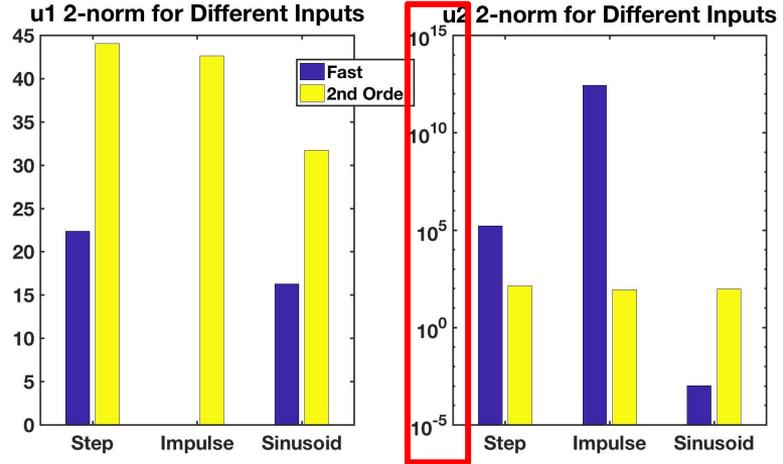
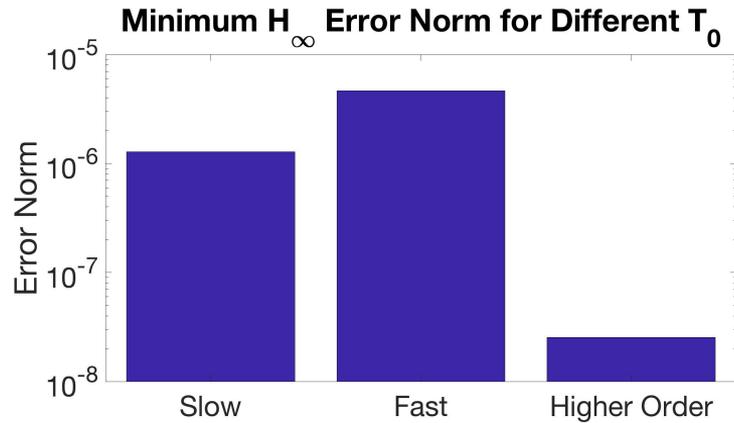
u1 2-norm for Different Inputs



u2 2-norm for Different Inputs



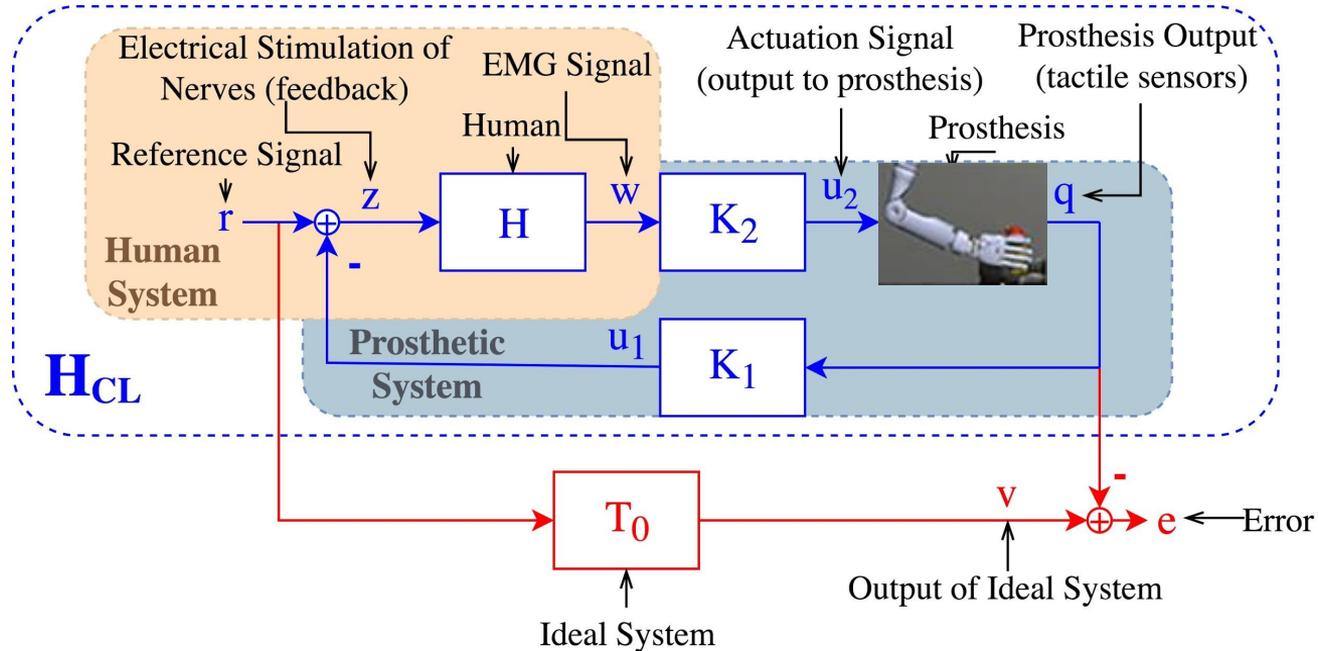
- Controllers work better for slower and higher order transfer functions
 - Slower TFs give more room for tuning
 - Higher order allows more flexibility in controller design
- Must add energy constraints to optimization



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Next Steps

- Integration of virtual prosthetic limb into control architecture



Thank you for your attention!

