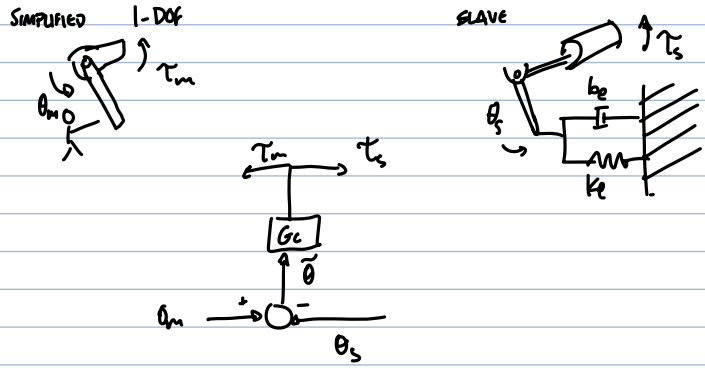
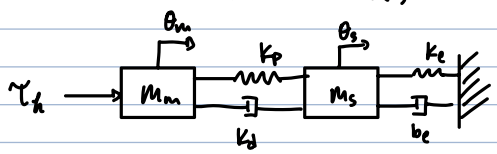
24 Teleoperation + Haptics



Choose $G_c = K_p + K_d s = \frac{\tau(s)}{\theta(s)}$ ← passed into both master + slave



τ_h = human-input torque

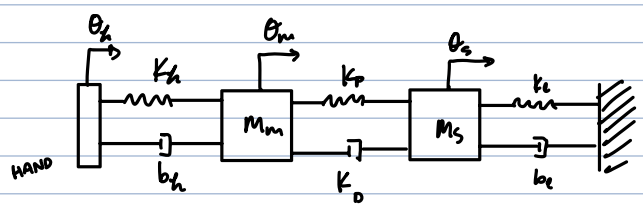
How can we ensure stability?

Neglecting damping

$$\frac{\theta_m(s)}{\tau_h(s)} = \frac{m_s s^2 + (k_e + k_p)}{m_m m_s s^4 + [(k_p + k_e) m_m + K_p m_s] s^2 + k_e + k_p}$$

Lets say we model the human as a position input w/some compliance

Human compliance

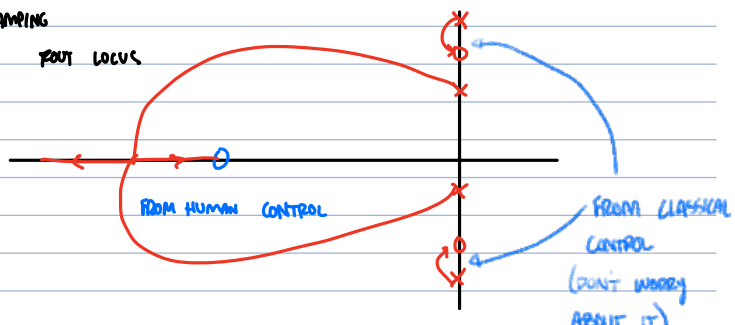


Control law: $\tau_h = K_h(\theta_h - \theta_m) + b_h(\dot{\theta}_h - \dot{\theta}_m)$ ← neglected all damping in system

$= (K_h + b_h s)(\theta_h - \theta_m)$

Human acts like PD controller

Root locus

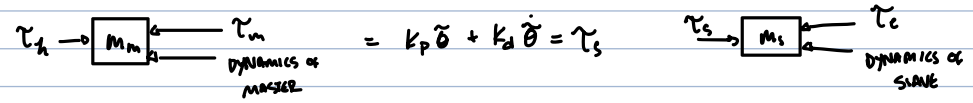


O.L. poles/zeros from plant

OUR CONTROLLER IS STABLE FOR ALL GAINS

TRANSPARENCY: WE'D LIKE THE OPERATOR TO ONLY FEEL DYNAMICS FROM SLAVE'S ENVIRONMENT

WHAT DOES OUR HUMAN FEEL IN THIS SCENARIO?



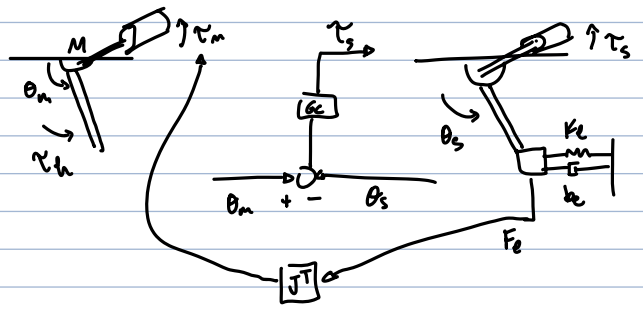
HUMAN FEELS DYNAMICS OF MASTER AND SLAVE IN ADDITION TO τ_e

IF SLAVE IS NOT VERY BACKDRIVEABLE (LARGE INERTIA / FRICTION), THEN τ_e NEEDS TO BE VERY LARGE BEFORE HUMAN FEELS IT

- CAN DAMAGE ENVIRONMENT
- JEOPARDIZE SUCCESS OF TASK (WEDGING/JAMMING)

$\therefore$ BILATERAL SERVO HAS GOOD STABILITY BUT POOR TRANSPARENCY

LET'S PUT A FORCE SENSOR ON SLAVE END-EFFECTOR & FEEDBACK ENVIRONMENT FORCE TO MASTER



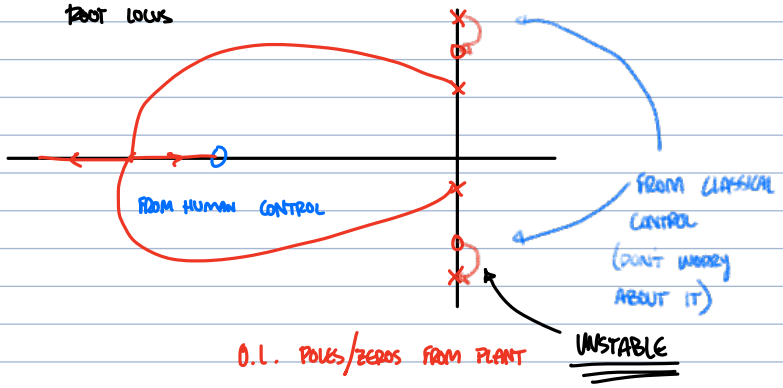
WE'VE IMPROVED TRANSPARENCY, BUT WE DON'T KNOW ABOUT STABILITY

"PLANT" $$\frac{\theta_s(s)}{\tau_h(s)} = \frac{m_s s^2 + (k_e + k_p)}{m_m m_s s^4 + m_m(k_e + k_p)s^2 + k_f k_e k_t}$$

ASSUME HUMAN ACTS LIKE A CONTROLLER ON THIS PLANT

$$\tau_h = (K_h + b_h s)(\theta_d - \theta_m)$$

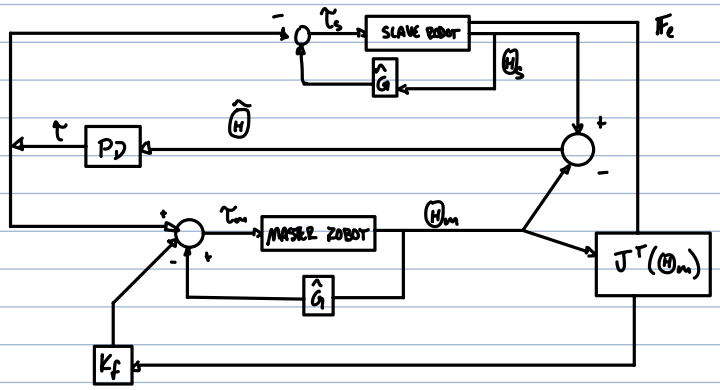
ROOT LOCUS



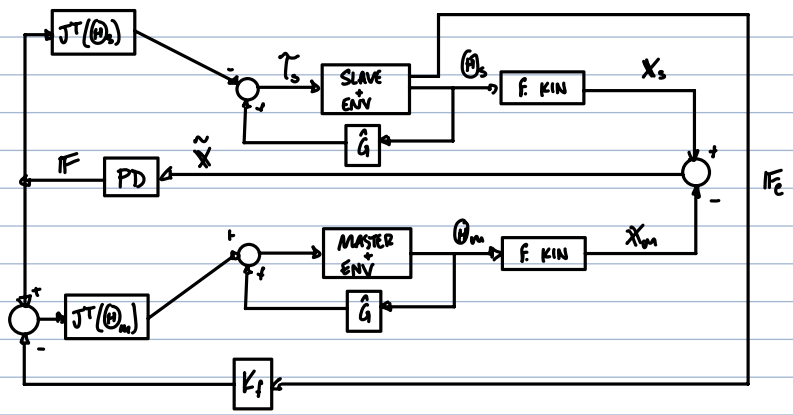
O.L. POLES/ZEROS FROM PLANT

∴ DIRECT FORCE FEEDBACK IS MORE TRANSPARENT BUT LESS STABLE

IN PRACTICE, WE CAN USE A COMBO OF BILATERAL SERVO & DIRECT FORCE FEEDBACK



AS WE INCREASE K_f, WE WILL GET MORE TRANSPARANCY AT THE EXPENSE OF STABILITY



TAKEAWAYS:

- IN OP-SPACE, THE MASTER & SLAVE CAN TOGGLE @ SINGULARITIES (ELBOW-UP VS ELBOW-DOWN)

- IN OP-SPACE, CAN USE PI CONTROL