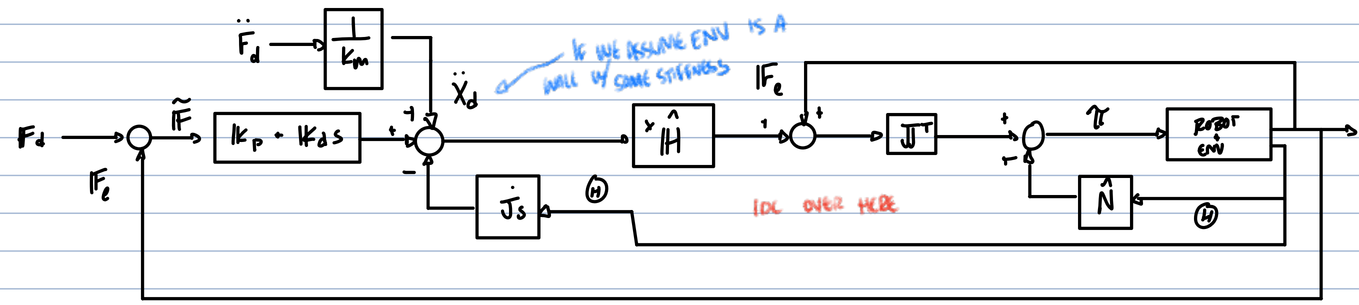
21 Direct Force Control

We want to specify a desired force & use force feedback to make actual force ⇒ desired force



F_d is usually const
⇝ $\ddot{F}_d$ usually 0

$$^x\hat{H} = J^{-T}\hat{H}J^{-1}$$

1. We don't always know wall stiffness K_w, so we typically leave out $\ddot{F}_d$ compensation
2. F_e is typically noisy, so differentiation is usually ill-advised.
   - PV control is better than PD
     - penalize velocity, not force derivative
   - We need derivative control to add damping to system
3. Ideally $\tilde{F} = F_d - F_e = 0$ @ equilibrium, but if we have an unmodeled disturbance then $\tilde{F} \neq 0$

O.L. Dynamics

$$\tau = H\ddot{\Theta} + N + J^T F_e + J^T F_{dist}$$

disturbance force (F_{dist}); physical force feedback ($J^T F_e$)

① Quasi-static case (pushing against wall)

$$\tau = H\cancel{\ddot{\Theta}}^{\,0} + \cancel{N}^{\,G} + J^T F_e + J^T F_{dist}$$

② Control law:

$$\tau = \hat{N} + J^T F_e + J^{T\,x}\hat{H} K_p \tilde{F} \quad \text{(quasi-state)}$$

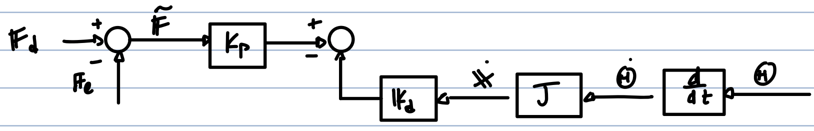
① + ② ⇒ C.L. Dynamics

$$\cancel{\hat{G}} + \cancel{J^T F_e} + J^{T\,x}\hat{H} K_p \tilde{F} = \cancel{G} + \cancel{J^T F_e} + \cancel{J^T} F_{dist}$$

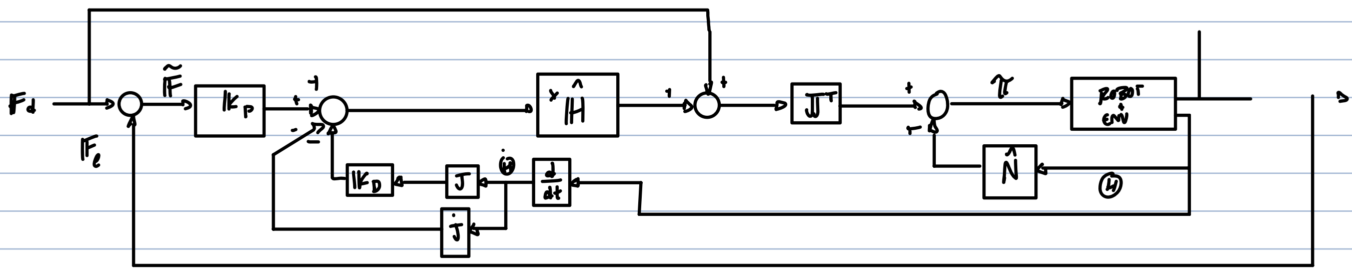
$$\tilde{F} = (^x\hat{H} K_p)^{-1} F_{dist}$$

At equilibrium $\tilde{F} \neq 0$ (steady state force error bad)

We would get better disturbance rejection if we feed forward $\mathbb{F}_d$ instead of feeding back actual force $\mathbb{F}_e$ to cancel physical force feedback in plant



Much better to differentiate Θ than the force sensor



(2a.) New control law

$$\tau = \hat{N} + J^T \mathbb{F}_d + J^T\, {}^x\hat{H}\, \mathbb{K}_p\, \mathbb{F} \qquad \text{(quasi-static}$$

(1)+(2a) New C.L. dynamics $\hat{G} + J^T \mathbb{F}_d + J^T\, {}^x\hat{H}\, K_p \tilde{\mathbb{F}} = G + J^T \mathbb{F}_e + J^T \mathbb{F}_{dist}$

$$\tilde{\mathbb{F}} = \left(I + {}^x\hat{H}\, \mathbb{K}_p\right)^{-1} \mathbb{F}_{dist}$$

similar, but inverse of a larger thing

inverse of a larger thing becomes a smaller thing