27 Final Exam

Things on the exam
- Robust Control
  - Sliding mode
- Adaptive control
  - Be able to write α, Y in terms of dynamic parameters

- Operational Space Control
  - $\underbrace{J^{-1} \quad J^{T} \quad \text{IDC}}_{\text{in op-space}}$
    - Draw block diagrams, write control laws

    - Be able to compute inertia matrix in op-space ^{x}H

- Stiffness/Impedance Control
  - Stiffness is
  - Impedance is version of stiffness w/

  } lower PD gains

- Compliance/Admittance control
  - Causality is flip
  - PD gains still high

- Direct Force Control

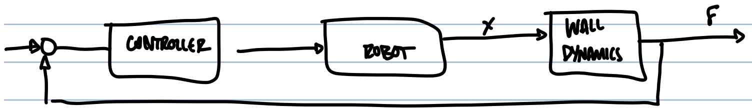
- Hybrid Control
  - How do we generate table of constraints & get S matrix?
  -

- Multi-arm Coordination (good level students)
  - Extension of hybrid
  - We should be able to do the same thing
  - Relative Jacobian

- Teleoperation
  - Bilateral servo
  - Force feedback
  - Combo of those

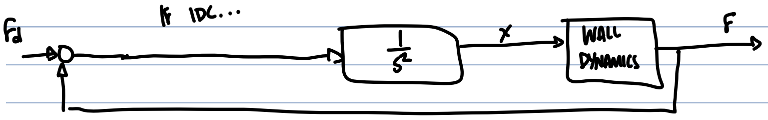
In general:
- Sketch block diagrams
- Write control laws (or adaptation laws)
- Sketch a root locus to demonstrate stability w/ wall stiffness included
  - Only happens w/ linear block diagram
- Able to discuss pros/cons of different methods

WALL STIFFNESS



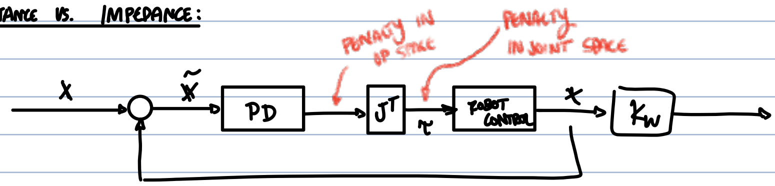
WE'LL SAY THE WALL ACTS LIKE A SPRING

IF IDC...

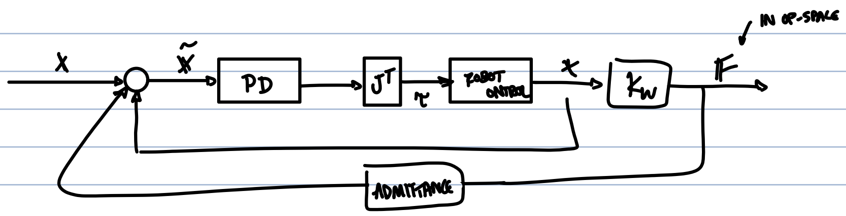


NOW WE CAN DRAW A
ROOT LOCUS PLOT

ADMITTANCE VS. IMPEDANCE:



IMPEDANCE
WE COMPUTE ERROR IN POSITION, PUNISHED BY FORCE ON MOTORS



FORCE NOW CAUSES A MODIFICATION OF DESIRED TRAJECTORY, SO WE CAN KEEP PD GAINS HIGH

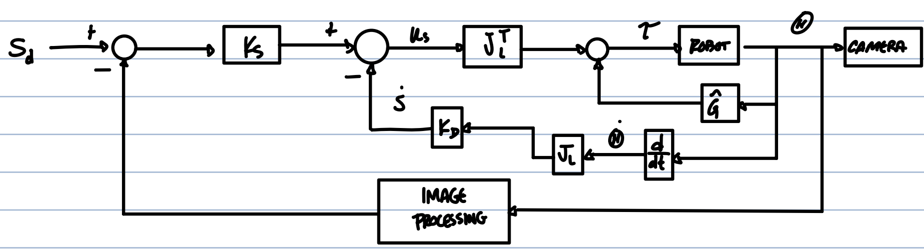
- IMPEDANCE CONTROL IS MUCH MORE STABLE THAN ADMITTANCE, SO SOMETIMES IT IS BETTER

ADMITTANCE MODIFIES TRAJECTORY
- CAN KEEP HIGH PD GAINS

EXTRA CREDIT TOPICS

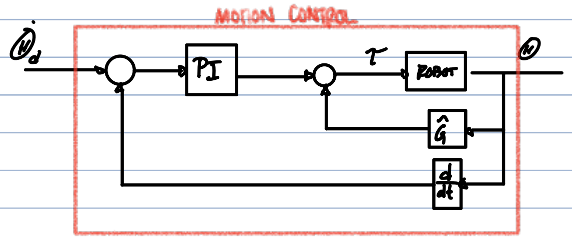
VISUAL SERVOING:

NEW SPACE, FEATURE SPACE



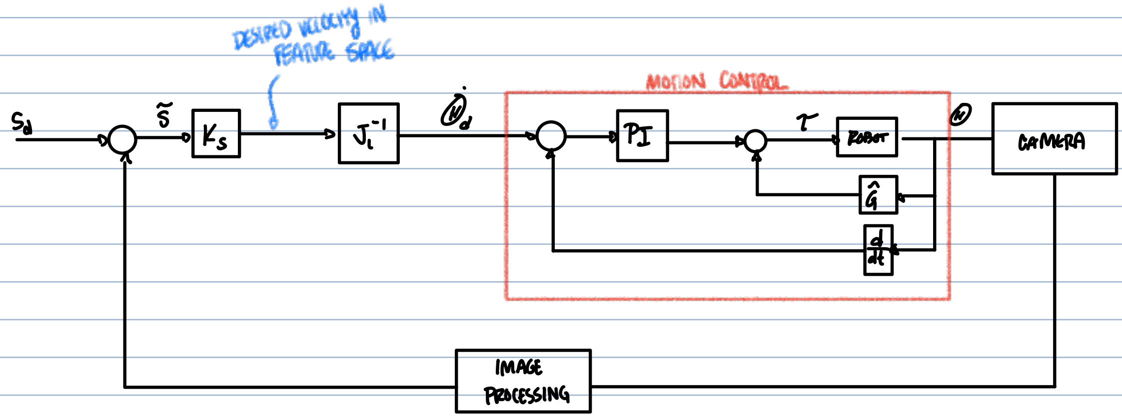
- SOMETIMES, ROBOTS DON'T HAVE DIRECT MOTOR-TORQUE CONTROL
- IN PRACTICE, ROBOT MAY NOT BE OPEN-ARCHITECTURE ⇒ NO DIRECT CONTROL OF MOTOR TORQUE
- IMAGE PROCESSING MAY BE COMPUTATIONALLY EXPENSIVE
  - WE WANT SAMPLING RATE TO BE FAST
  - FEATURE MEASUREMENT

RESOLVED VELOCITY IMAGE BASED VISUAL SERVOING



THE I TERM WILL FORCE A DESIRED POSITION
- THE DESIRED POSITION IS RELATIVE TO WHEREVER YOU STARTED

- MOTION CONTROL CAN BE DONE AT FAST SAMPLE RATE

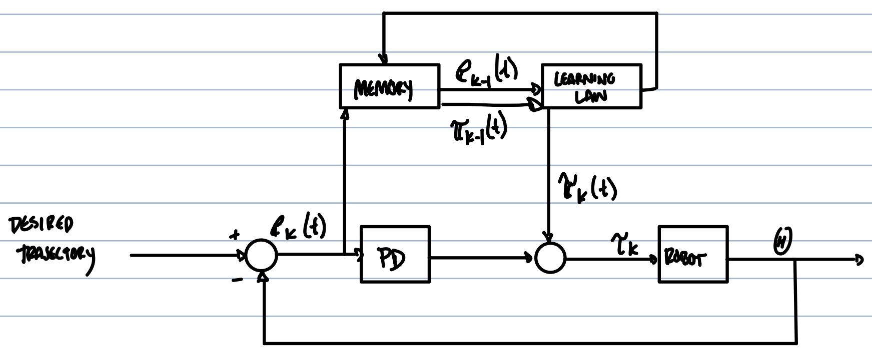


- NOW MOTION PLANNING IS QUICK, AND IMAGE PROCESSING CAN BE SLOW
- WE ALSO MAY NOT HAVE A CHOICE, SO THIS IS A SOLID OPTION

LEARNING CONTROL

- SLIDING MODE CONTROL IS SUSCEPTIBLE TO CHATTER

- SUPPOSE WE HAVE A ROBOT WITH UNKNOWN DYNAMICS DOING A SINGLE REPEATED TRAJECTORY
  - CAN THE ROBOT LEARN HOW MUCH TORQUE IS NEEDED AT EACH POINT ON THE TRAJECTORY?



k = ITERATION OF TRAJECTORY

$\tau_k(t)$ = TORQUE ADDED @ k^{th} REPETITION
- USES $\tau_{k-1}(t)$ & $e_{k-1}(t)$ TO LEARN (PRIOR ITERATION)

ASSUME:
1. EVERY TRIAL ENDS ON A FIXED TIME DURATION
2. SAME INITIAL CONDITIONS @ $t=0$ EVERY TRIAL ← DOESN'T FREAKING WORK
3. ASSUME DYNAMICS DON'T CHANGE BETWEEN TRIALS

CAN PROVE THAT A PROPORTIONAL (P-TYPE) LEARNING LAW

$$\tau_k(t) = \tau_{k-1}(t) + \Phi\, e_{k-1}(t)$$ [ARIMOTO, 1986]

Φ ↑ P GAIN

MORE GENERALLY WE CAN HAVE

$$\tau_k = \tau_{k-1} + \Phi e_{k-1} + \Gamma \frac{d}{dt} e_{k-1} + \psi \int e_{k-1} \, dt$$

CAN ALSO BUILD IN A FORGETTING FACTOR α $\left(\alpha \in [0-1] \right)$

$$\tau_k = (1-\alpha)\tau_{k-1} + \alpha T_0 + \Phi e_{k-1}$$

$$0 < \alpha < 1$$

IF $e = 0$, SYSTEM WILL FORGET LEARNING AND TEND BACK TO T_0

ROBUST AGAINST : ERRORS IN INITIAL CONDITIONS
FLUCTUATIONS IN DYNAMICS
MEASUREMENT NOISE

GUARANTEES TRACKING PRECISION [ARIMOTO 1991]