ME 328: Medical Robotics
Winter 2019

Lecture 3: Teleoperation

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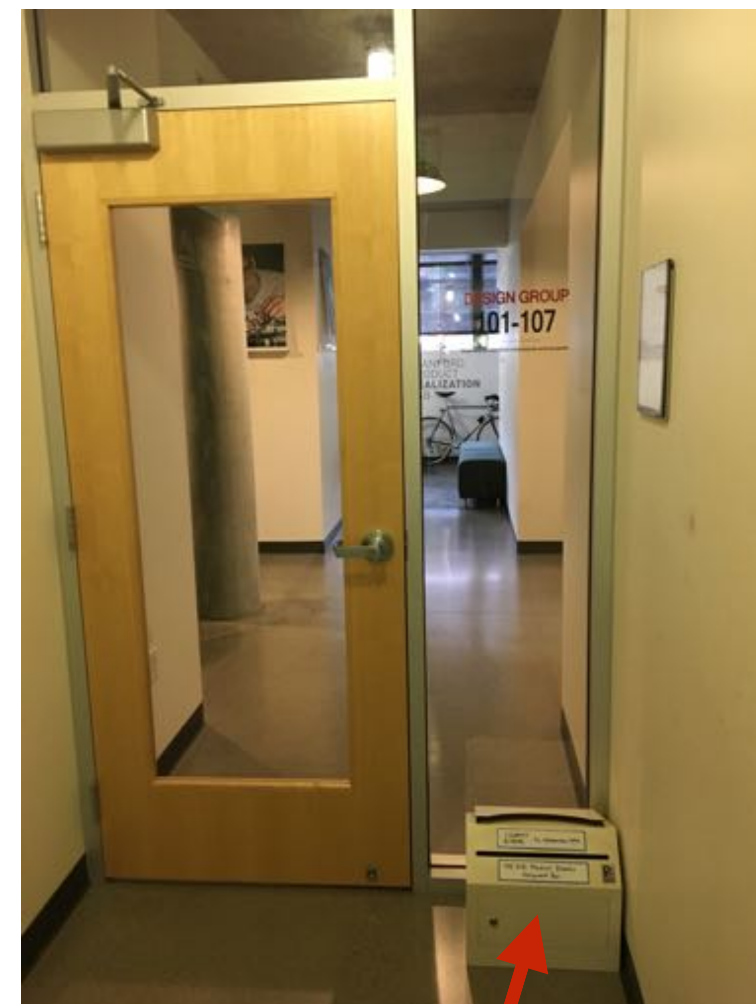
Updates/Reminders

- If you are taking this class, make sure you are registered on Axess
- Q&A on piazza:
  https://piazza.com/stanford/winter2019/me328
- Office hours (near 550-108):
  Lisa: Fridays 2:30-4:30 pm
  Cole: Mondays 3-4 pm, 6-7 pm
  Allison: Tuesdays 12-1:30 pm
  or by appointment
- Assignment #1 due Wednesday at 4 pm
  look for question 0 posted to Canvas today



turn in box

Open Surgery

Surgeon

Patient

Image source: www.physicianphotos.com

Minimally Invasive Surgery

Surgeon

Instrument/Camera

Patient

Image source: www.womenssurgerygroup.com

Teleoperated Robot-Assisted Minimally Invasive Surgery

Surgeon

Master Console

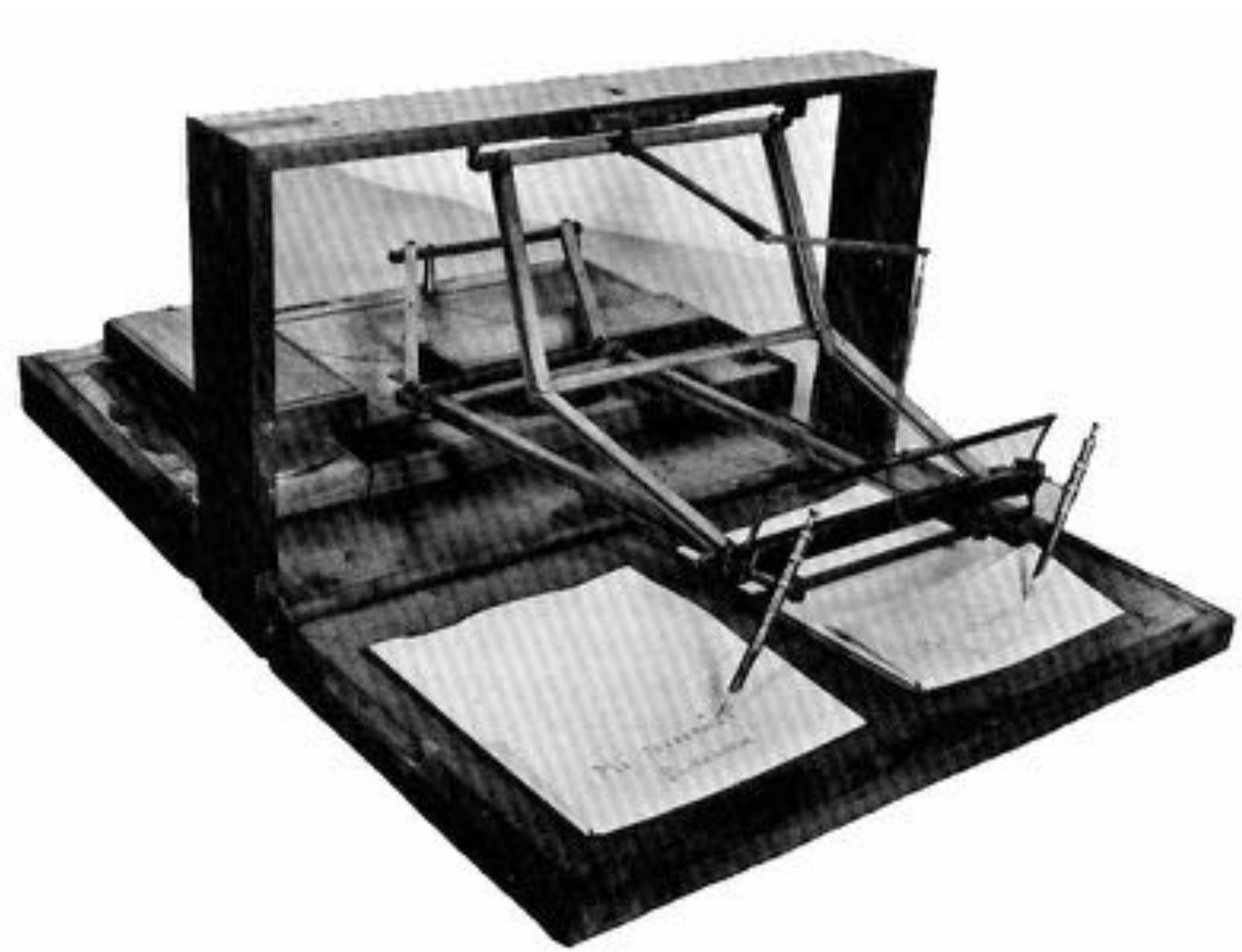
Information-Enhanced RMIS

Patient-Side Robot

Instrument/Camera

Patient

the genesis of teleoperation?



A Polygraph is a device that produces a copy of a piece of writing simultaneously with the creation of the original, using pens and ink. Famously used by Thomas Jefferson ~1805.

Typically uses a pantograph mechanism: a five-bar linkage with parallel bars such that motion at one point is reproduced at another point

teleoperation history

History:

- First teleoperated Manipulator: 1948, Ray Goertz, U.S. Atomic Energy Commission
- Goal: protection of workers from radiation, while enabling precise manipulation of materials
- a device which is responsive to another device is termed a “slave”/“follower” and the controlling device is termed a "master”

At first, mechanical linkages and cables

- 1954: electrical and hydraulic servomechanisms
- 1960s: Closed circuit television and HMDs

these people probably never envisioned robot-assisted surgery

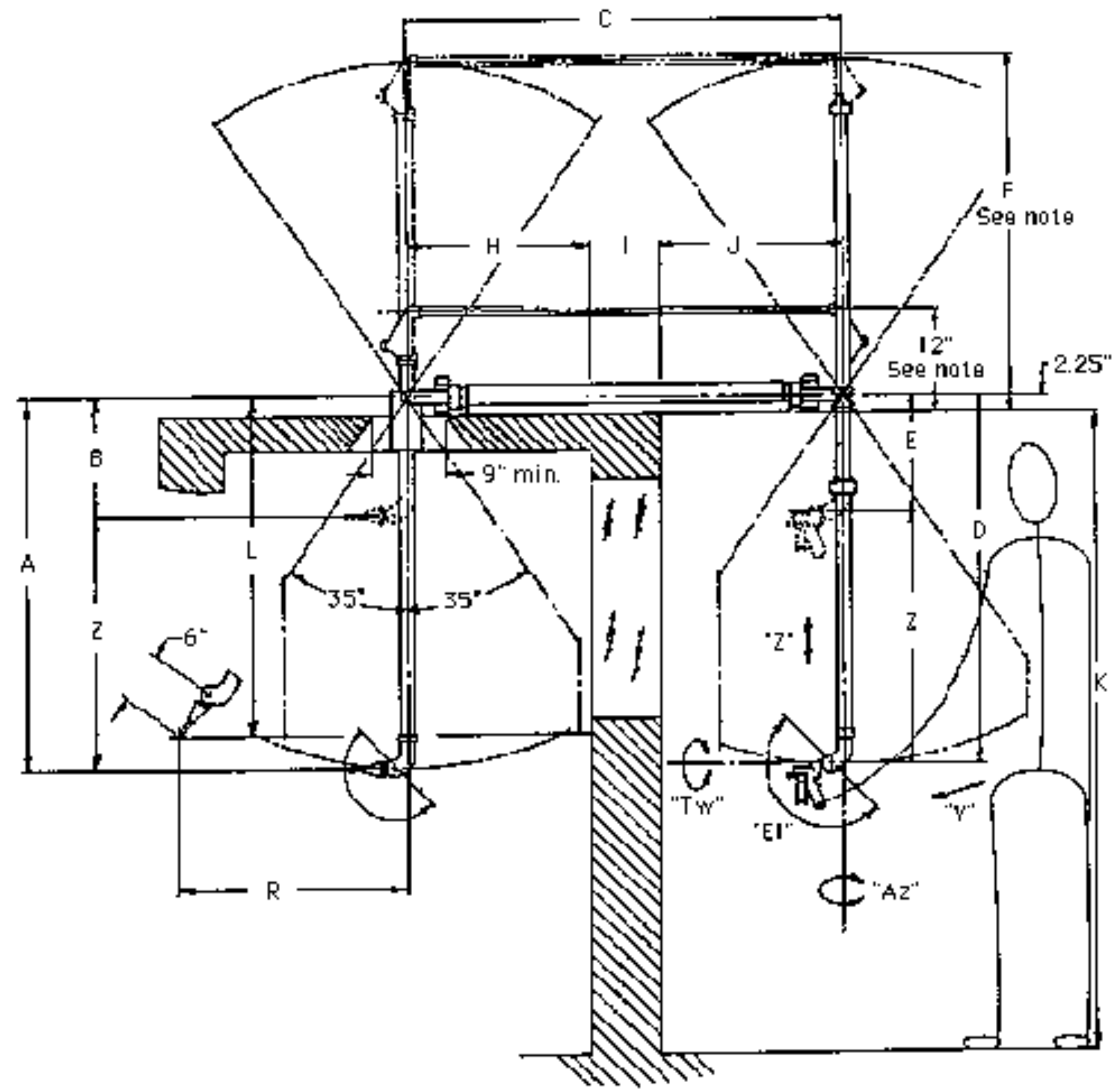
in surgery, follower robot = patient-side robot

bilateral control: force/haptic feedback

inherent in “mechanical” teleoperators

forces at the follower end-effector are reflected to the master end-effector

displacements produced at the follower end-effector produce a displacement at the master end-effector



modern telemanipulators

Undersea: exploration and oil acquisition

Space

- 1967: Surveyor III landed on the surface of the Moon (a few seconds delay in the two-way transmission to earth of commands and information)

- 1976: Viking spacecraft, landed on Mars was programmed to carry out strictly automated operations

- Shuttle Remote Manipulator System (SRMS): retrieves satellites and place them in the cargo bay; mobile work platform for astronauts during space walks

even more dexterous teleoperation

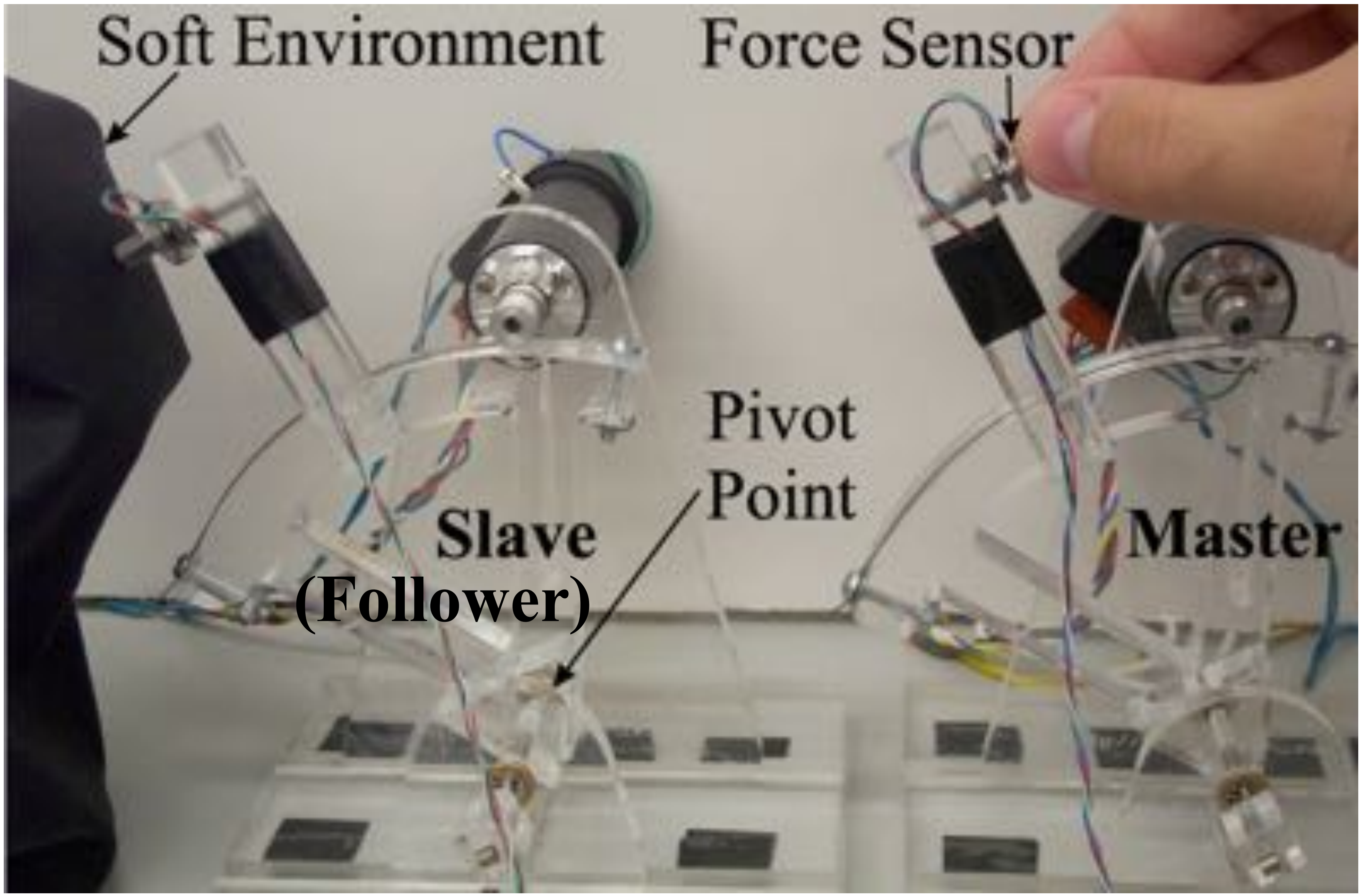
Robonaut

- Robot Systems Technology Branch at NASA's Johnson Space Center

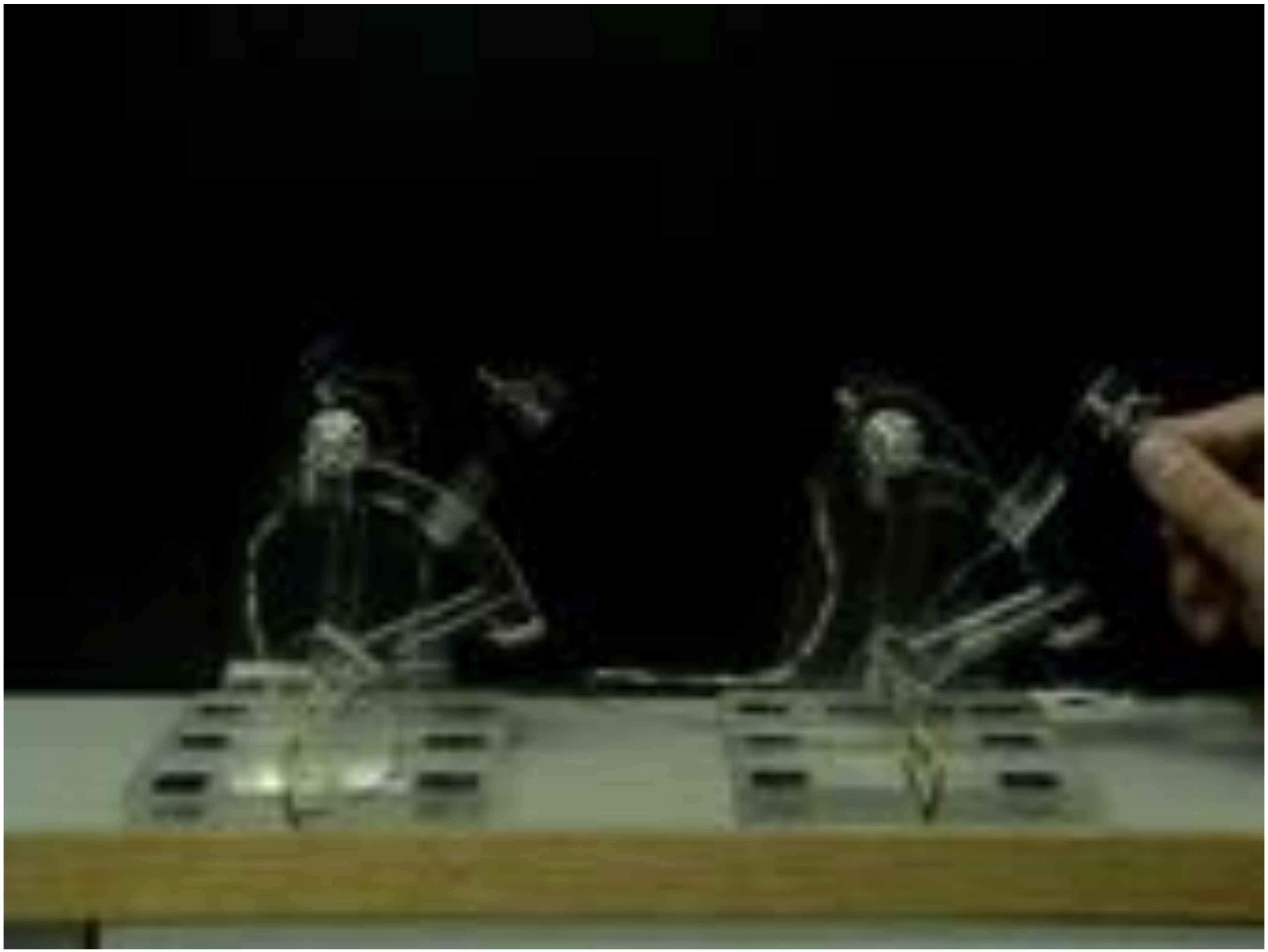
- Purpose: Replace astronauts in dangerous missions, such as space walk, on the space shuttle and/or the space station

- Both autonomous operation and teleoperation are being developed

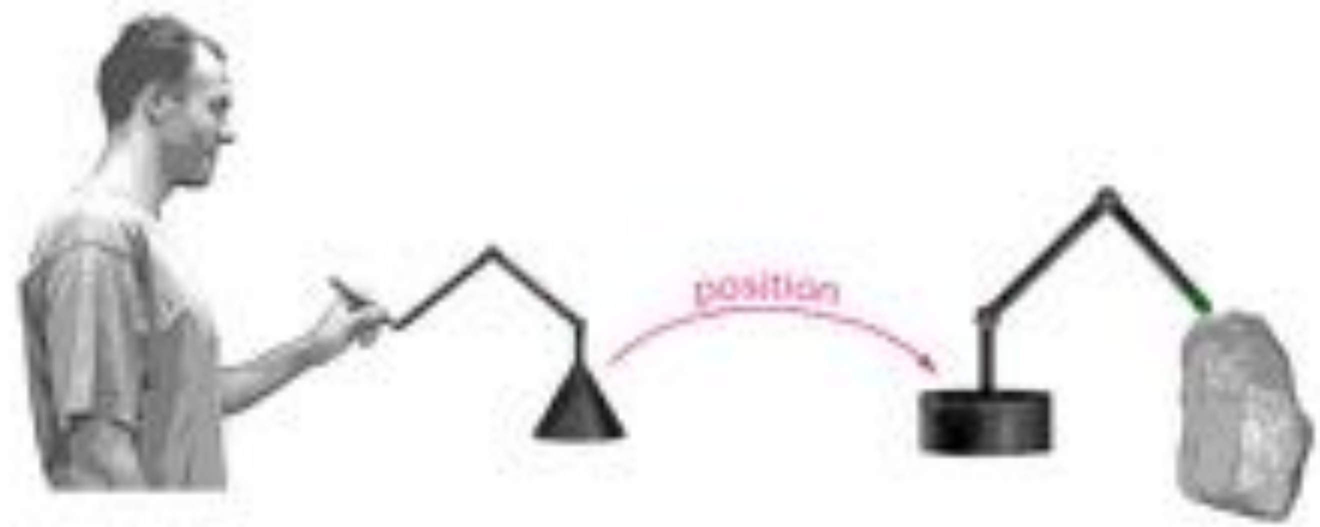
simple system example

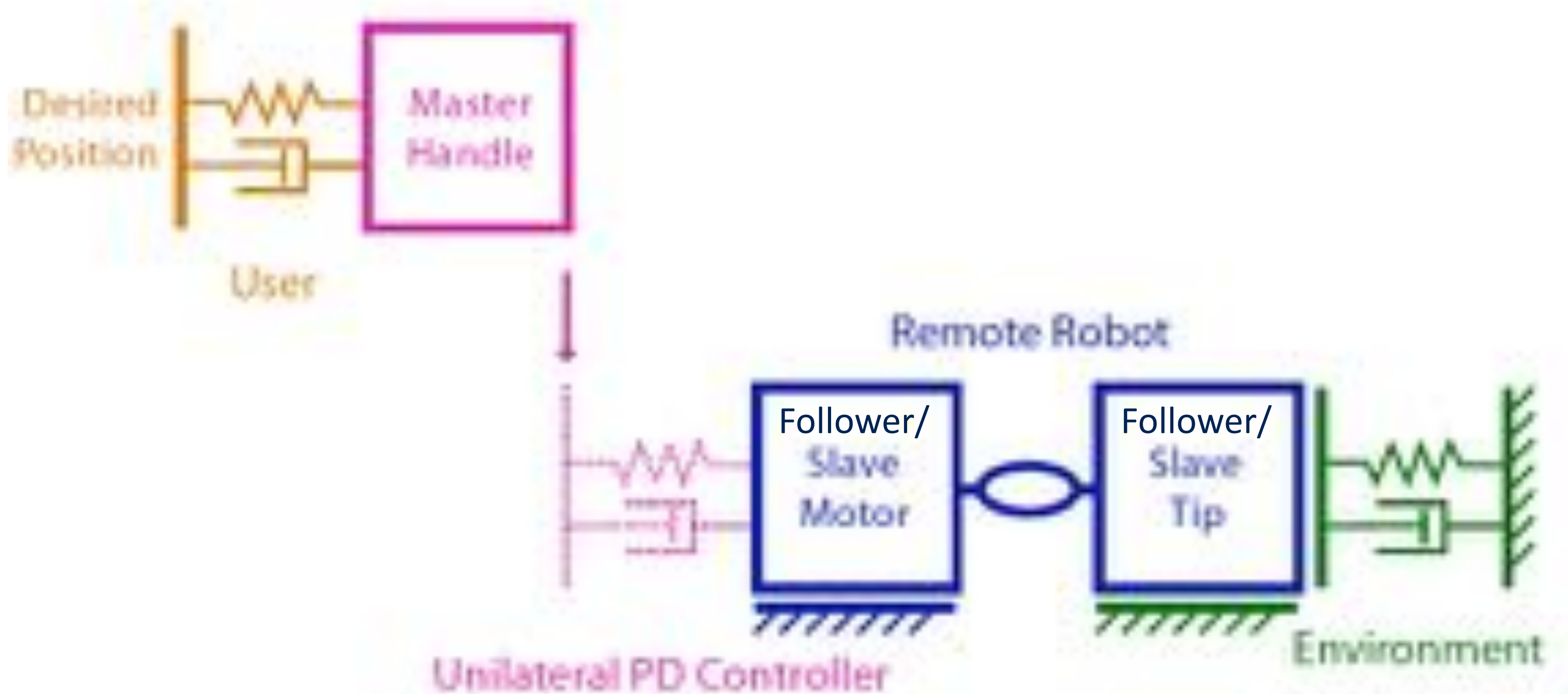


simple system example



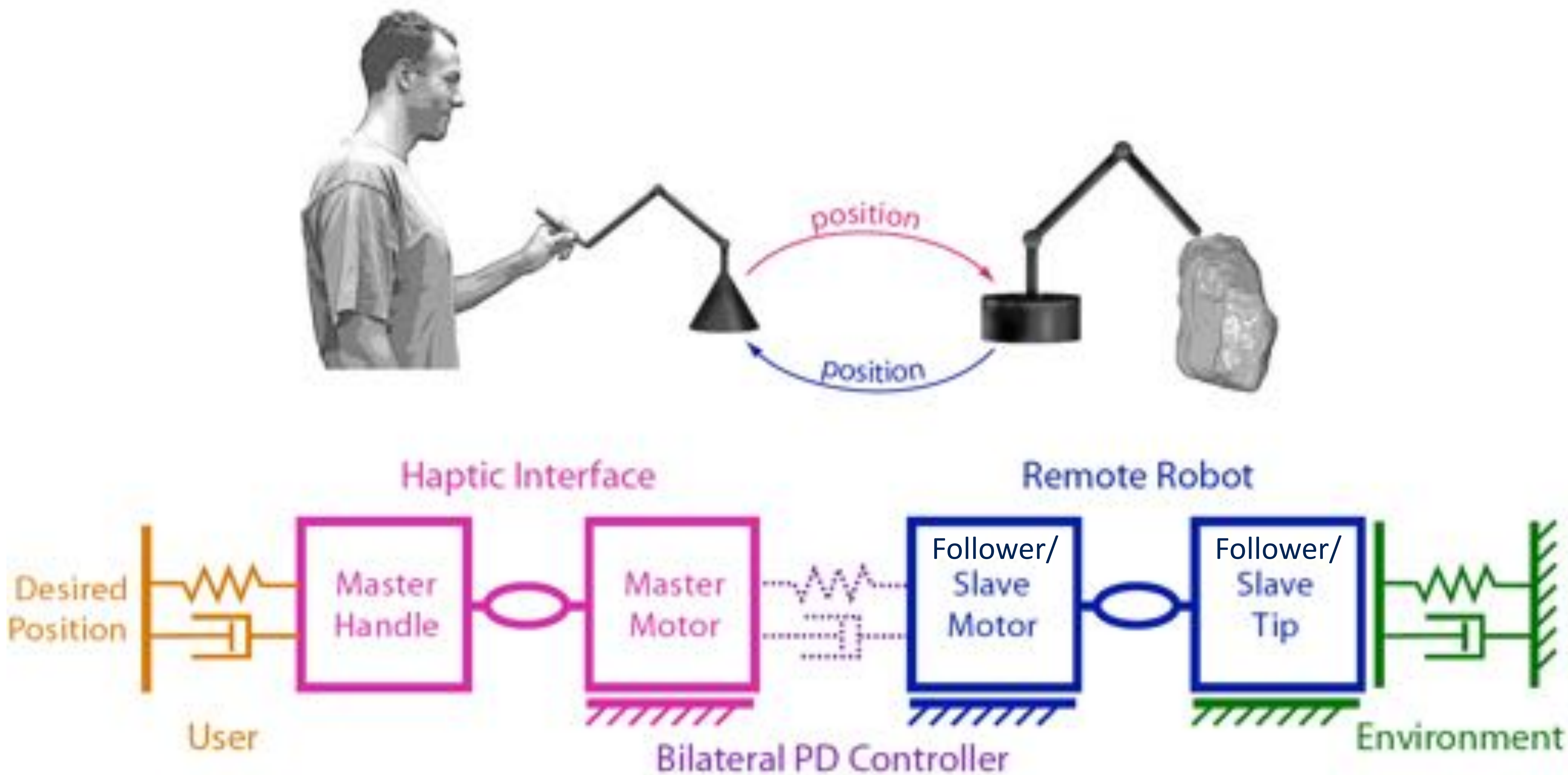
unilateral teleoperator model





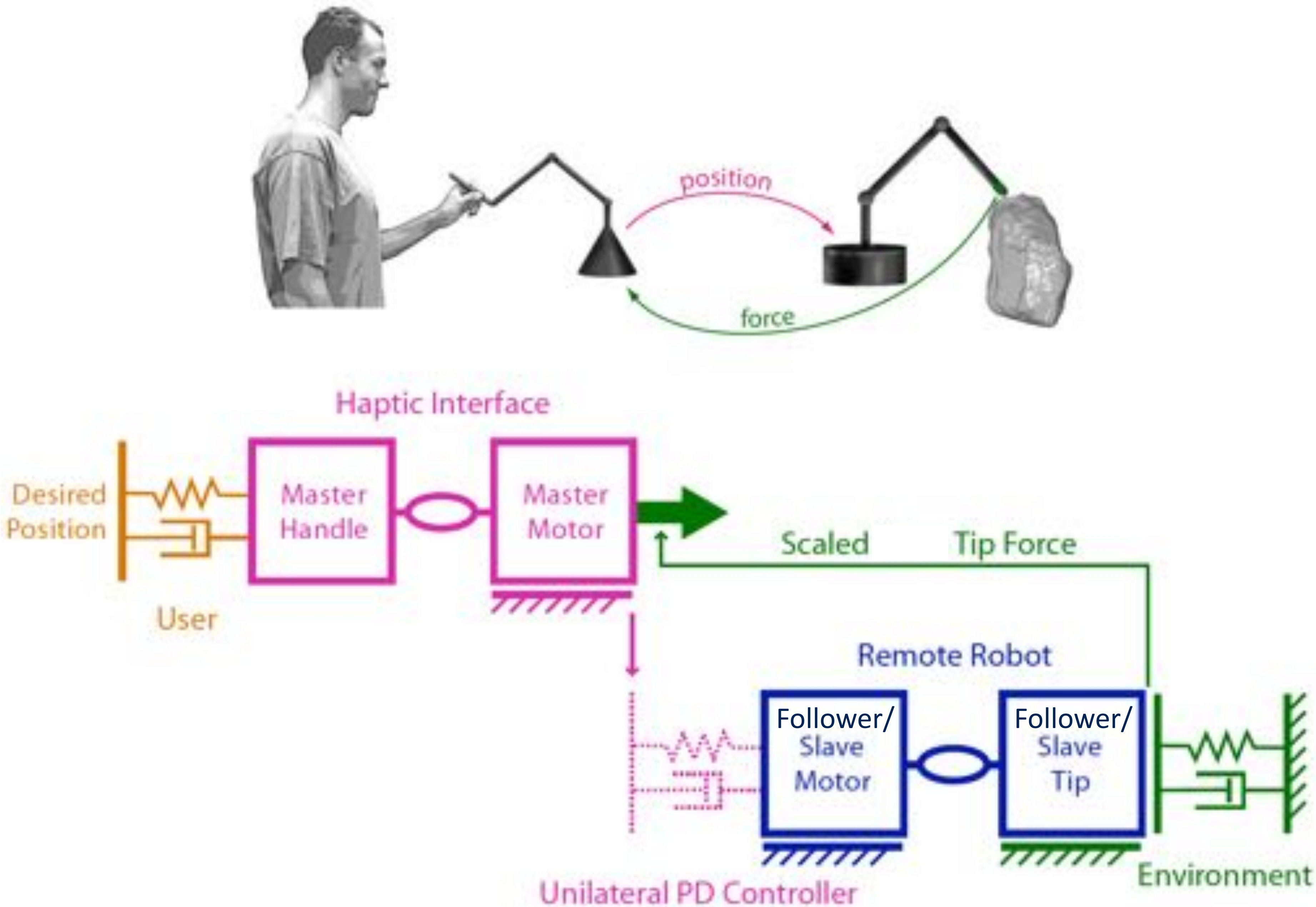
modified from Kuchenbecker Ph.D. Thesis (2006)

bilateral teleoperator model (using position)



from Kuchenbecker Ph.D. Thesis (2006)

bilateral teleoperator model (using force)



from Kuchenbecker Ph.D. Thesis (2006)

typical follower robot controller

this is a proportional-derivative controller, which attempts to make the follower (2) follow the master (1) position *and* velocity

$$f_{a2}(t) = k_{p2}(x_1 - x_2) + k_{d2}(\dot{x}_1 - \dot{x}_2)$$

$f_{a2}(t)$ follower actuator force

x_1 position of master

x_2 position of follower

k_{p2} follower proportional gain

k_{d2} follower derivative gain

every time the master's position is recorded, the follower robot attempts to follow the master using this control law

master robot controller for unilateral teleoperation

$$f_{a1}(t) = 0$$

$f_{a1}(t)$ master actuator force

the force applied by the master actuator (if it even exists) is zero

master robot controller for bilateral teleoperation (using position)

$$f_{a1}(t) = k_{p1}(x_2 - x_1) + k_{d1}(\dot{x}_2 - \dot{x}_1)$$

$f_{a1}(t)$	master actuator force
x_1	position of follower
x_2	position of master
k_{p1}	master proportional gain
k_{d1}	master derivative gain

every time the follower's position is recorded, the master robot attempts to follow the follower using this control law

master robot controller for bilateral teleoperation (using force)

$$f_{a1}(t) = f_e$$

$f_{a1}(t)$ master actuator force

f_e measured environment force

every time the force between the follower and the environment is recorded, the master robot outputs this amount of force

impedance control

attempts to make the user feel a particular impedance

an assumption often made in analysis/prediction of performance
both the master and follower are ideal impedance-type devices:

- linear $f(t) = m\ddot{x} + b\dot{x}$
- no multi-dof coupling
- no nonlinear friction
- no backlash
- infinite mechanical stiffness

if you are interested in further analysis of systems like this, take ME 327: Design and Control of Haptic Systems (Spring 2019)

questions

motion scaling: why would you want this, and how would you change the control laws to accomplish this?

force amplification: why would you want this, and how would you change the control laws to accomplish this?

questions

what might limit the values of the controller gains that you can choose?

what are the comparative advantages and disadvantages of position- and force-based bilateral teleoperation?

teleoperation performance metrics

tracking

the ability of the follower to follow the master

transparency

(for bilateral teleoperation only)

many definitions, but a popular one is whether the mechanical impedance felt by the user is the same as the impedance of the environment

questions

what factors might affect tracking?

what factors might affect transparency?

force generation signals

desired force (in computer)

counts

D/A

volts

amplifiers

voltage or current

motor force/torque

kinematics

endpoint force/torque

you are computing kinematics in Assignment 1, but in the Assignment 2 (lab), all this will be done for you

controller on one end, system dynamics on the other

a controller computes the desired force

e.g. $f = k_p * (x - x_d)$

desired force (in computer)

→ endpoint force/torque

in Assignment 2 (lab), you will need to write the controllers

this force and externally applied loads result in robot motion

e.g., solve for x in $f = m\ddot{x} + b\dot{x}$