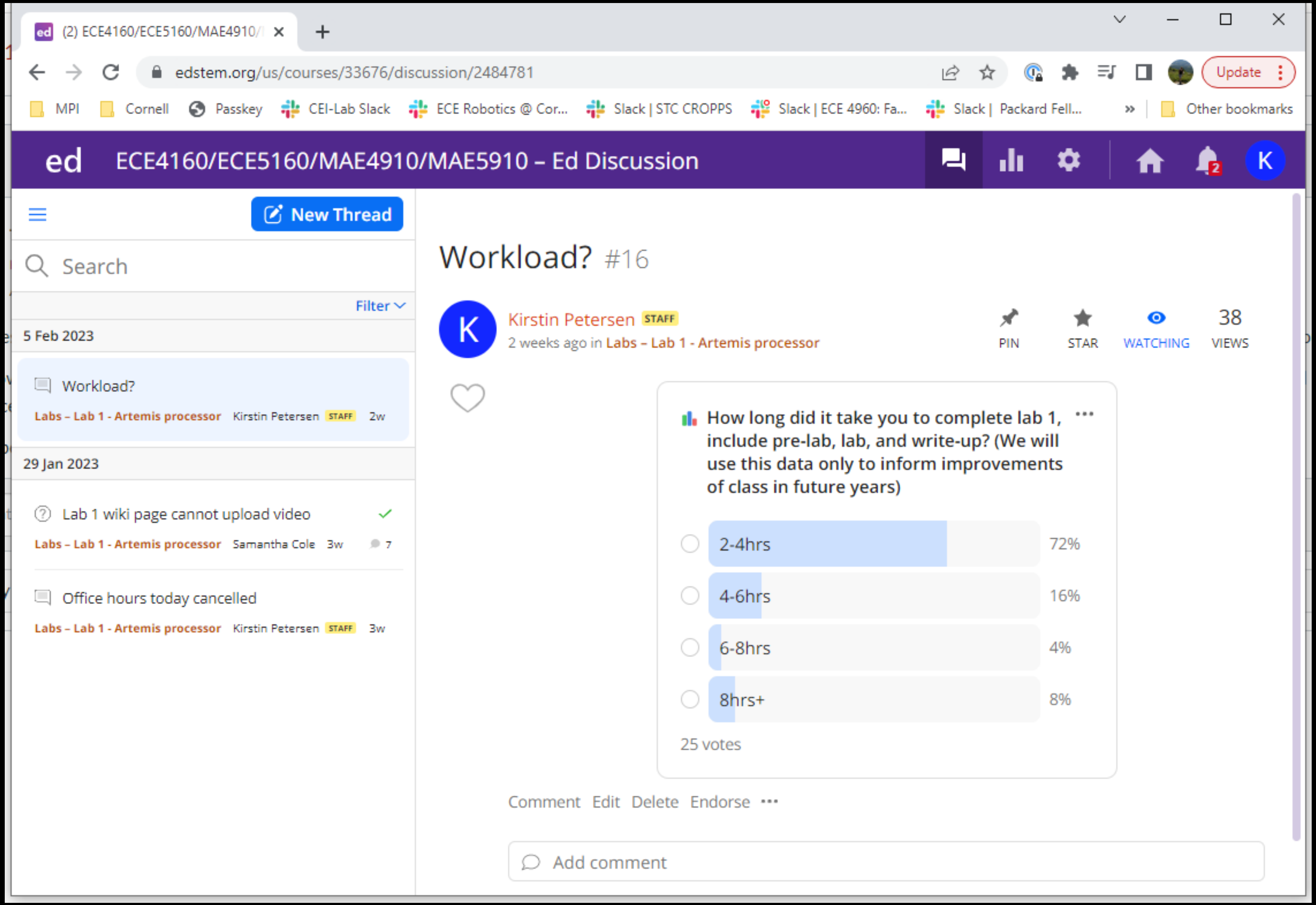
Prof. Kirstin Hagelskjær Petersen
kirstin@cornell.edu

ECE 4160/5160
MAE 4910/5910

Fast Robots
PID (continued)

Logistics

- Please answer workload polls to help students next year!



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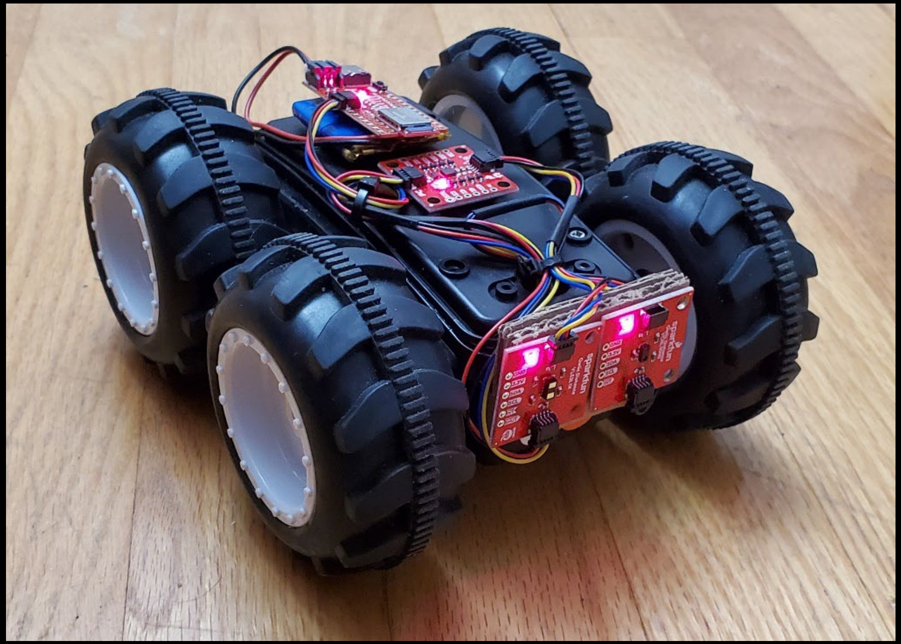
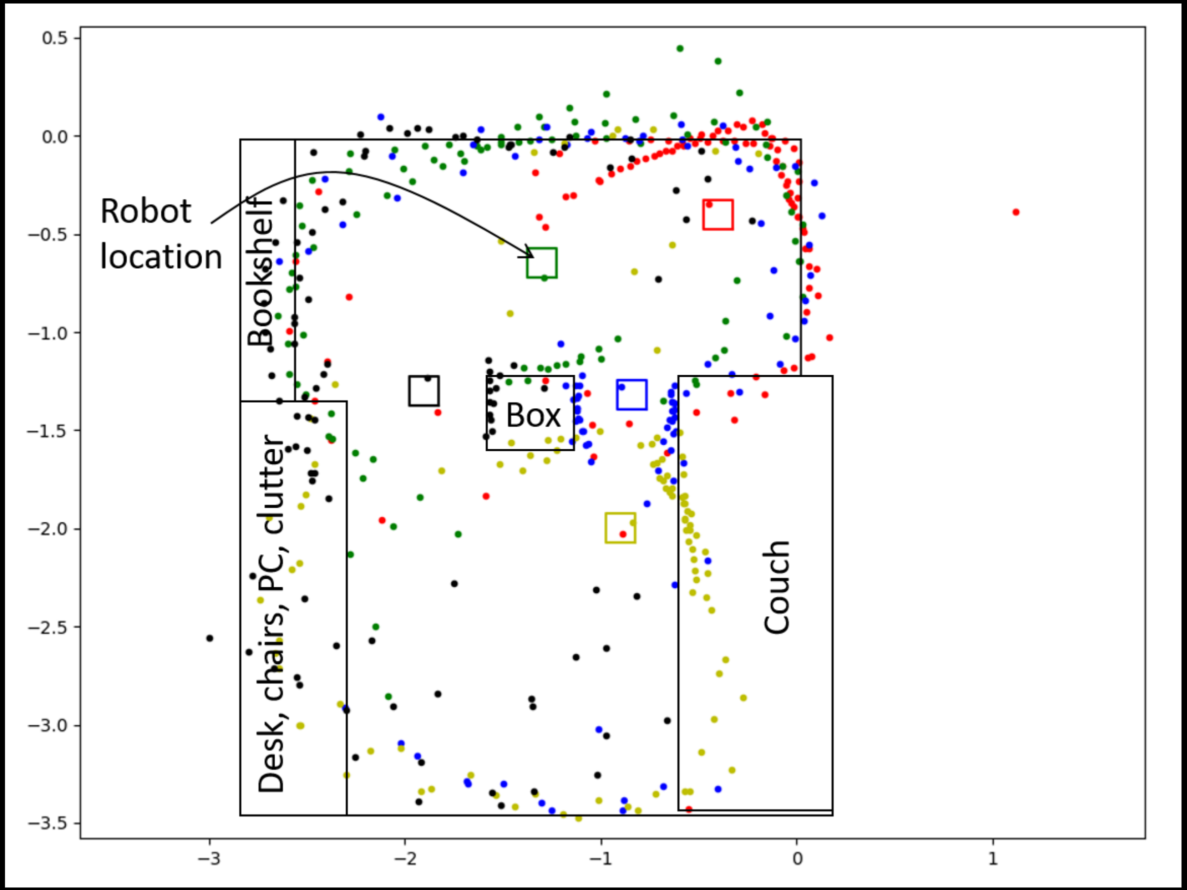
Fast Robots
PID (continued)

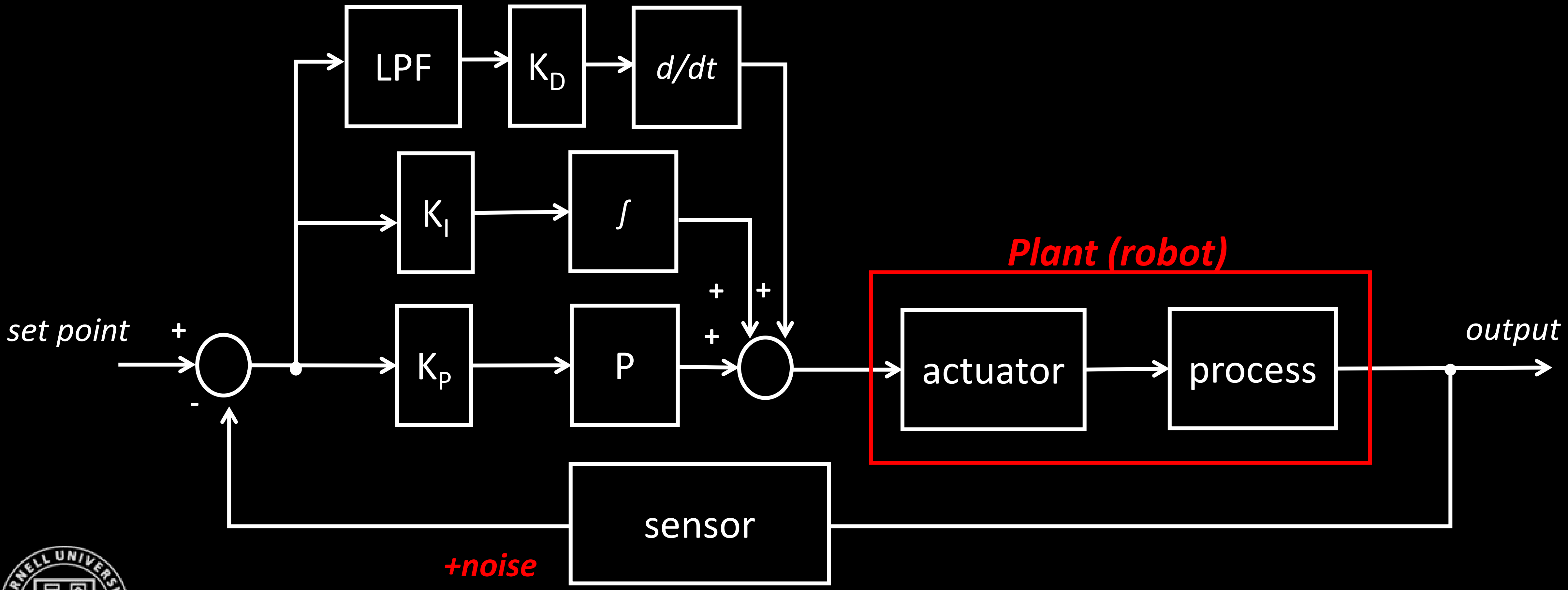
Feedback Control

- Use cases in this class
  - Stunt: Maintaining speed at different battery levels and over different surfaces
  - Mapping: Space out sensor readings evenly for mapping
  - Path execution: adhere to generated path plans

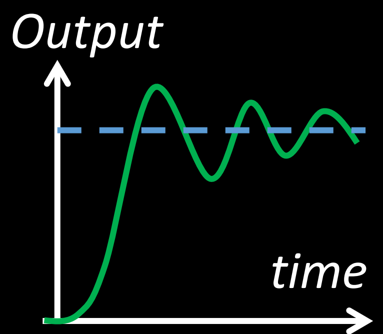




PID architecture



PID architecture



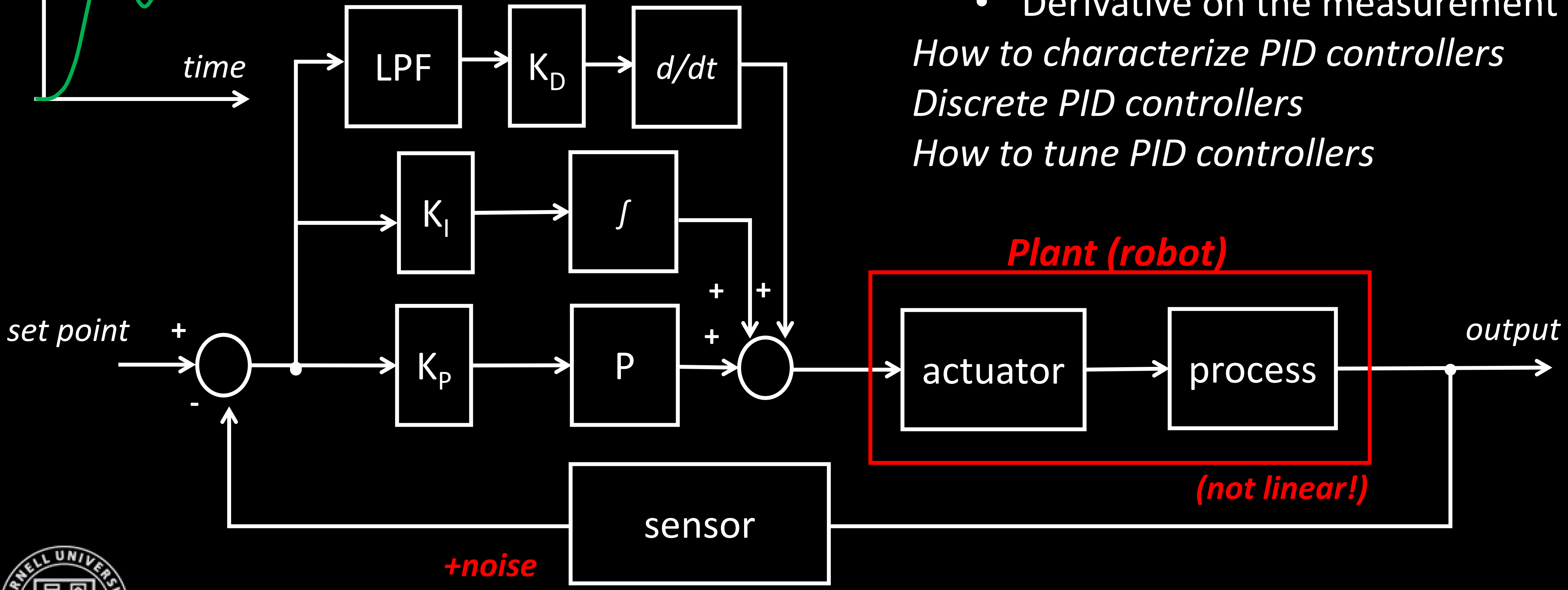
Common things to address:

- Derivative low pass filter
- Integrator wind-up
- Derivative kick
    - Derivative on the measurement

How to characterize PID controllers

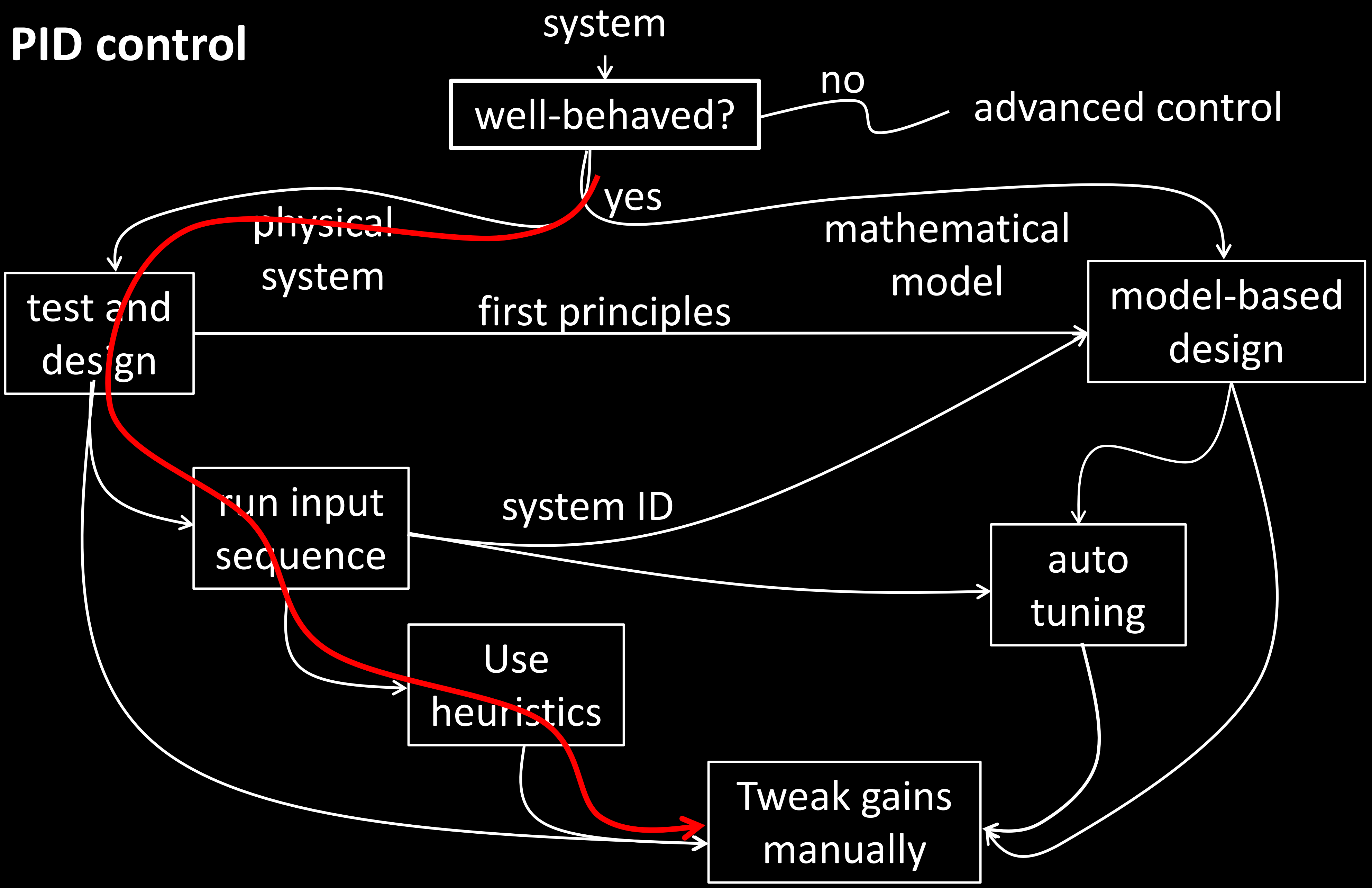
Discrete PID controllers

How to tune PID controllers

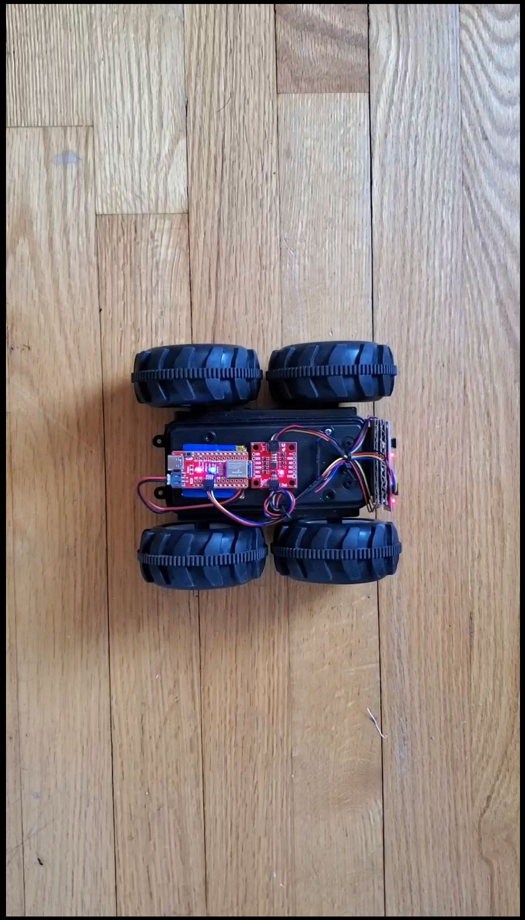


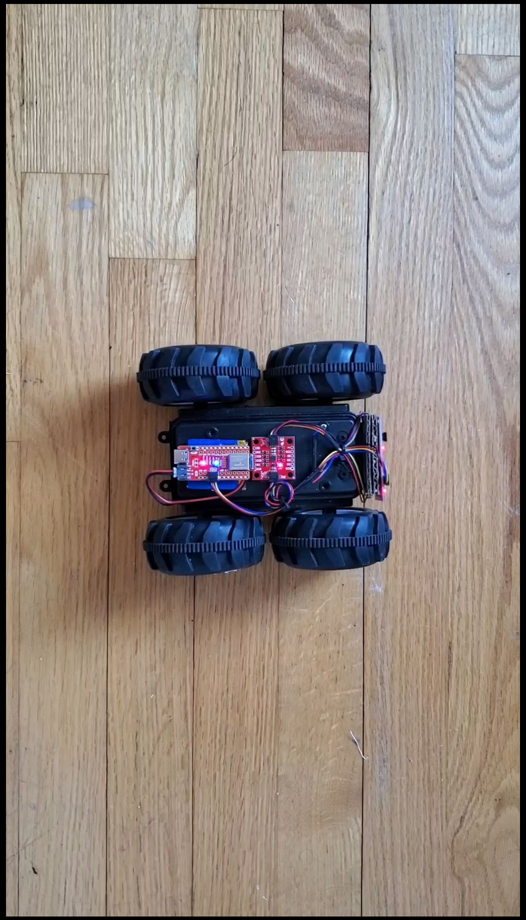
Fast Robots

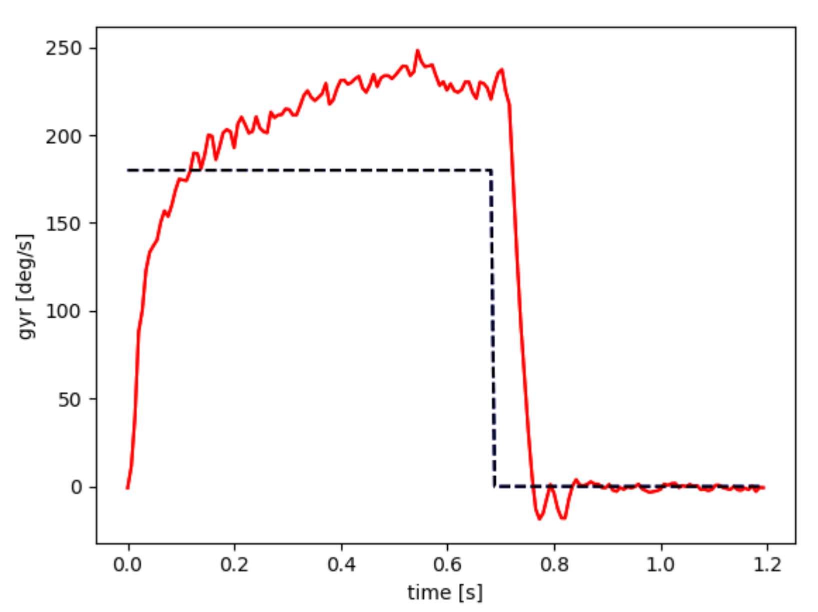
Tuning PID control

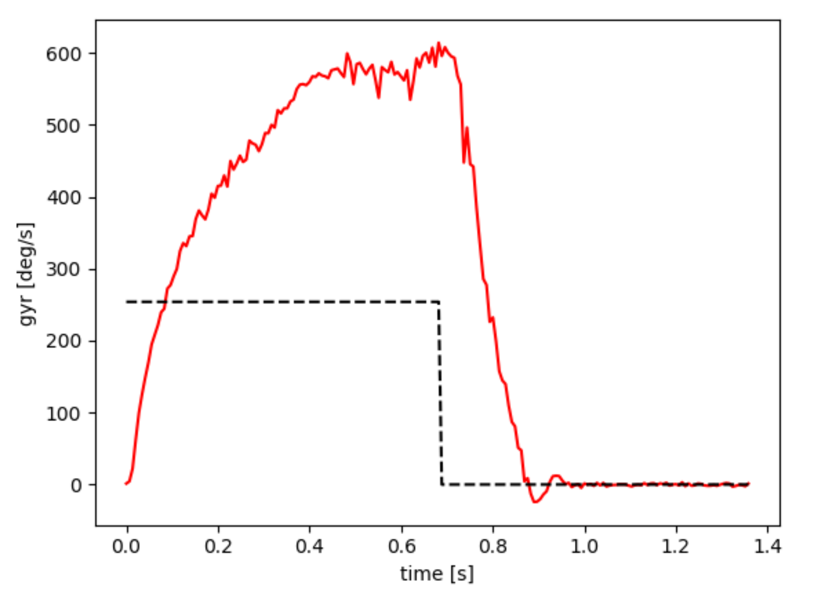


Tuning PID control









Tuning PID control (Heuristic)

- Chien, Hornes, and Reswick method

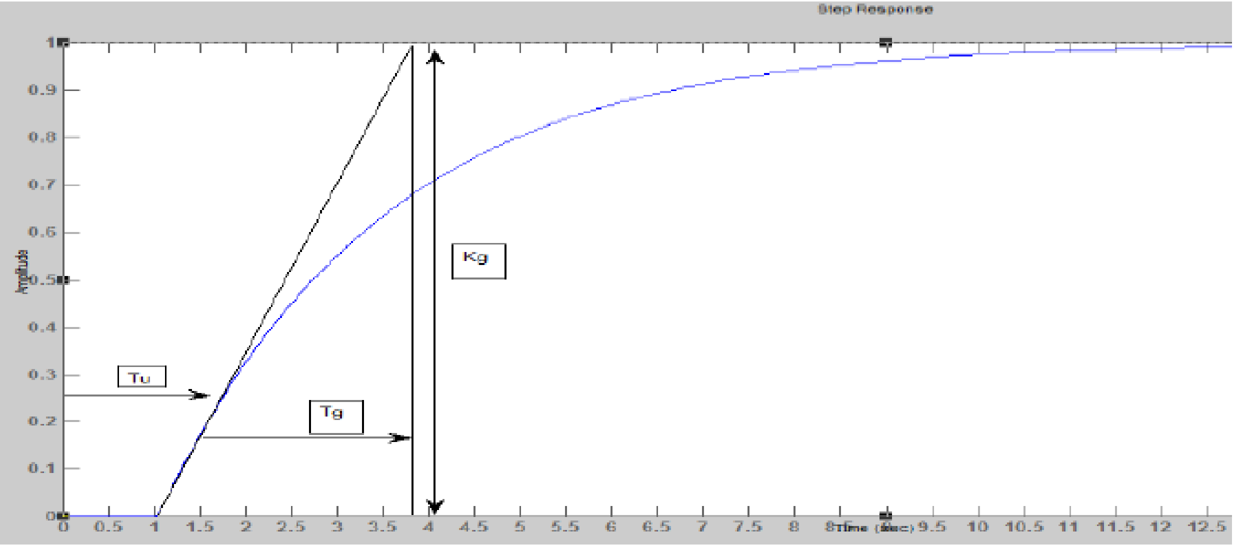
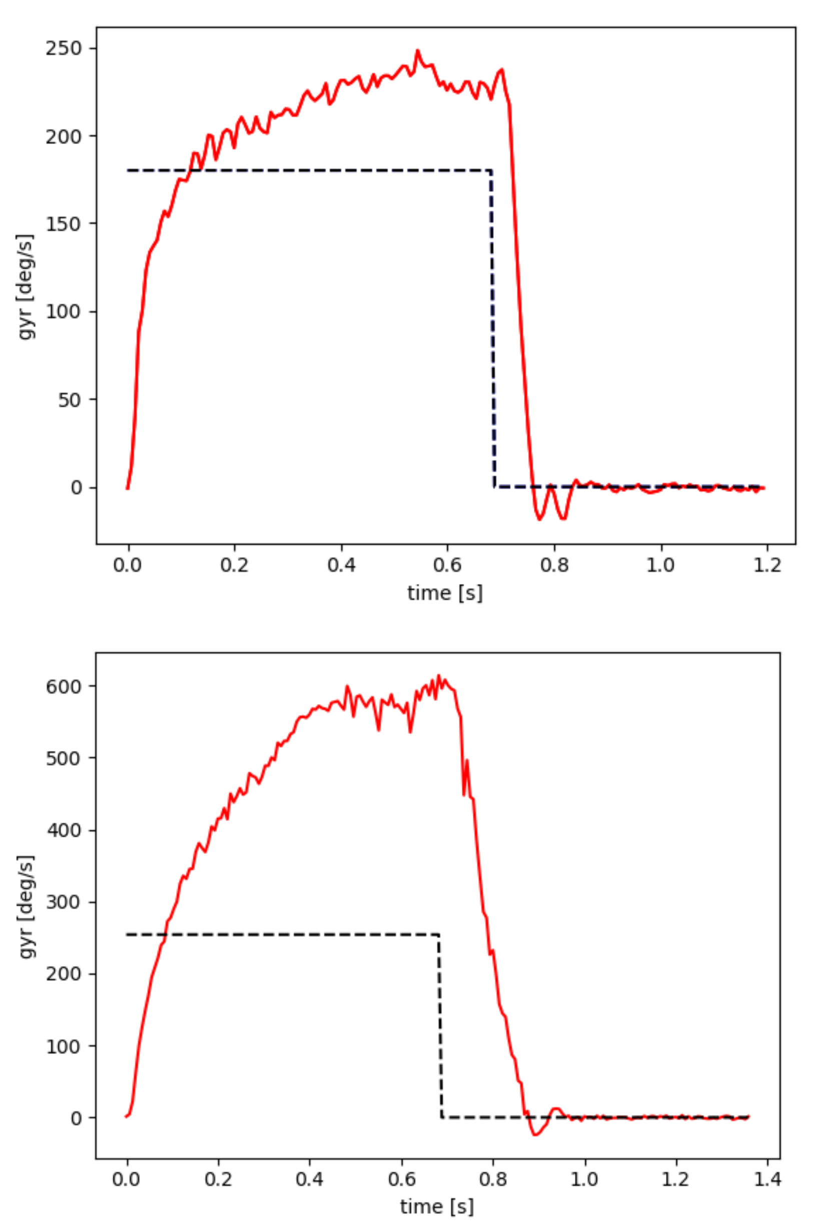


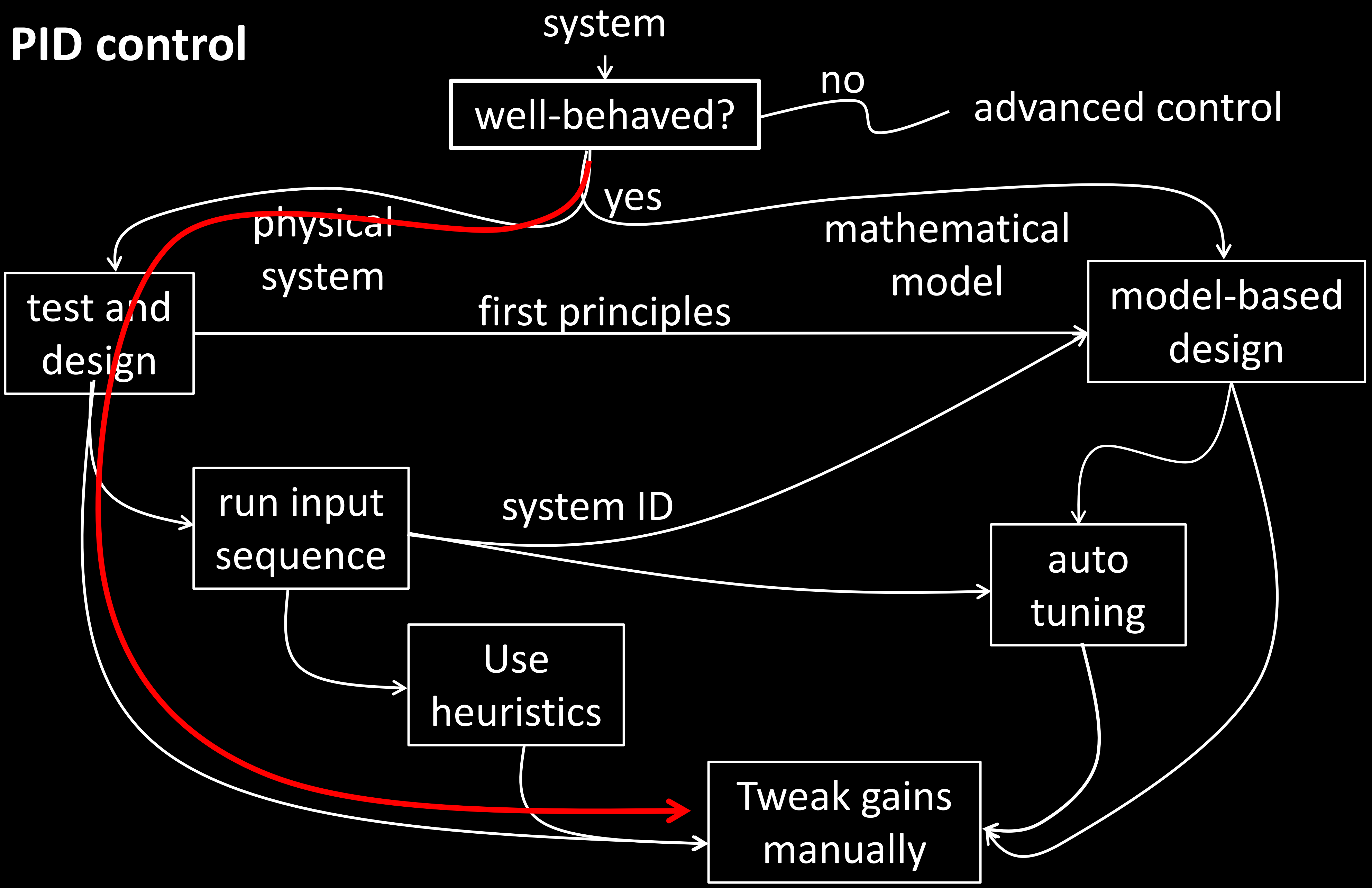
Fig.7. Open loop response of CHR method

Table.11. CHR Compensator

Type of controller	K_p	T_i	T_d
PID	$0.6T_g/T_uKg$	T_g	$0.5T_u$



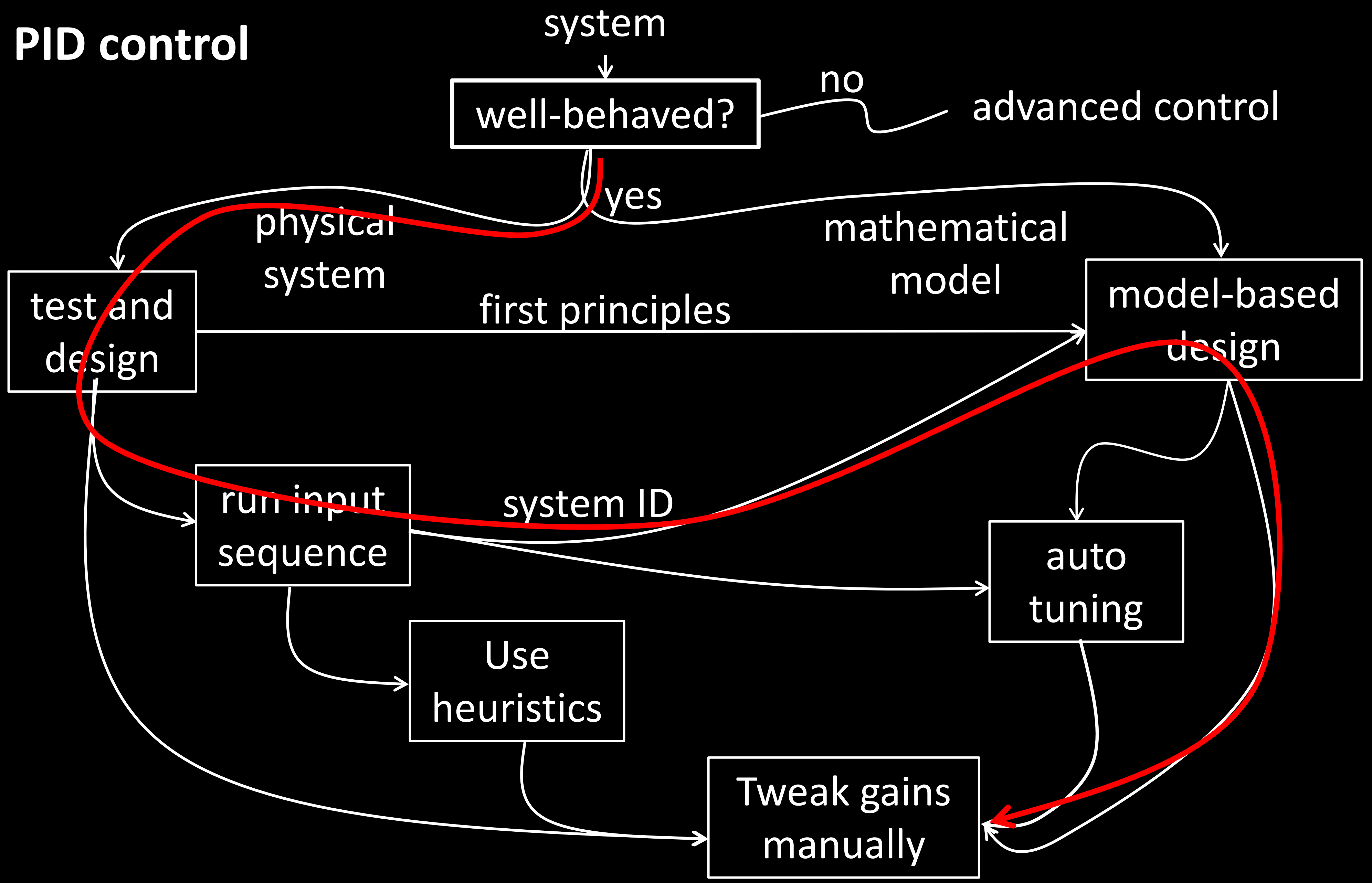
Tuning PID control



PID control (test and design)

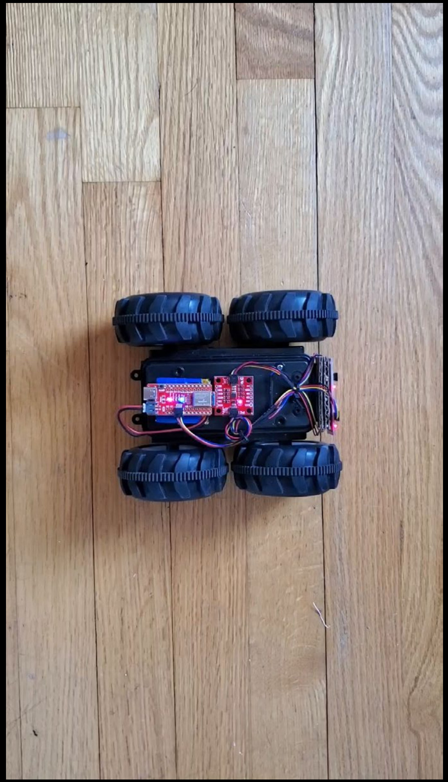
- **Heuristic procedure #1:**
  - Set Kp to small value, KD and KI to 0
  - Increase KD until oscillation, then decrease by factor of 2-4
  - Increase KP until oscillation or overshoot, decrease by factor of 2-4
  - Increase KI until oscillation or overshoot
  - Iterate
- **Heuristic procedure #2:**
  - Set KD and KI to 0
  - Increase KP until oscillation, then decrease by factor of 2-4
  - Increase KI until loss of stability, then back off
  - Increase KD to increase performance in response to disturbance
  - Iterate

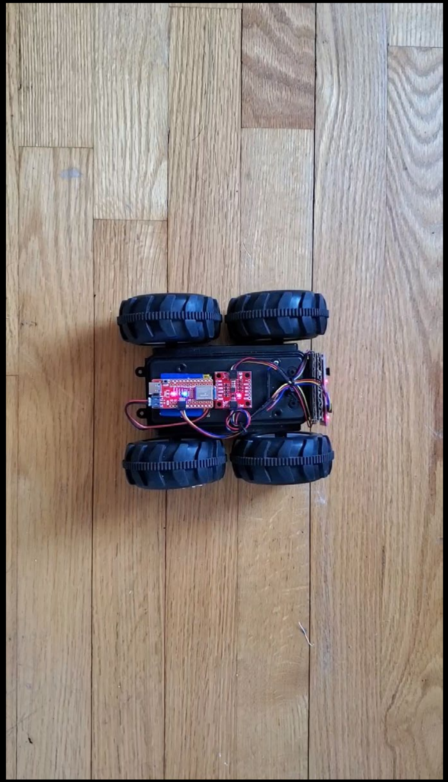
Tuning PID control

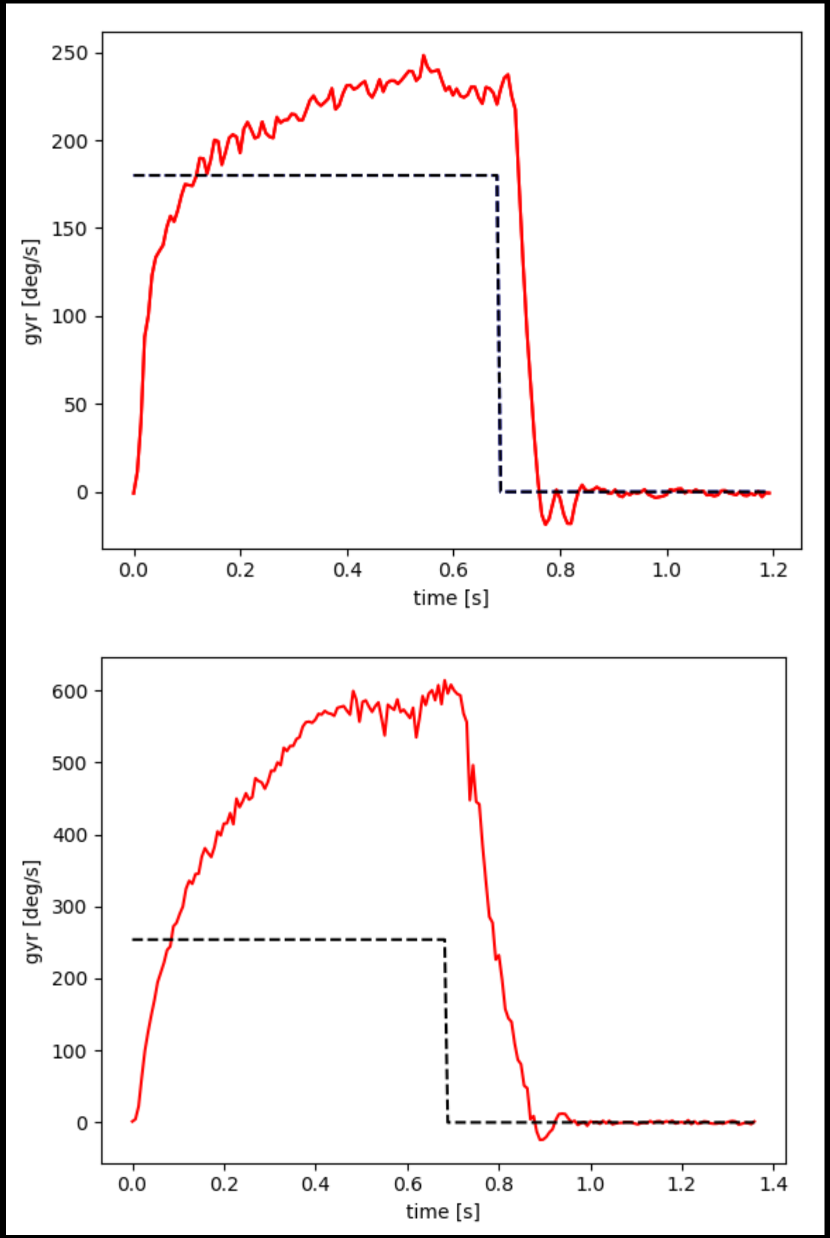


Tuning PID control

- Equations of motion
  - First order system…

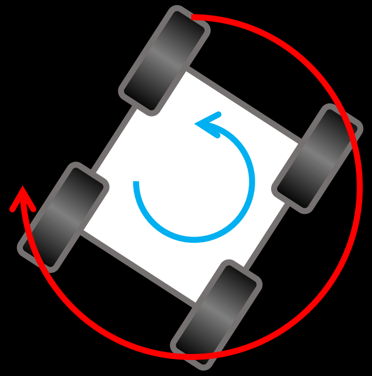






PID control for constant angular speed, $\dot{\theta}$

- Equations of motion
  - ~~$x = \dot{\theta}$~~
  - $x = \begin{bmatrix} \theta \\ \dot{\theta} \end{bmatrix}$



$$F = ma$$

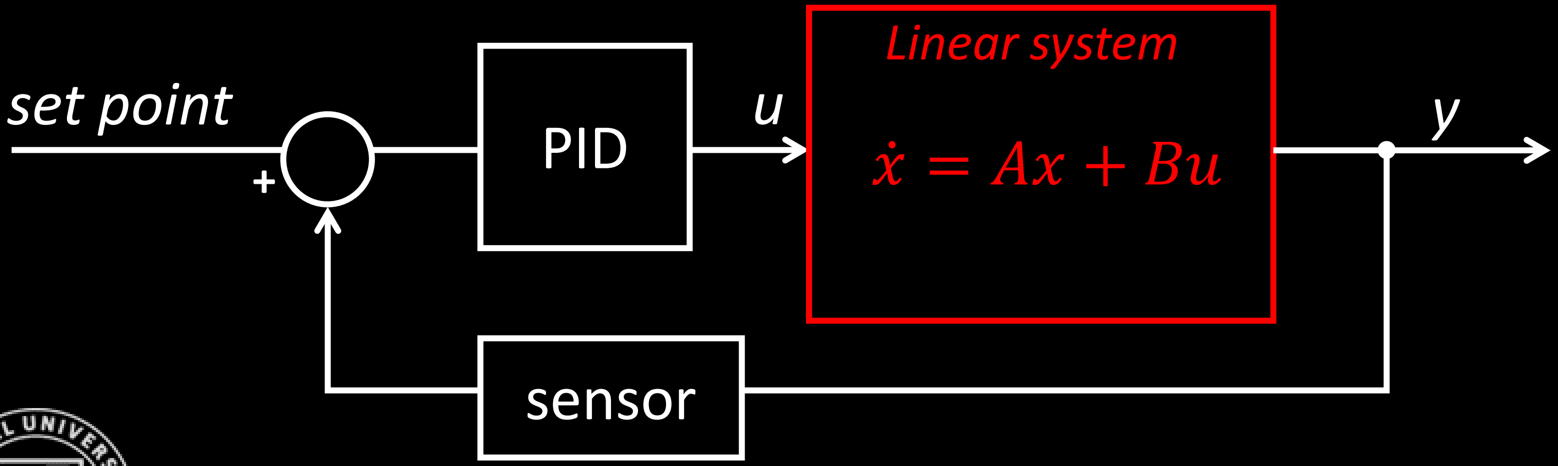
$$\tau = I\alpha$$

$$\tau = I\ddot{\theta}$$

$$u - \dot{\theta}c = I\ddot{\theta}$$

$$\ddot{\theta} = \frac{-\dot{\theta}c}{I} + \frac{1}{I}u$$

~~$$[\ddot{\theta}] = \left[\frac{-c}{I}\right][\dot{\theta}] + \left[\frac{1}{I}\right]u$$~~



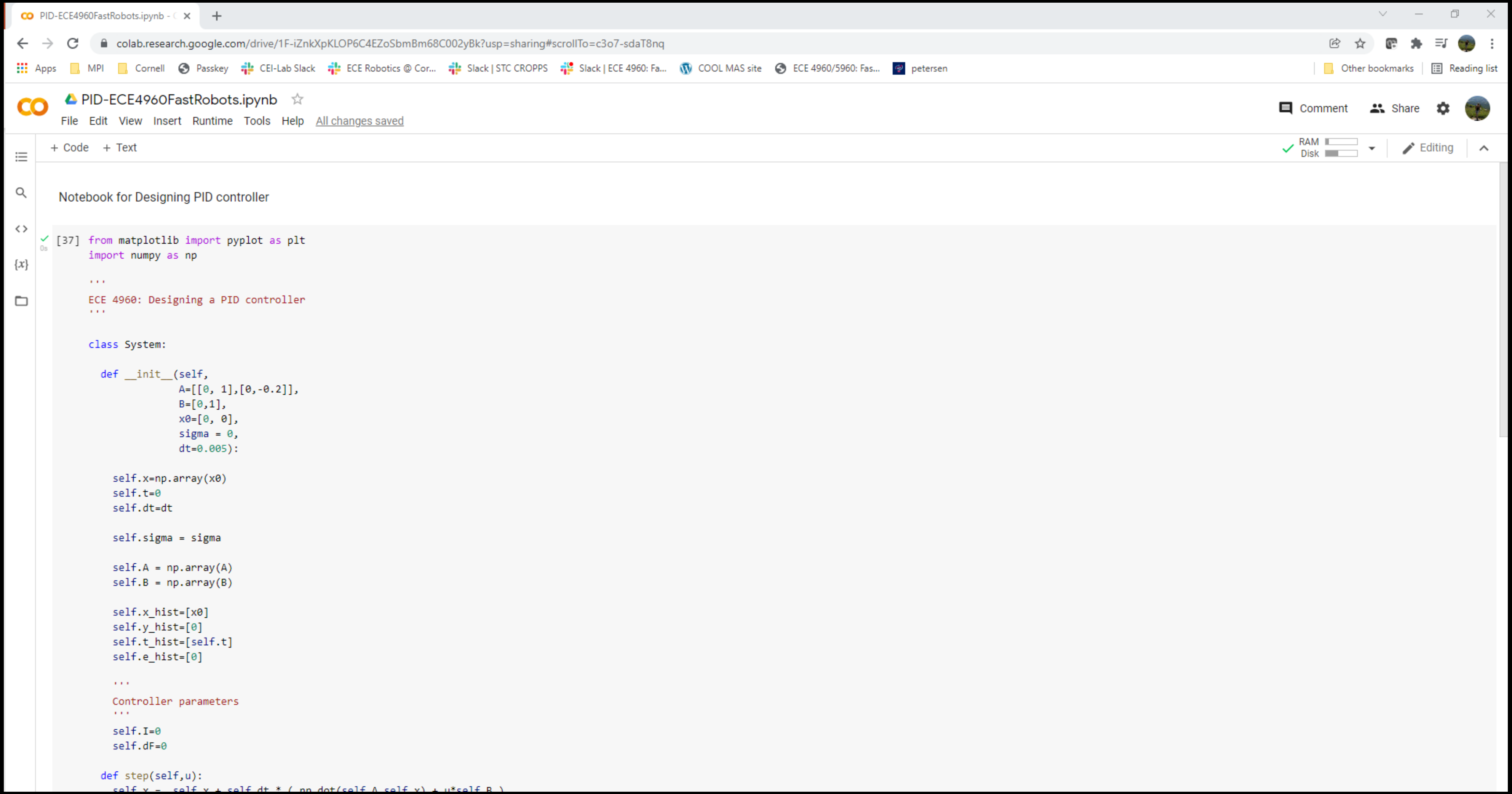
$$\begin{bmatrix} \dot{\theta} \\ \ddot{\theta} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & \frac{-c}{I} \end{bmatrix} \begin{bmatrix} \theta \\ \dot{\theta} \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{I} \end{bmatrix} u$$

A B

Can't affect θ directly

PID control for constant angular speed, $\dot{\theta}$

- https://bit.ly/3LIAxae



PID control for constant angular speed, $\dot{\theta}$

- https://bit.ly/3LIAxae

- **Heuristic procedure #1:**
  - Set Kp to small value, KD and KI to 0
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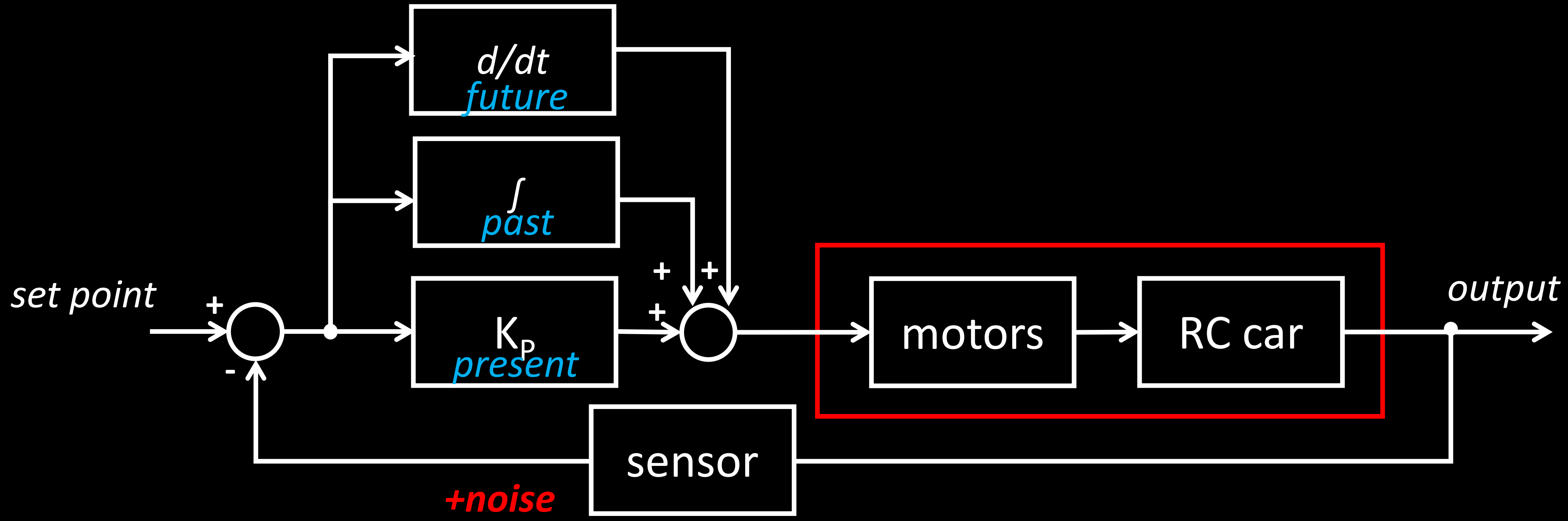
  - Increase KI until loss of stability, then back off
  - Increase KD to increase performance in response to disturbance
  - Iterate

PID control for constant angular speed, $\dot{\theta}$

- https://bit.ly/3LIAxae
- Overshoot (K_p = 10, K_I = 100)
- Dampening (K_p = 10, K_I = 100, K_D = 0.8)
- Noise (sigma = 0.1)
- LPF (alpha = 0.05)
- Derivative kick (alpha = 1, sigma = 0)

PID control of a 2nd order system



1st order system: $\begin{bmatrix}\dot{\theta}\\ \ddot{\theta}\end{bmatrix} = \begin{bmatrix}0 & 1\\ 0 & \frac{-c}{I}\end{bmatrix}\begin{bmatrix}\theta\\ \dot{\theta}\end{bmatrix} + \begin{bmatrix}0\\ \frac{1}{I}\end{bmatrix}u$

2nd order system: $\begin{bmatrix}\dot{\theta}\\ \ddot{\theta}\end{bmatrix} = \begin{bmatrix}0 & 1\\ cst & \frac{-c}{I}\end{bmatrix}\begin{bmatrix}\theta\\ \dot{\theta}\end{bmatrix} + \begin{bmatrix}0\\ \frac{1}{I}\end{bmatrix}u$

Looking ahead: lab 6, PID control

- Control for fast mode
  - Stunt: orientation
  - Stunt: speed control
- Control for slow mode
  - Mapping: angular speed
  - Path execution: position control

Biggest limitation?

- Sensor noise
- Sensor sampling time
- PID control is preferably 5-10 times faster than your system
- *Lab 7 Kalman filter*
- *Lab 8 Stunt*

Next three lectures

- Control theory
  - Linear systems
  - Eigenvectors
  - Stability
  - Controllability
  - Observability
  - Kalman filters

$$\dot{x} = Ax + Bu$$

These should look familiar from..
- MATH 2940 Linear Algebra
- ECE3250 Signals and systems
- ECE5210 Theory of linear systems
- MAE3260 System Dynamics
- etc…