Feedback control

Fast Robots, ECE4160/5160, MAE 4190/5190

E. Farrell Helbling, 2/11/25

Class Action Items

- Lab 3 starts today! Please aim to get your soldering done first! A really good writeup from last year: https://mavisfu.github.io/lab3.html
  - Not everyone can solder at the same time (we only have 8 soldering irons)
  - If you have access to another soldering iron, feel free to use it.
- There is no lab next week and lab 3 is not due until Feb. 25-26, this is mostly due to Feb. break, but also because there is a lot of soldering to do over the next two labs. Please plan ahead!
- Lab 4 also has a significant soldering component, please if you can, work on this early (i.e., next week after February break)

Some notes about the labs

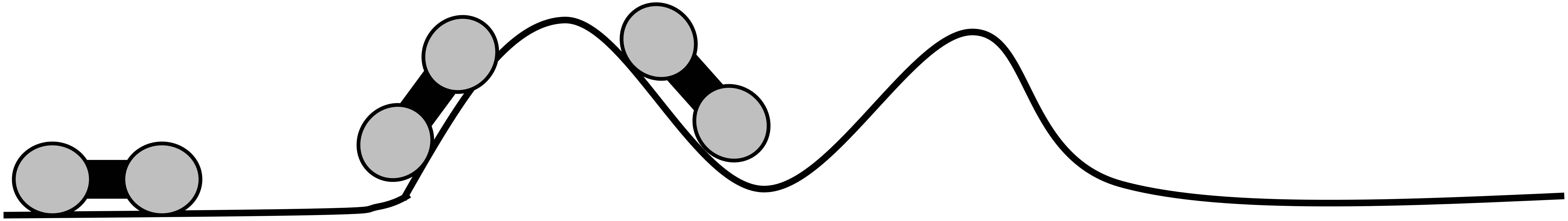
- There have been a lot of questions about rubrics for the labs and questions about how people should answer particular questions.
  - Questions can be answered in a lot of ways. This will become even harder as the labs go on. Your code is starting to diverge, your sensor placement will be different, each of your cars are different, your motors are different, your mass distribution is different.
  - What evidence can you provide to answer the questions we've posed?
  - If you don't understand what the question is asking then we can help clarify, but how to answer it can vary and we will accept a lot of different answers.
- If you break a component, please send us a message on Ed. I have supplies for spares, but we cannot replace components multiple times. Please use your lab kits. Keep things well protected.

Ed Discussion Polls

- We are going to ask students for preferred OH times (preference will be given to students who need to use the lab computers to complete the labs)
- There will also be polls posted at the end of every lab to ask how many hours the lab took. This is mostly for our own knowledge to make sure we are timing the labs correctly.

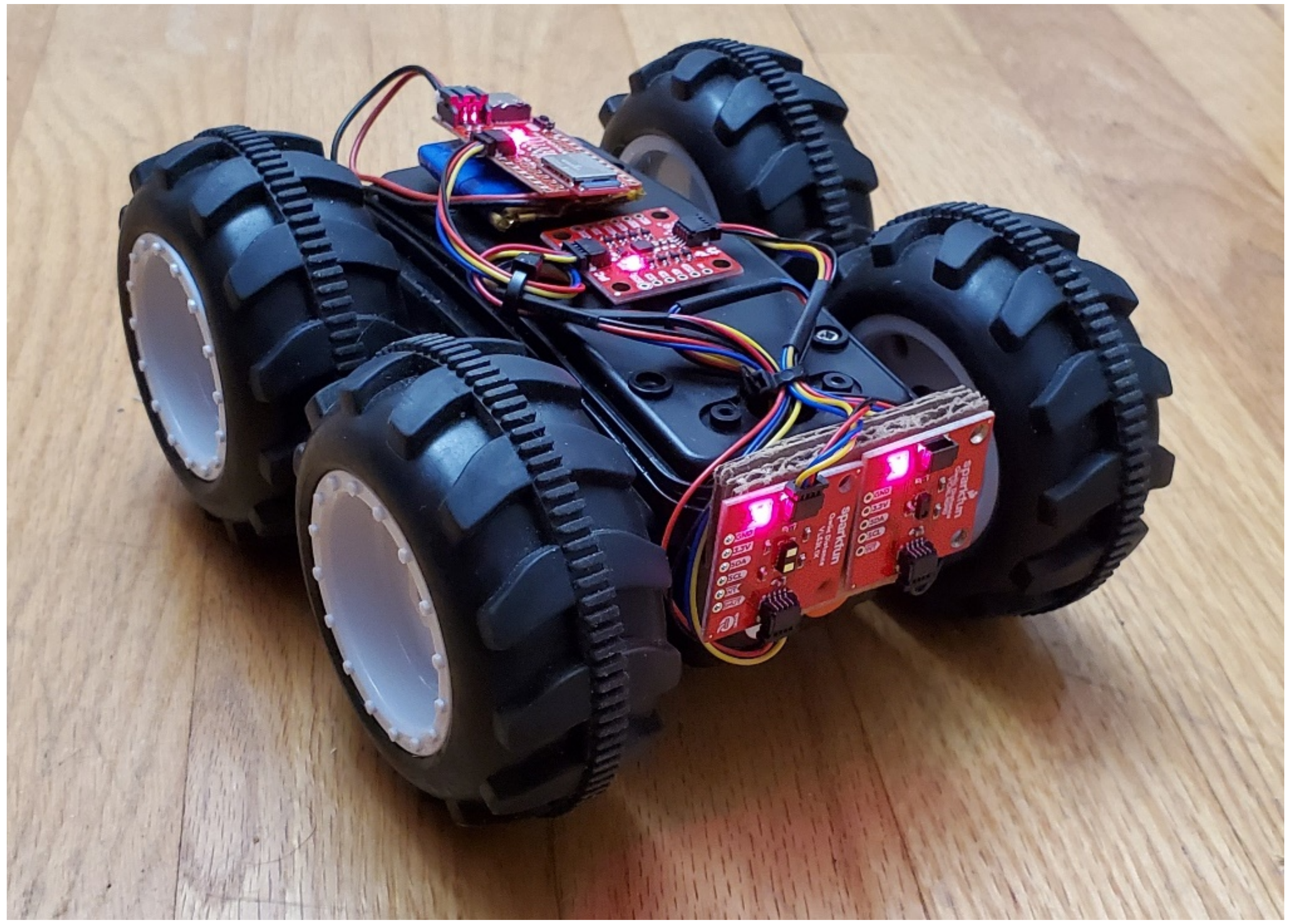
Feedback Control

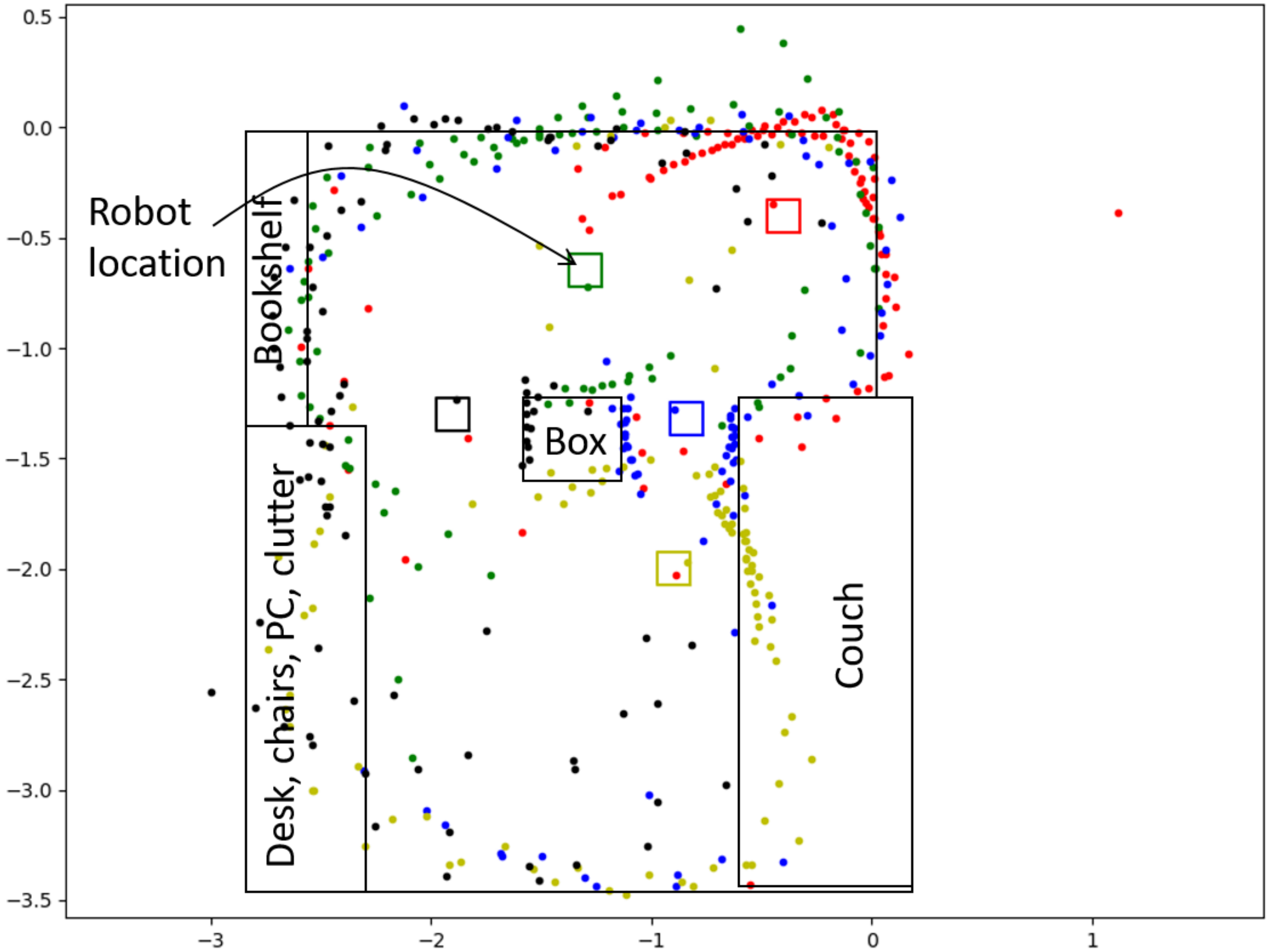
- Maintain speed prediction at different battery levels, over different surfaces
- Maintain position with respect to walls
- Maintain heading angle
- Etc.



Feedback Control

- Stunts: maintain speed prediction at different battery levels, over different surfaces
- Mapping: evenly spaced out sensor readings
- Path execution: adhere to generated path plans





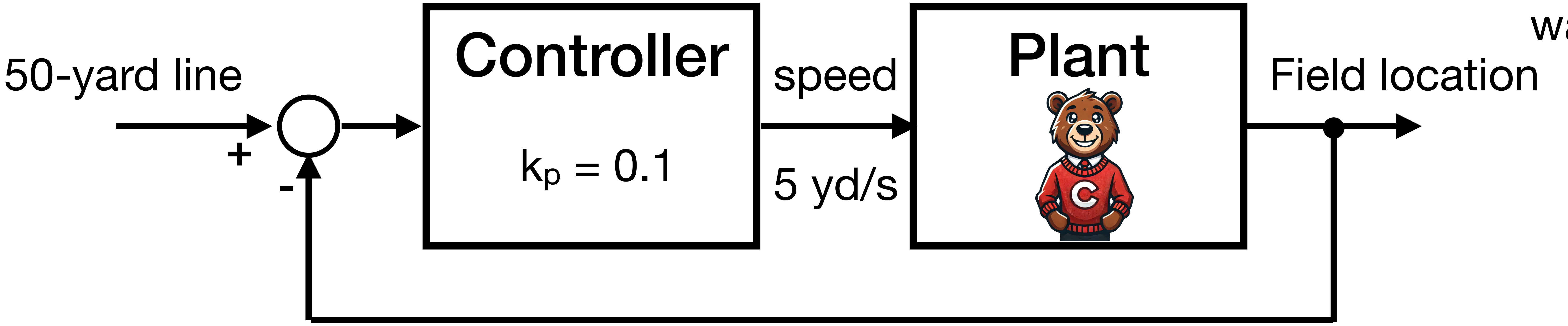
PID control

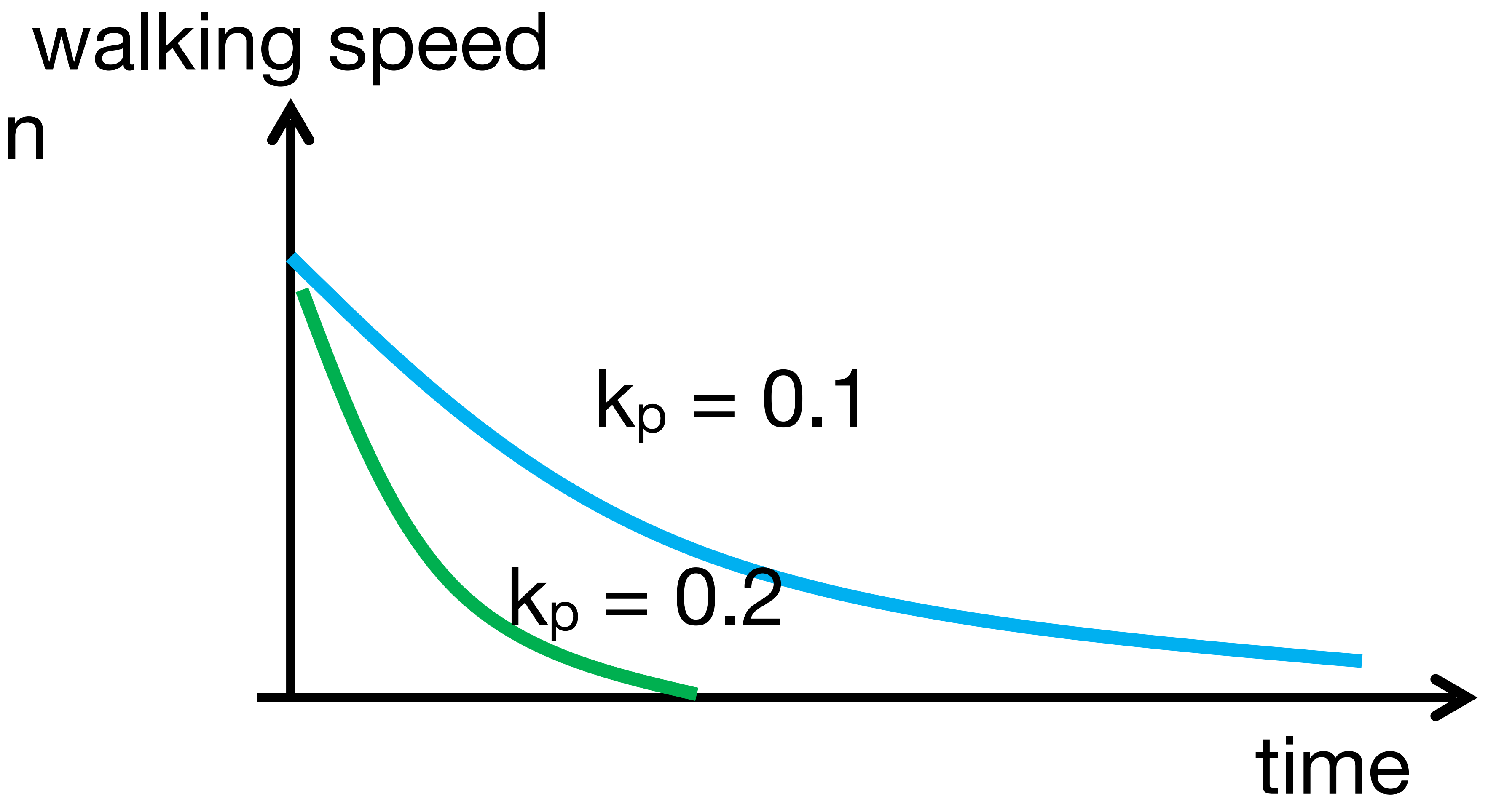
$$u(t) = K_P e(t) + K_I \int_0^t e(t)dt + K_D \frac{de(t)}{dt}$$

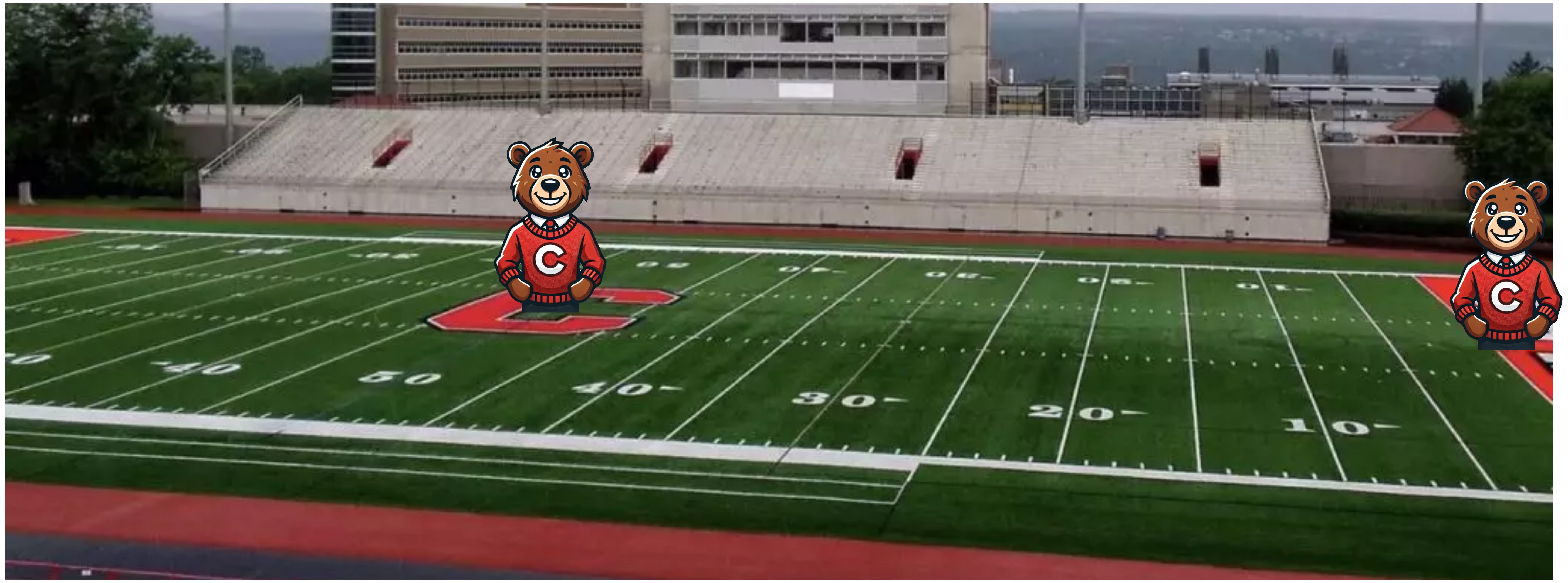
Based heavily on MATLAB's Tech Talk: Understanding PID control

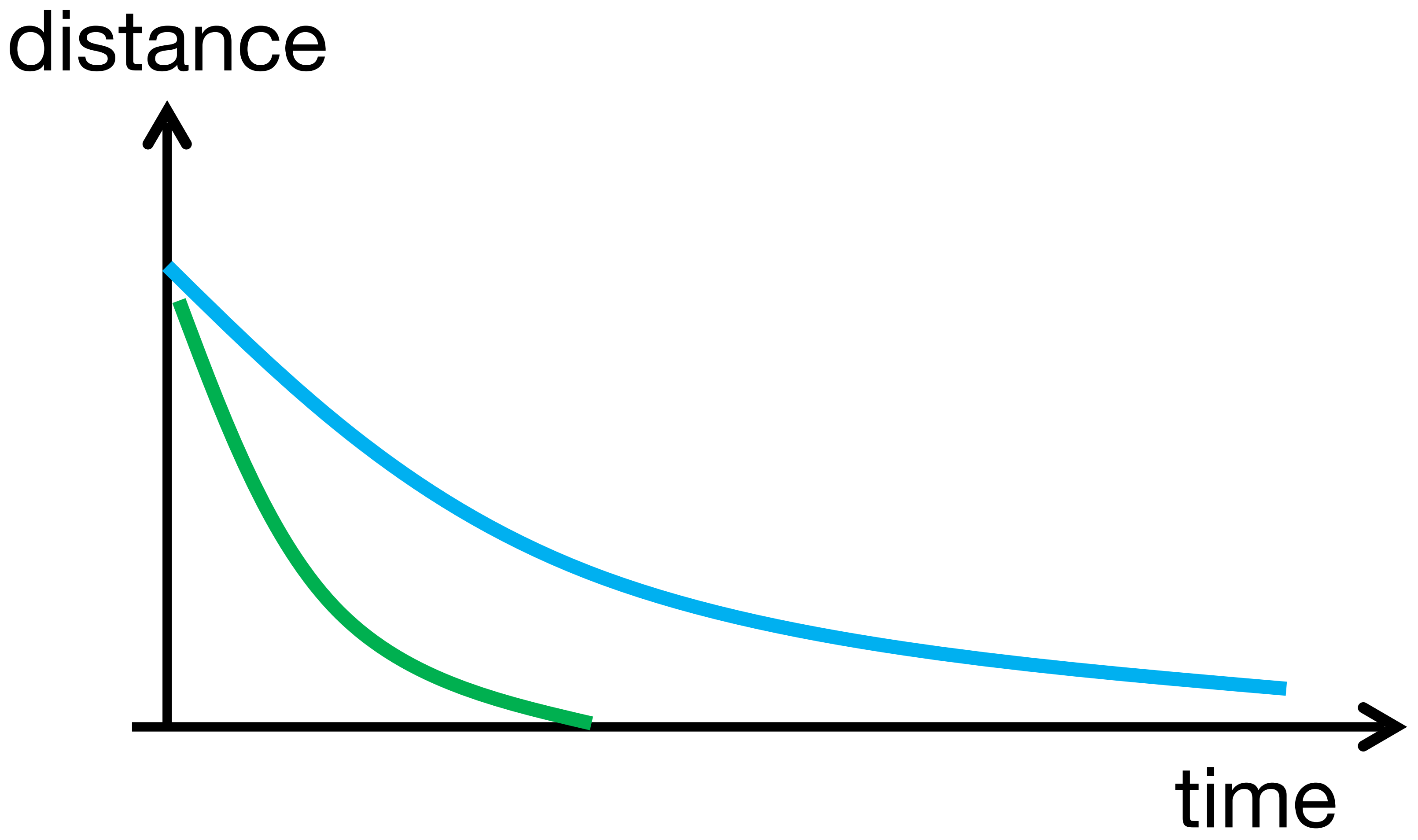
PID control

Football Field



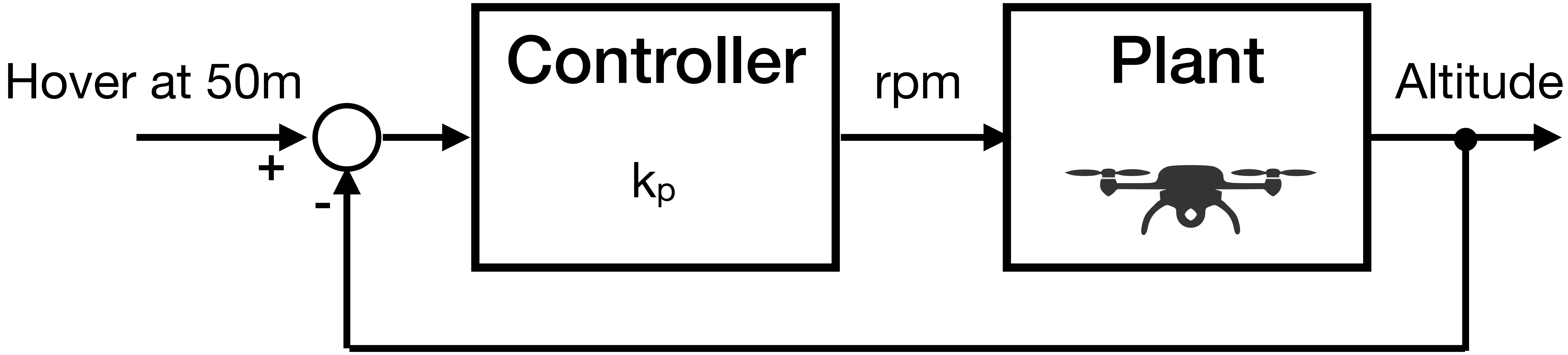


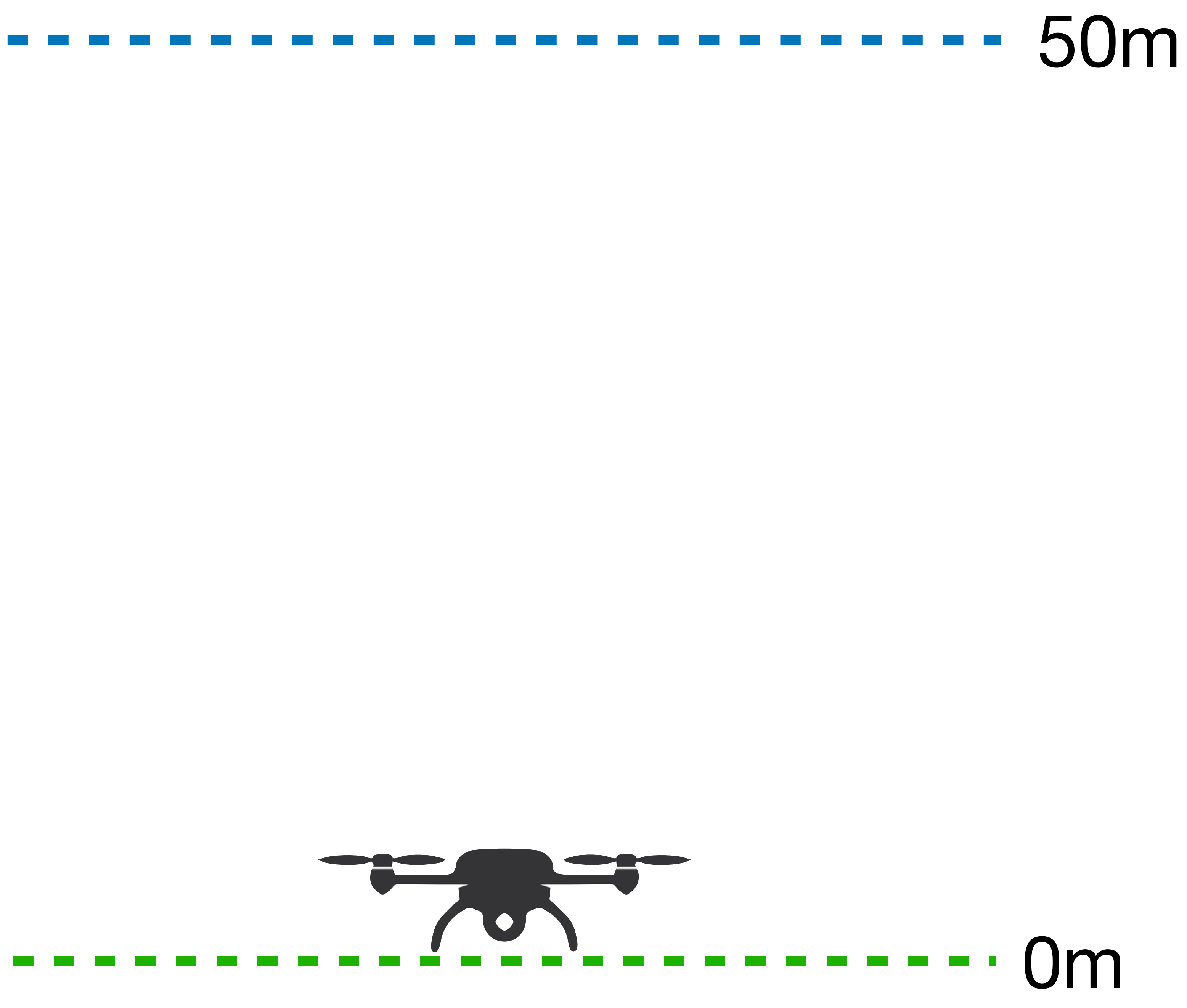




PID control

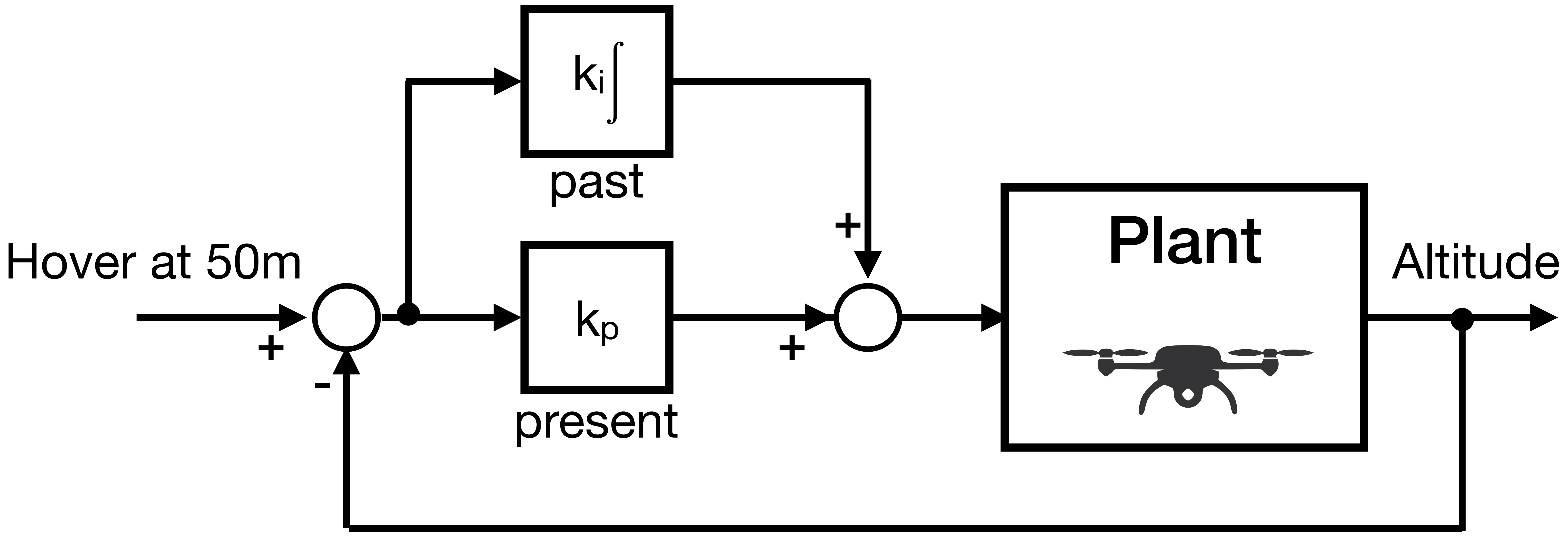
Drone

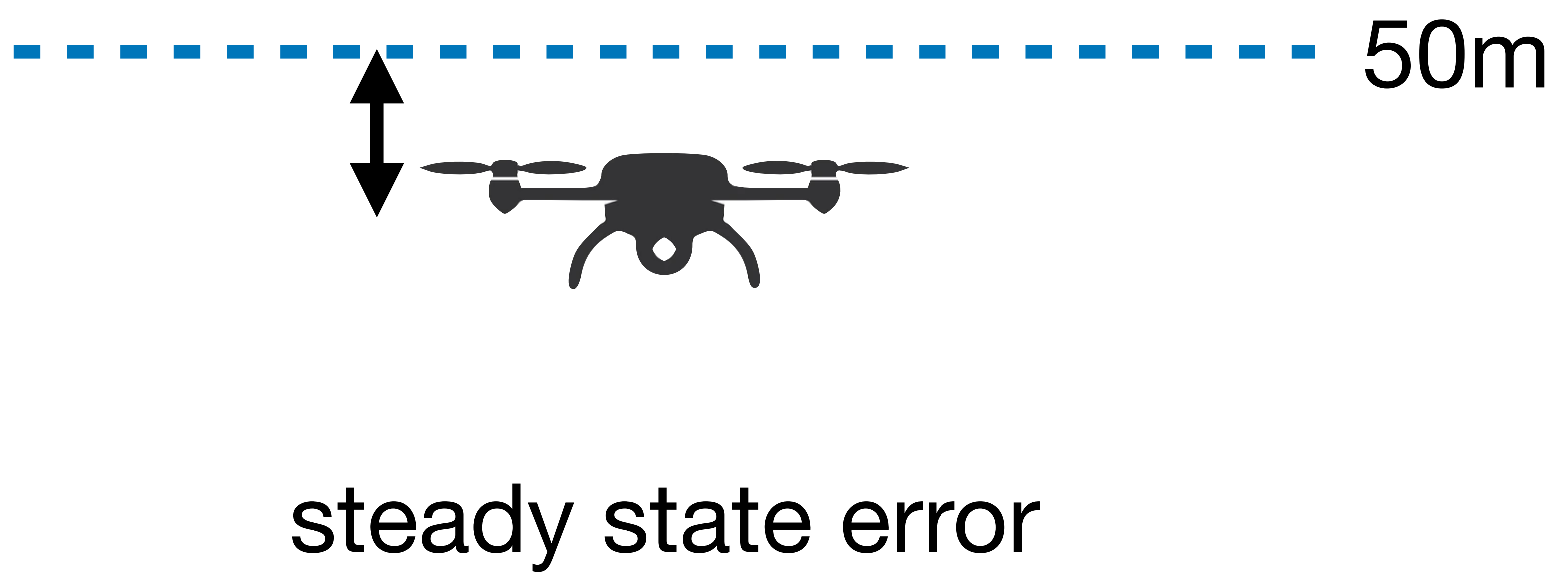




PID control

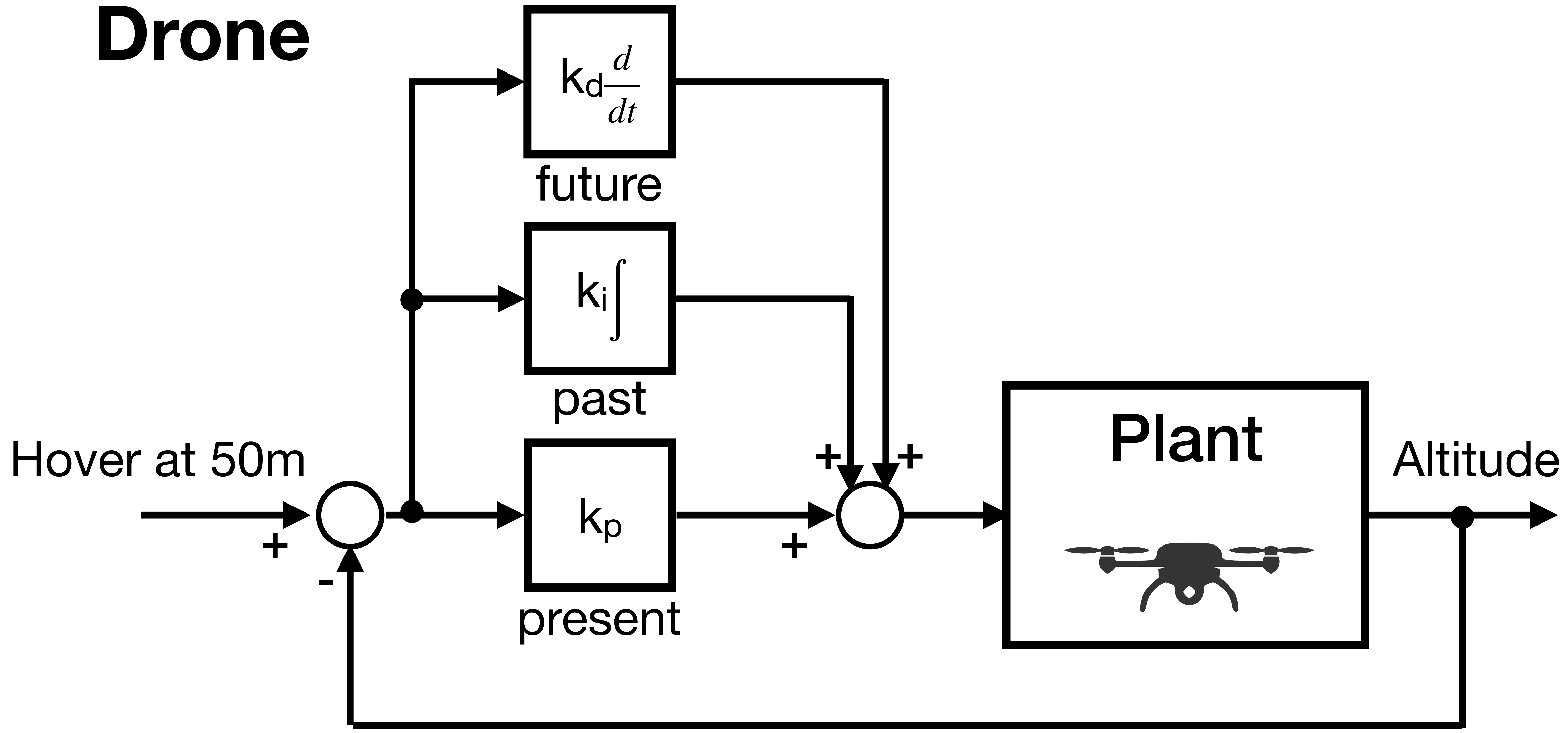
Drone

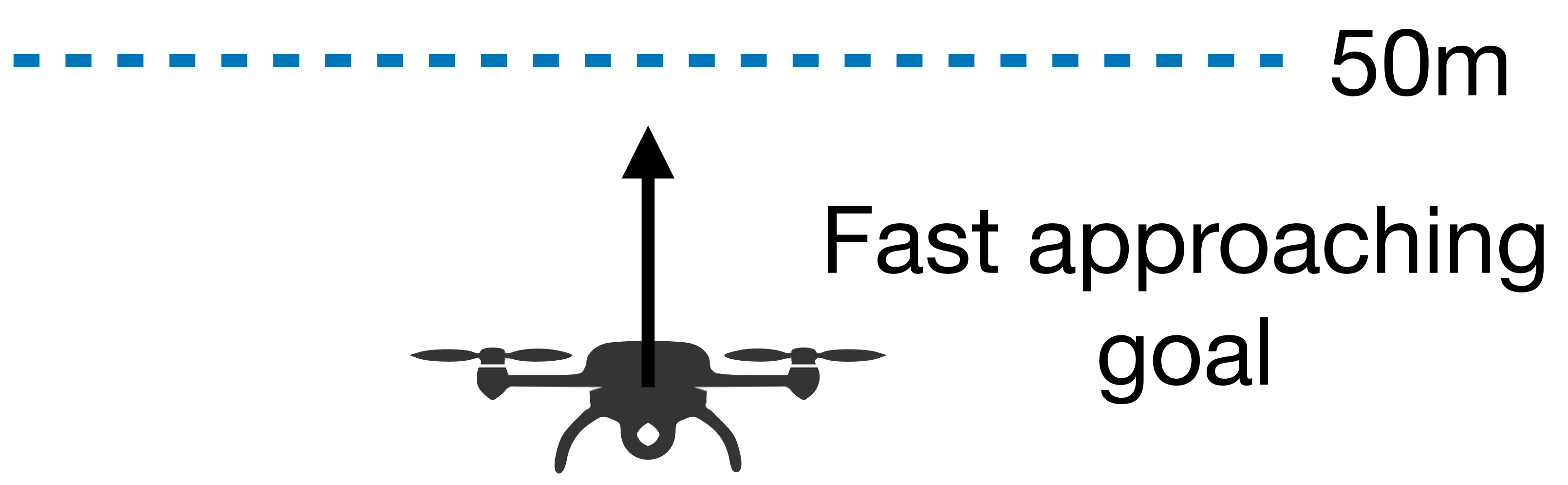




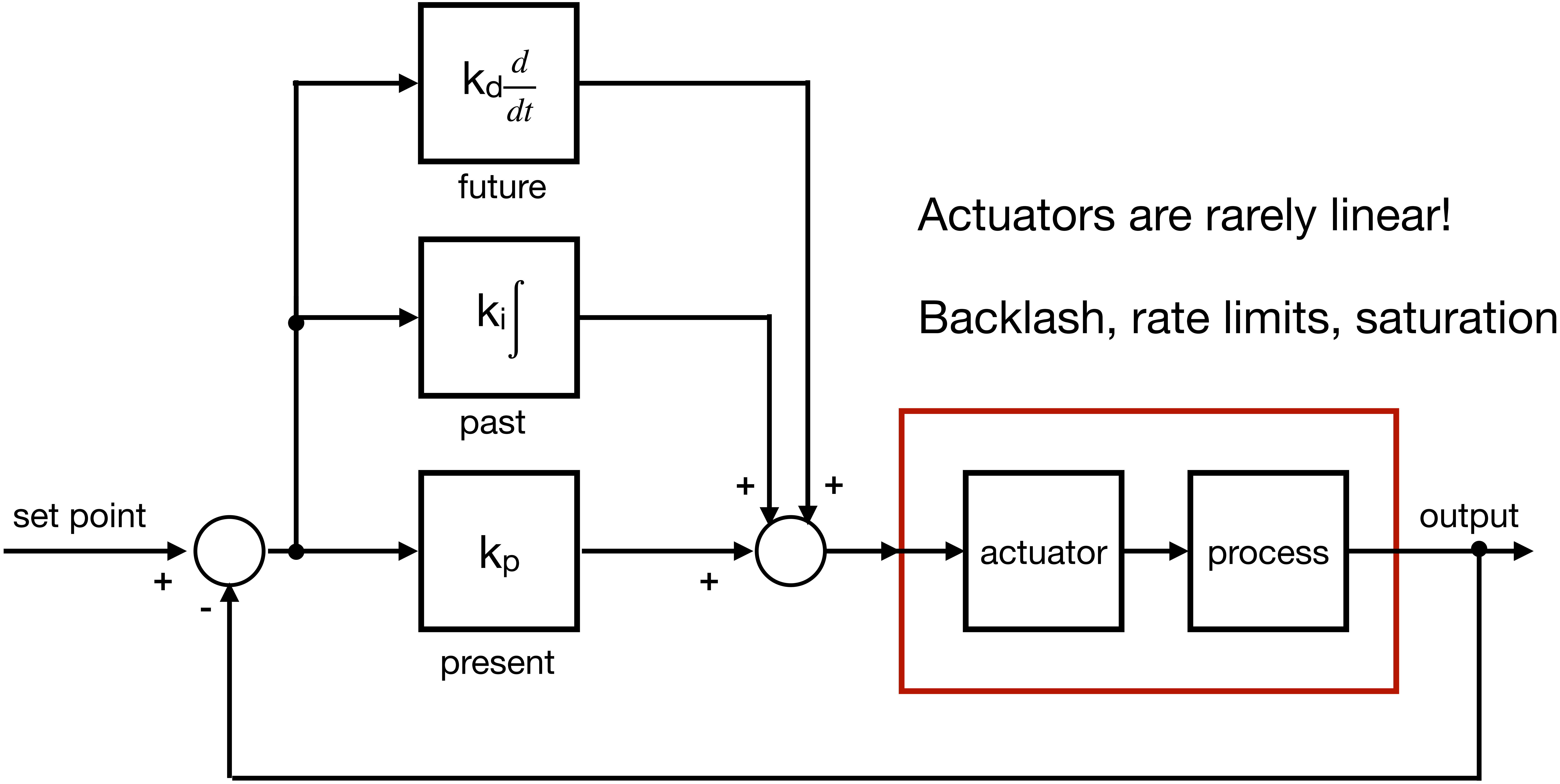
PID control

Drone





PID Control

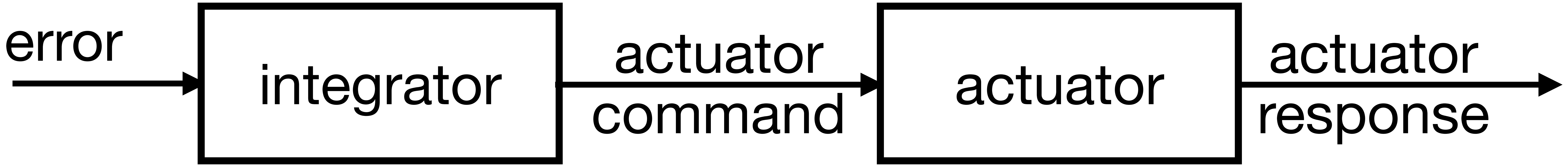


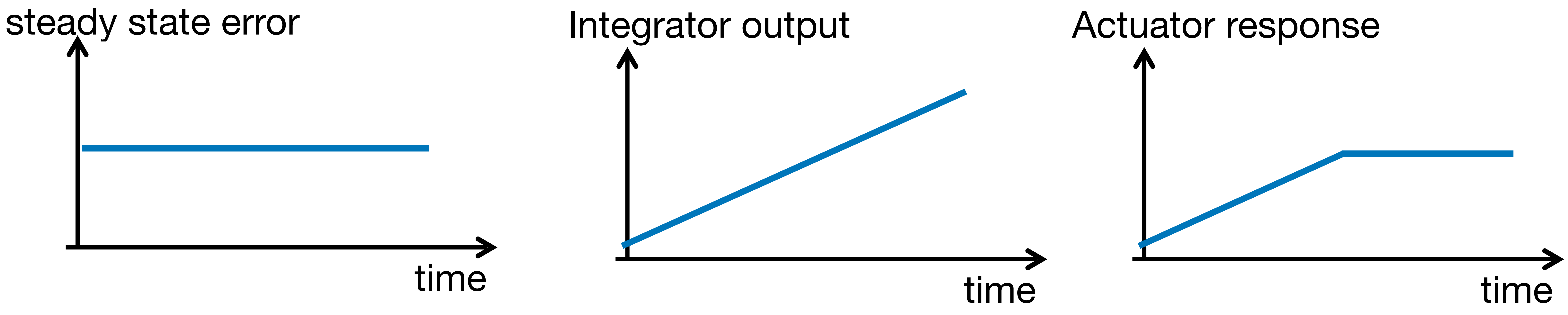
Actuators are rarely linear!

Backlash, rate limits, saturation

Real systems are not linear

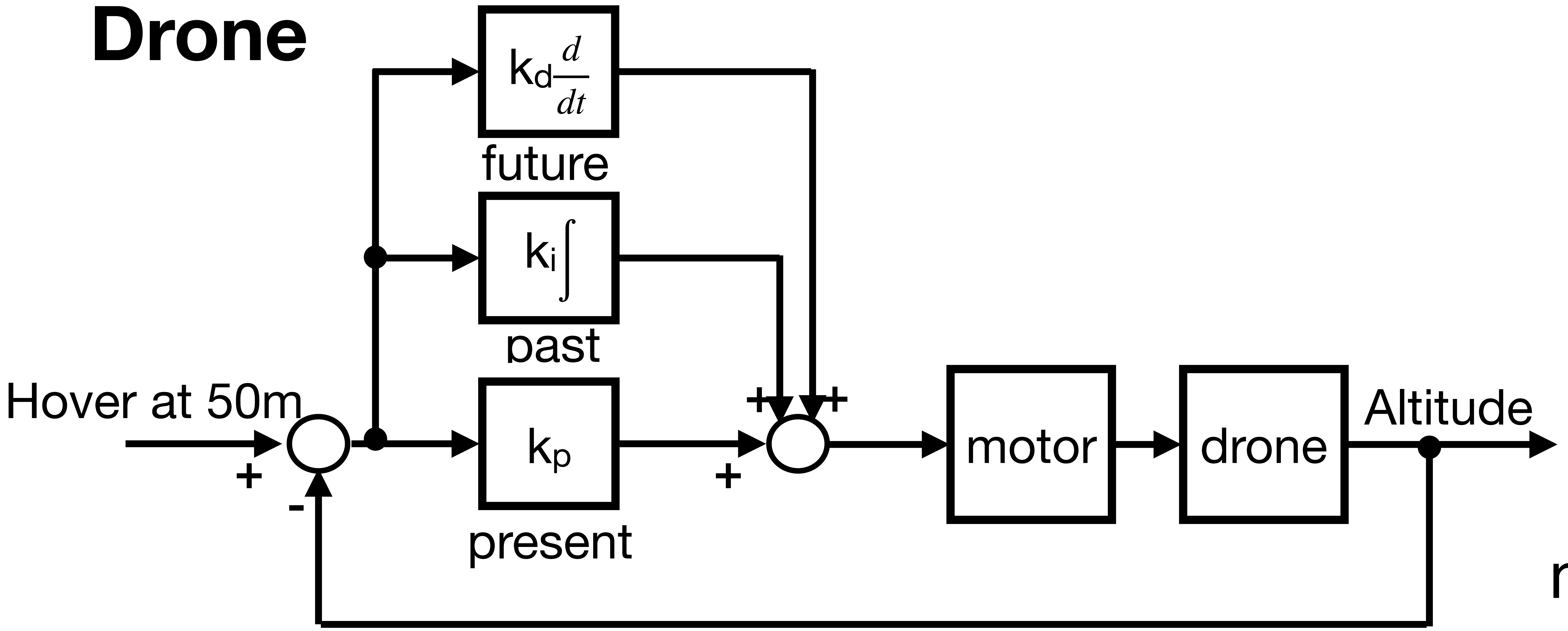
Actuator response

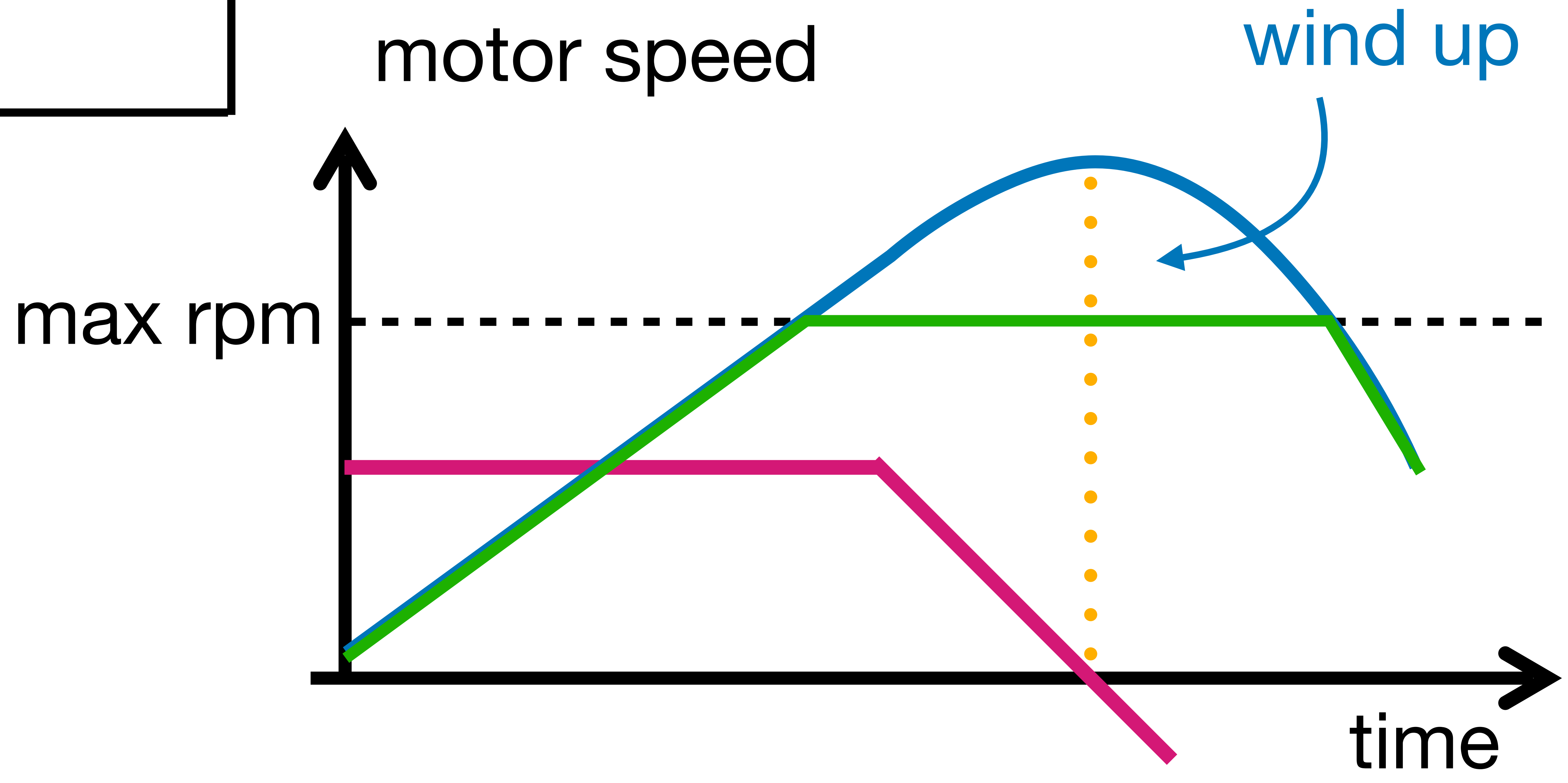




Real systems are not linear

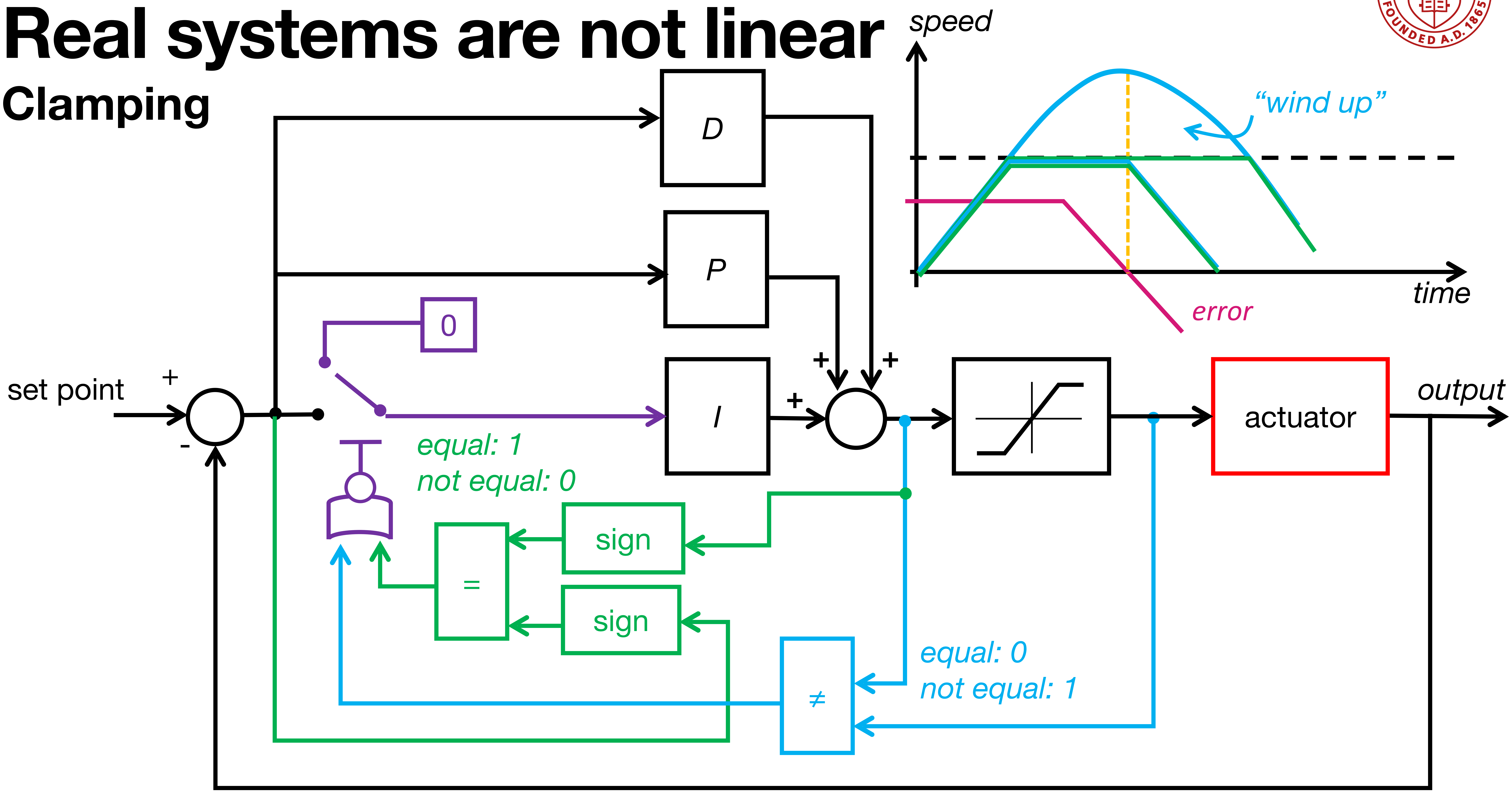
Drone



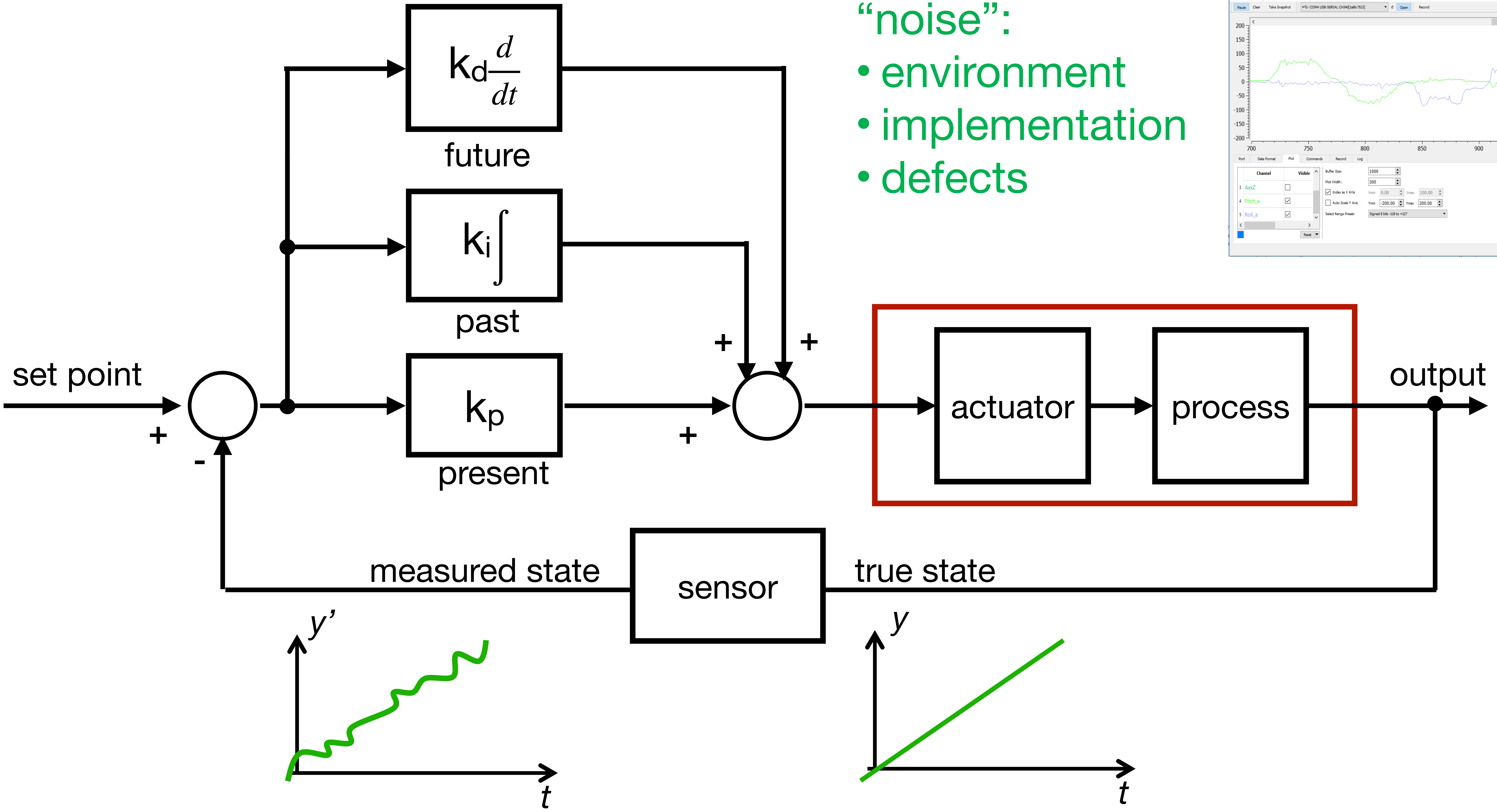


Real systems are not linear

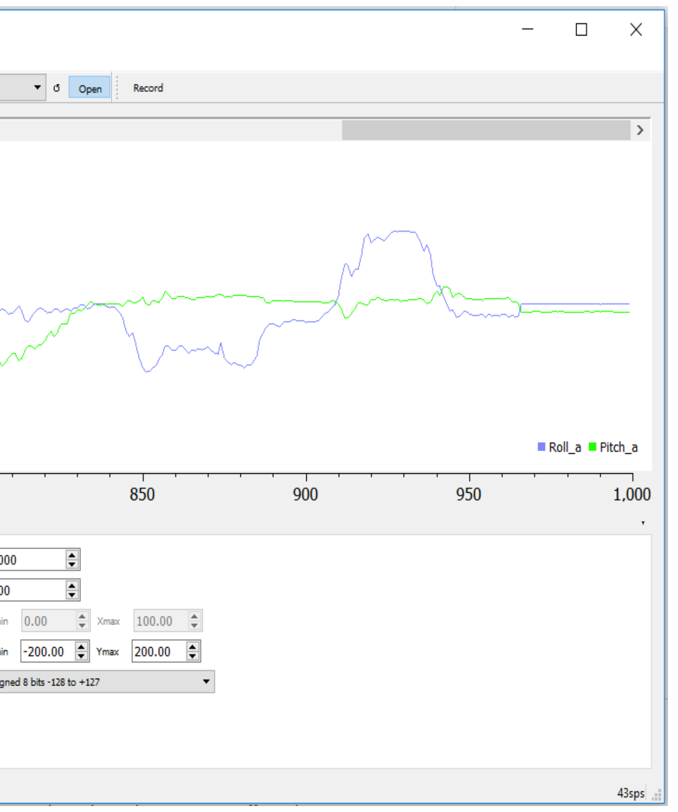
Clamping



PID and Sensor Noise

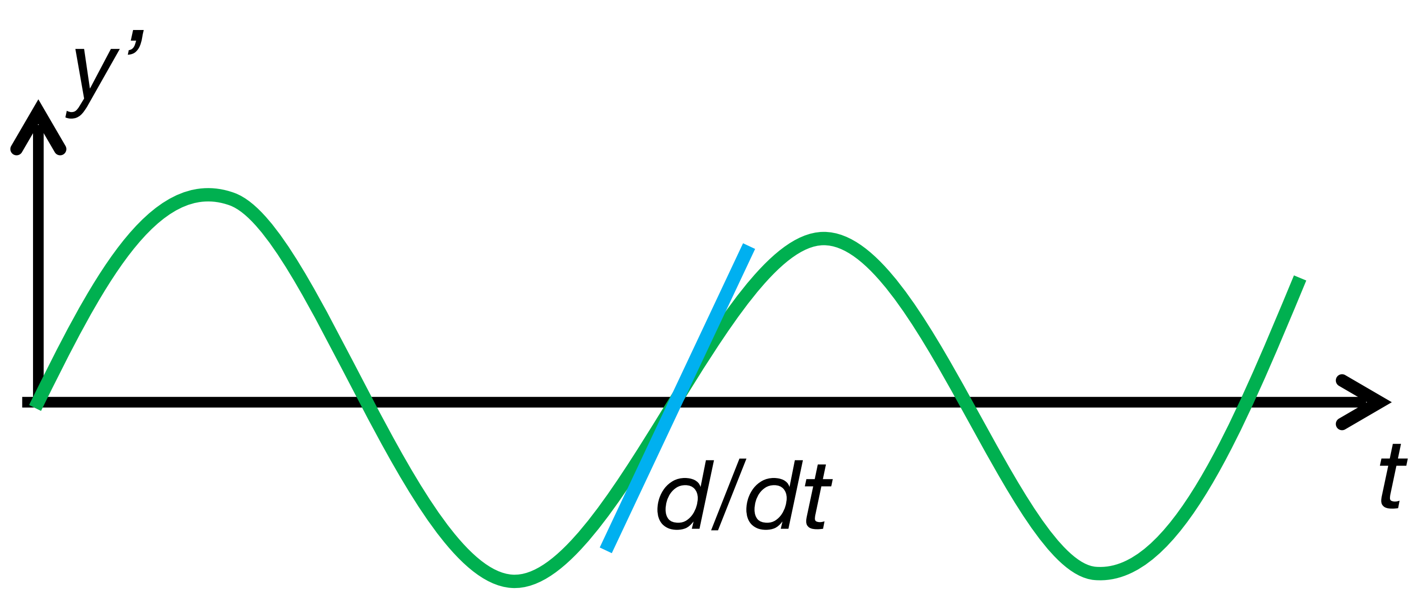


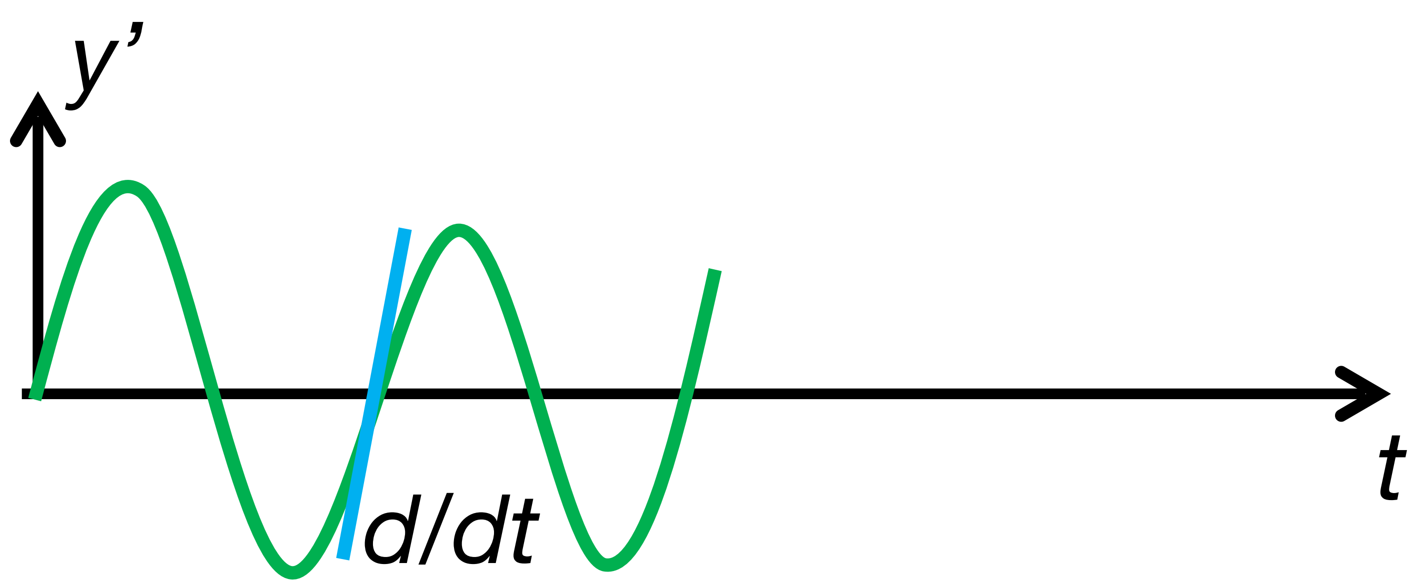
"noise":
- environment
- implementation
- defects

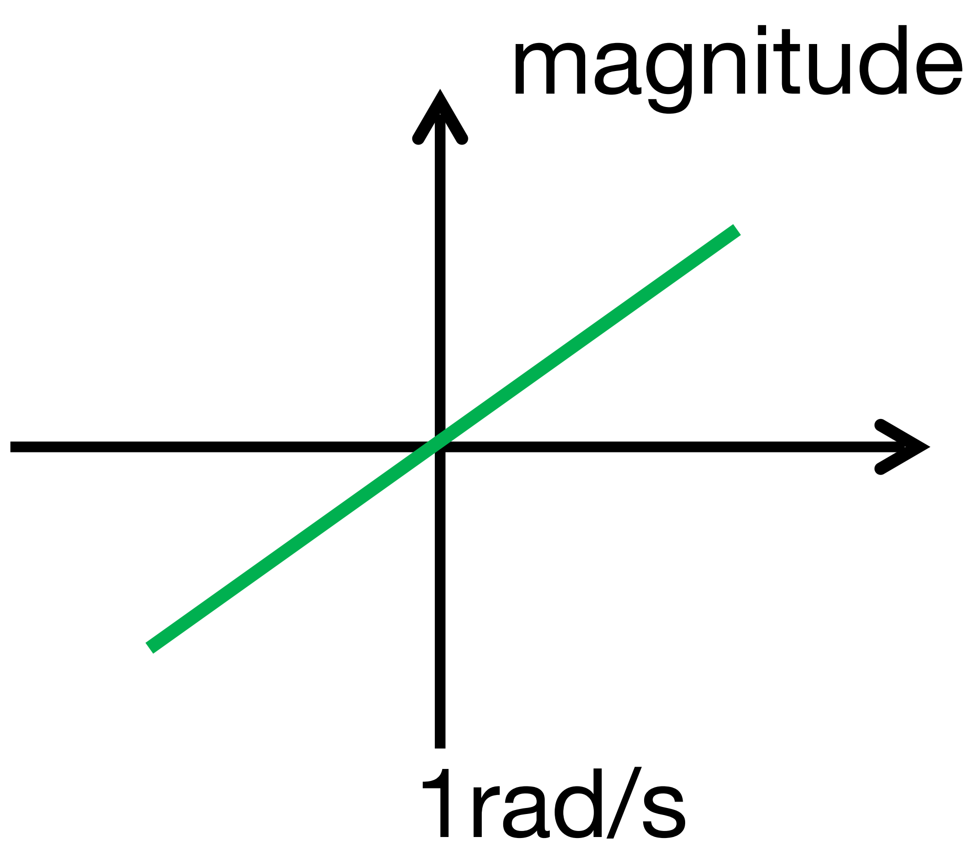


PID and Sensor Noise

Derivatives amplify HF signals more than LF signals





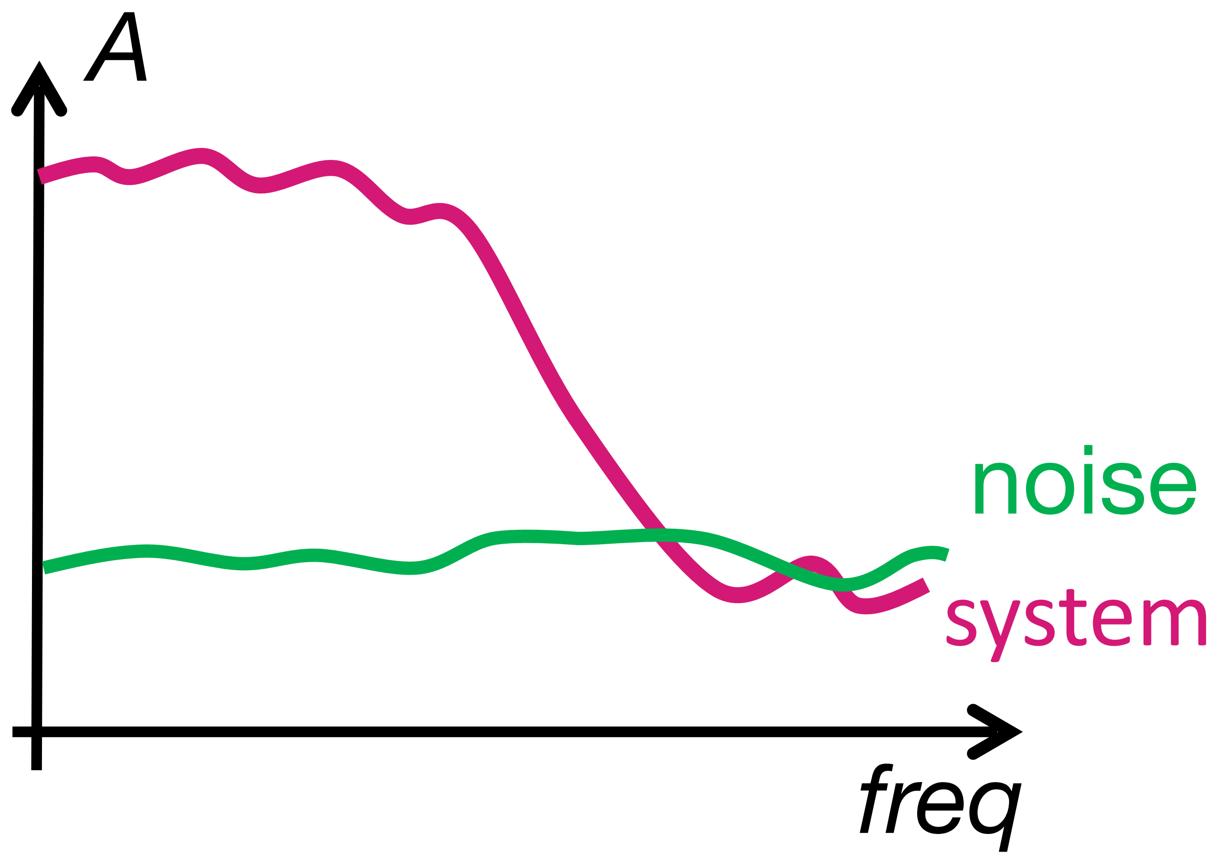


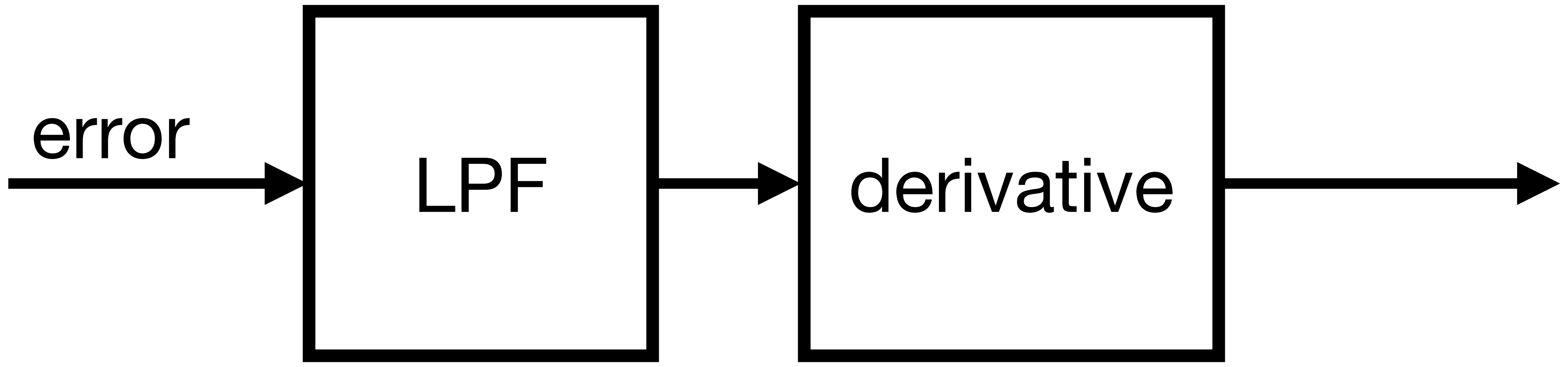
$$y(t) = A\sin(\omega_a t+\phi_a) + B\sin(\omega_b t+\phi_b) + \ldots$$

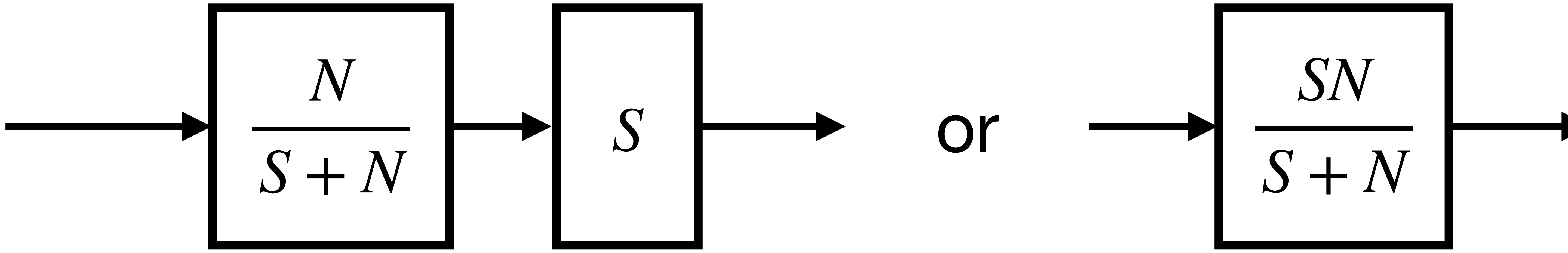
$$dy(t)/dt = A\omega_a\sin(\omega_a t+\phi_a+90^o) + B\omega_b\sin(\omega_b t+\phi_b+90^o) + \ldots.$$

- if ω_a >1rad/s, then amplitude will increase
- if ω_a <1rad/s, then amplitude will decrease

PID and Sensor Noise

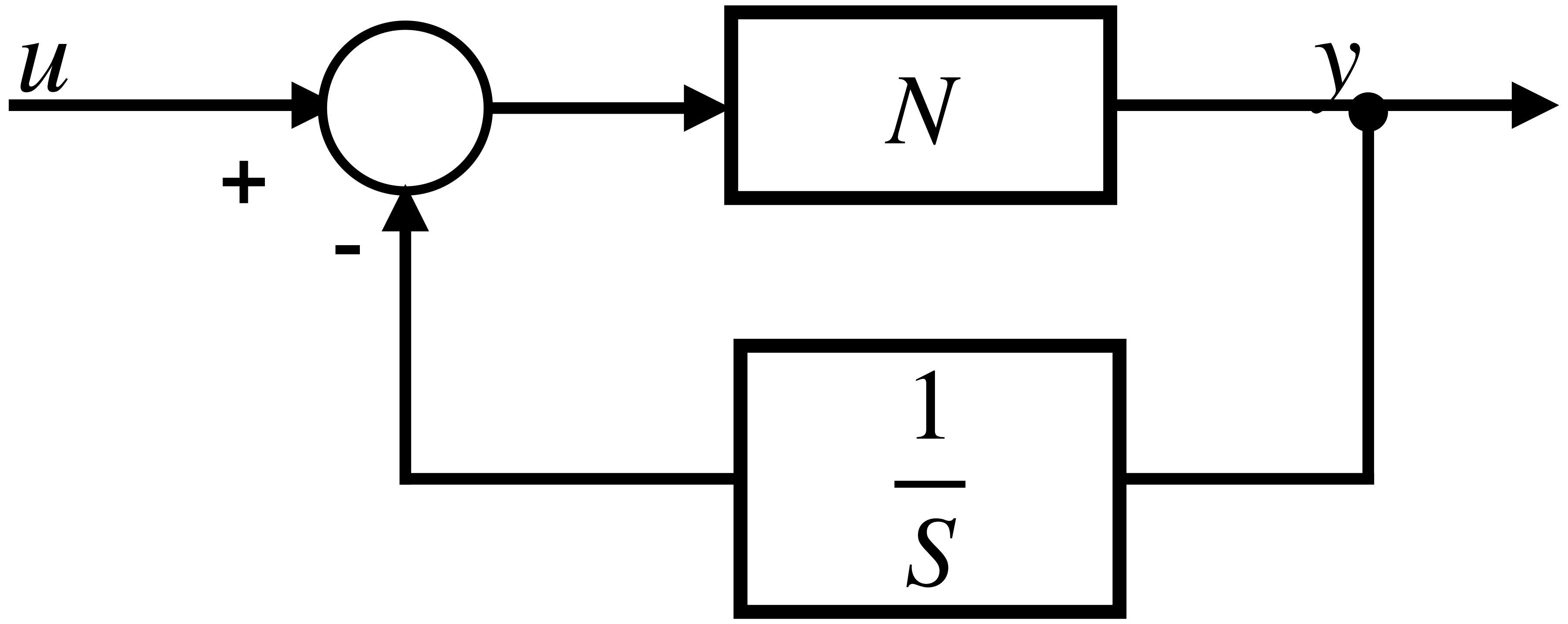






Time	Laplace
$\frac{d}{dt}$	S
$\int dt$	$\frac{1}{S}$
	$\frac{N}{S+N}$

$$= \frac{1}{\frac{1}{N}S+1} = \frac{1}{\tau S+1}$$



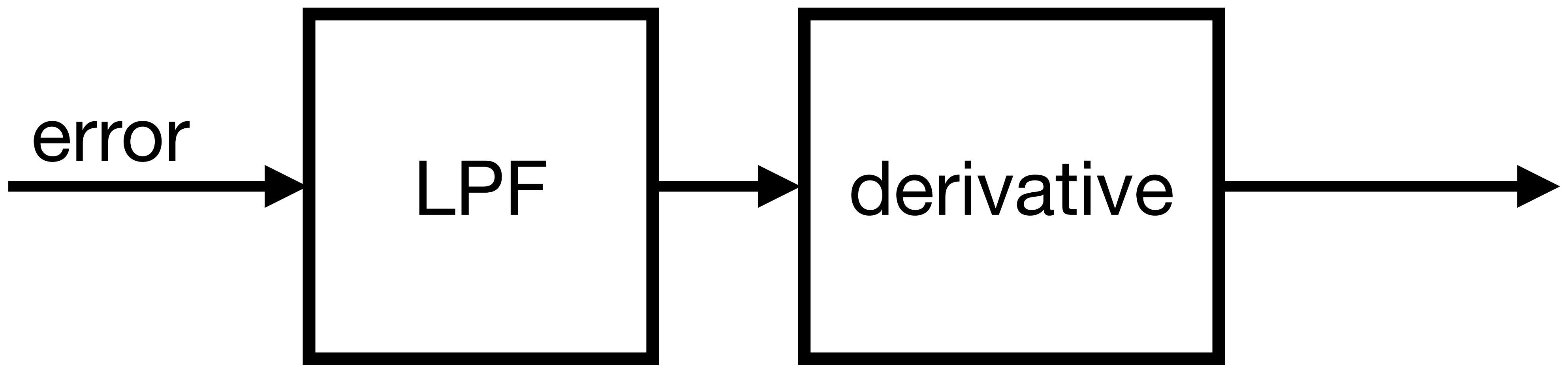
PID and Sensor Noise

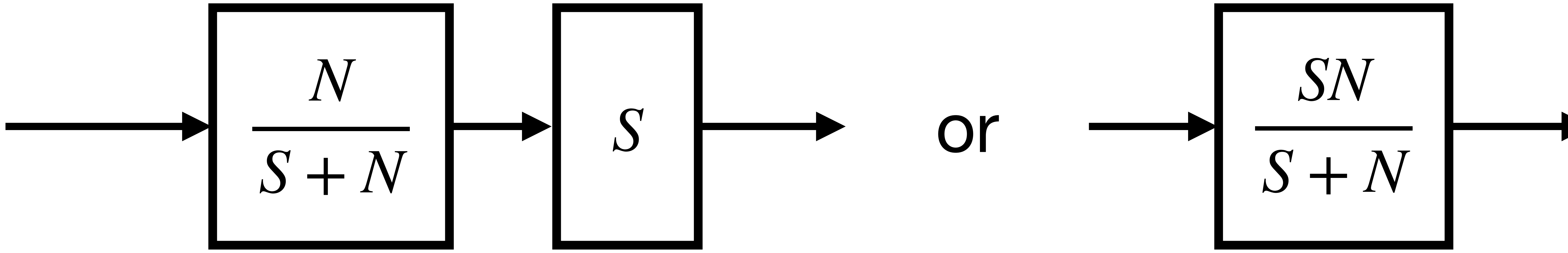
$$y = N\left(u - \frac{y}{s}\right) \qquad y = \frac{N}{1+\frac{N}{s}}u$$

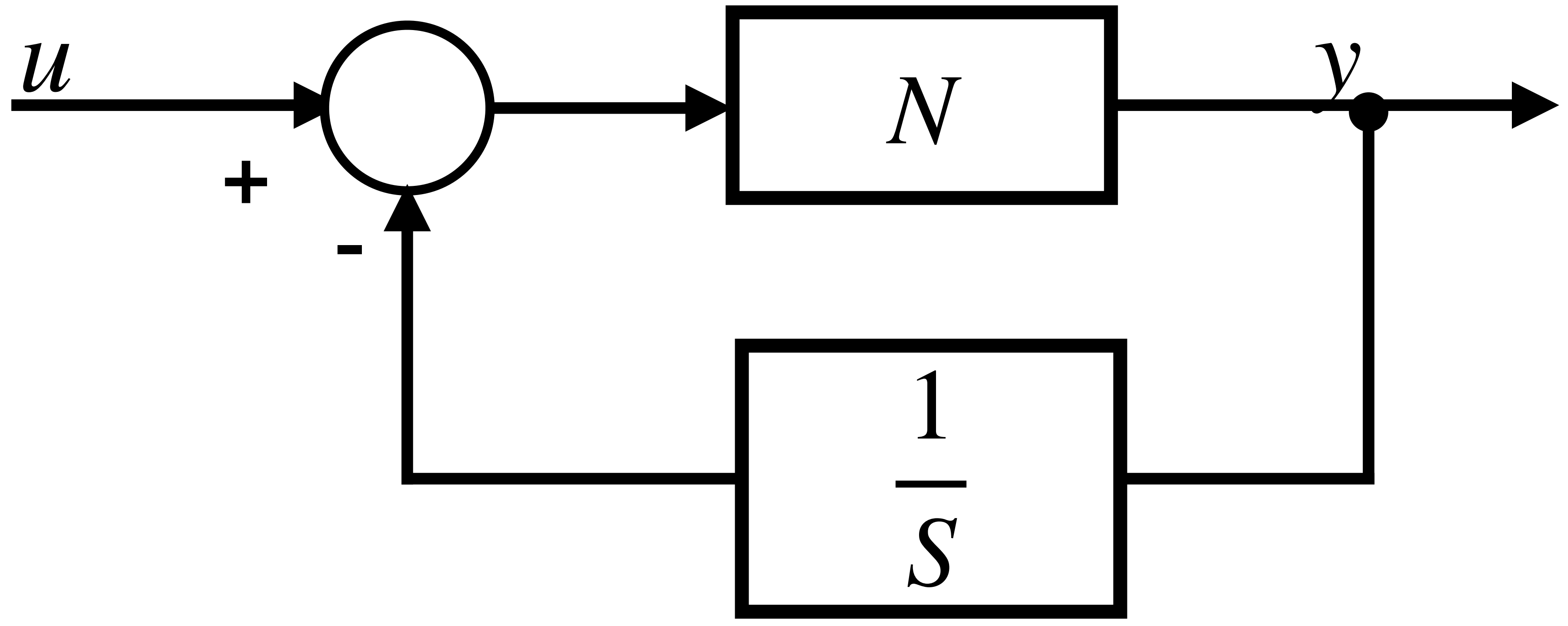
$$y + \frac{Ny}{s} = Nu \qquad \frac{y}{u} = \frac{N}{1+N\frac{1}{s}}$$

Time	Laplace
$\frac{d}{dt}$	S
$\int dt$	$\frac{1}{S}$
1st order LPF	$\frac{N}{S+N}$

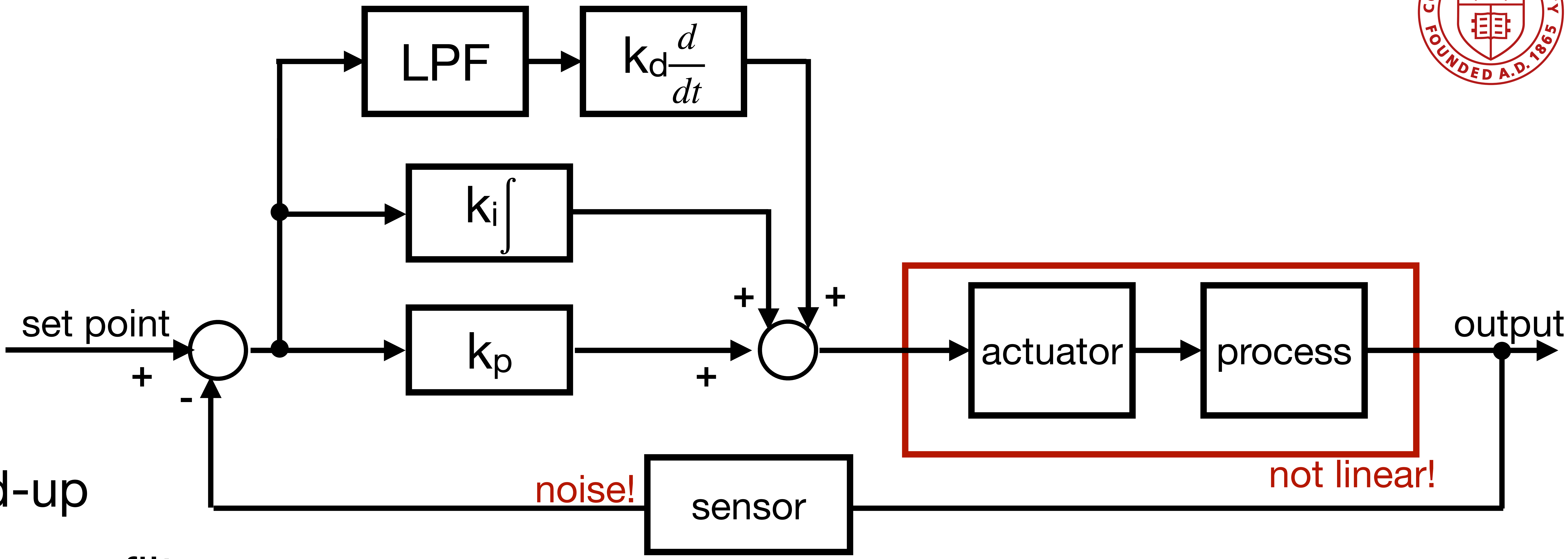
$$= \frac{1}{\frac{1}{N}S+1} = \frac{1}{\tau S+1}$$





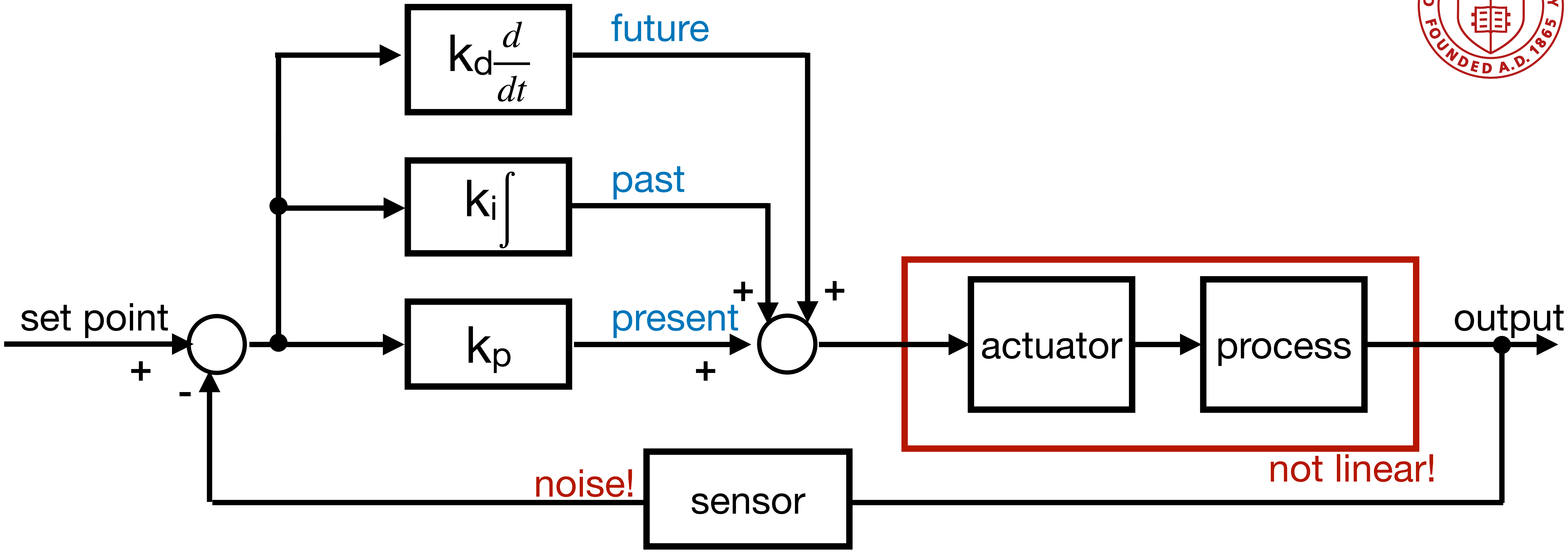


PID



- Integrator wind-up
- Derivative low pass filter
- Derivative kick
  - $\frac{de}{dt} = \frac{dset}{dt} - \frac{dmeas}{dt}$
  - Constant setpoint: $\frac{de}{dt} = -\frac{dmeas}{dt}$

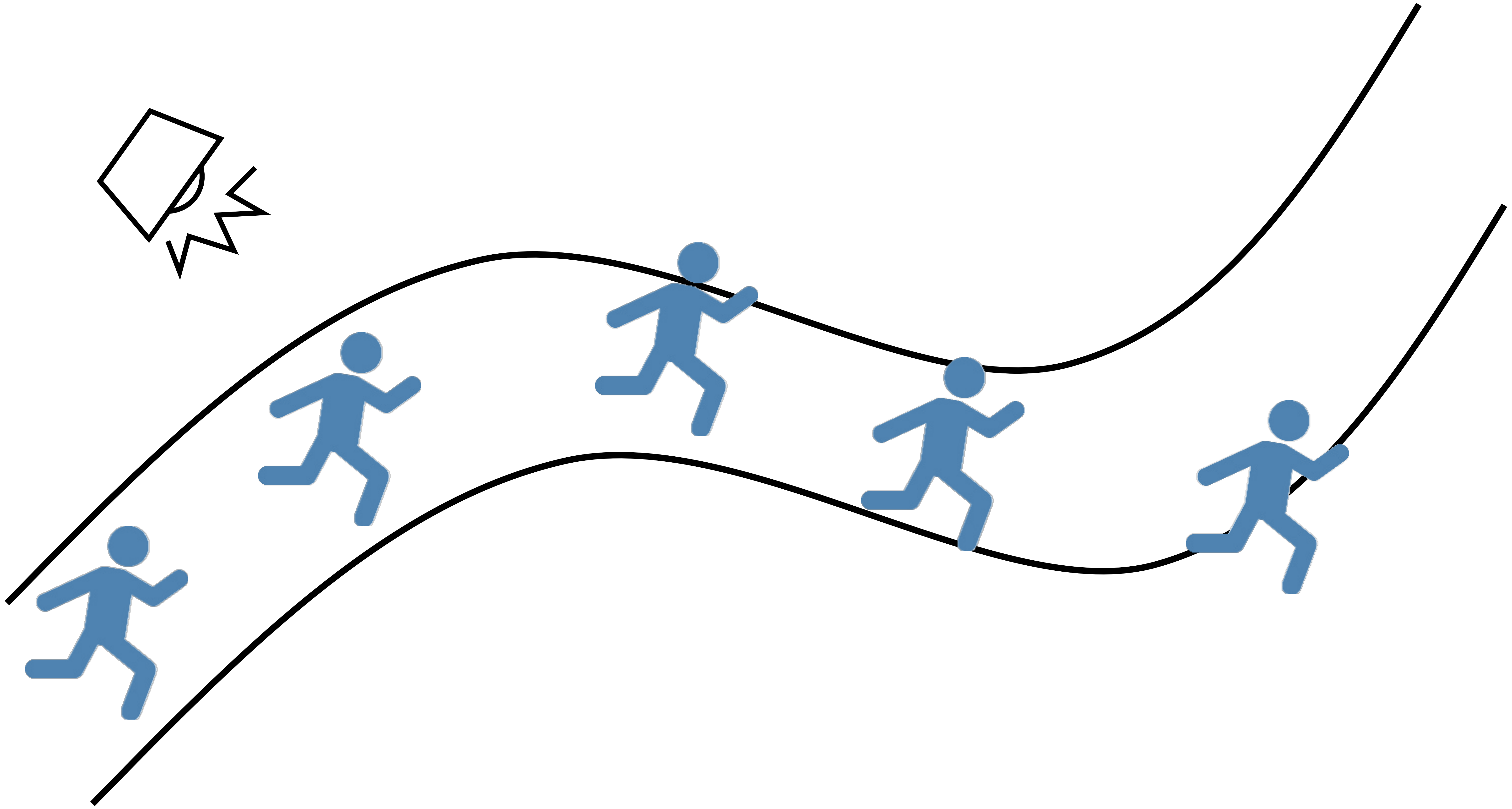
PID



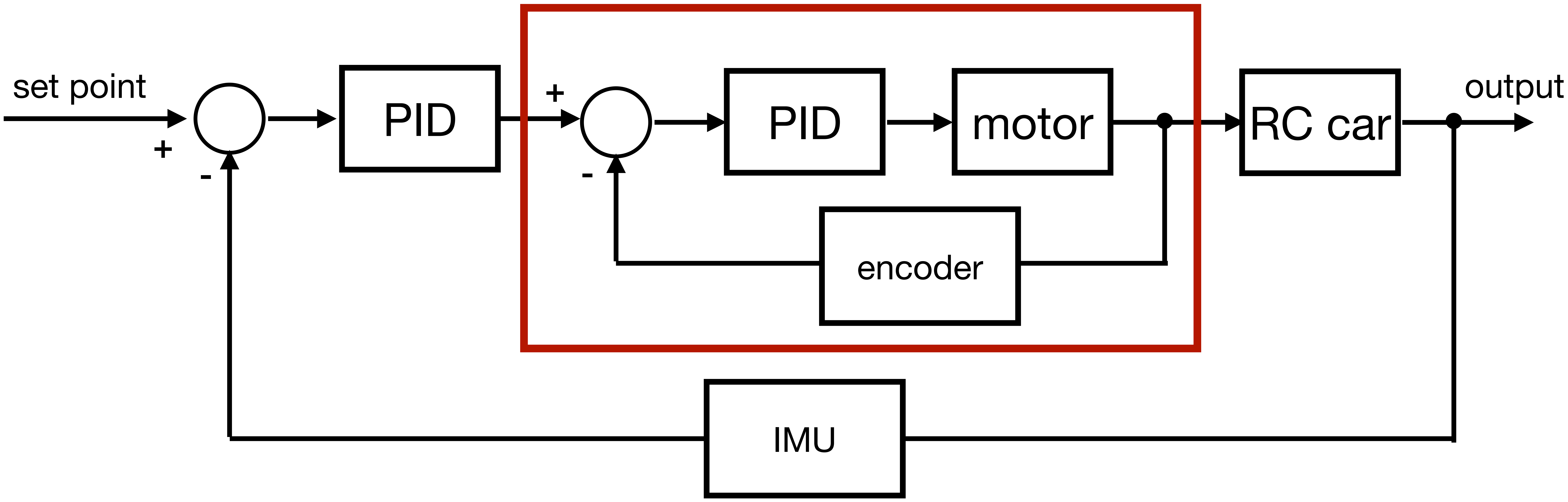
- Rise time/ response: some percent of final value
- Peak time: time to reach first peak
- Overshoot: amount in excess of final value
- Settling time: time before output settles to x% of final value

Discrete PID Control

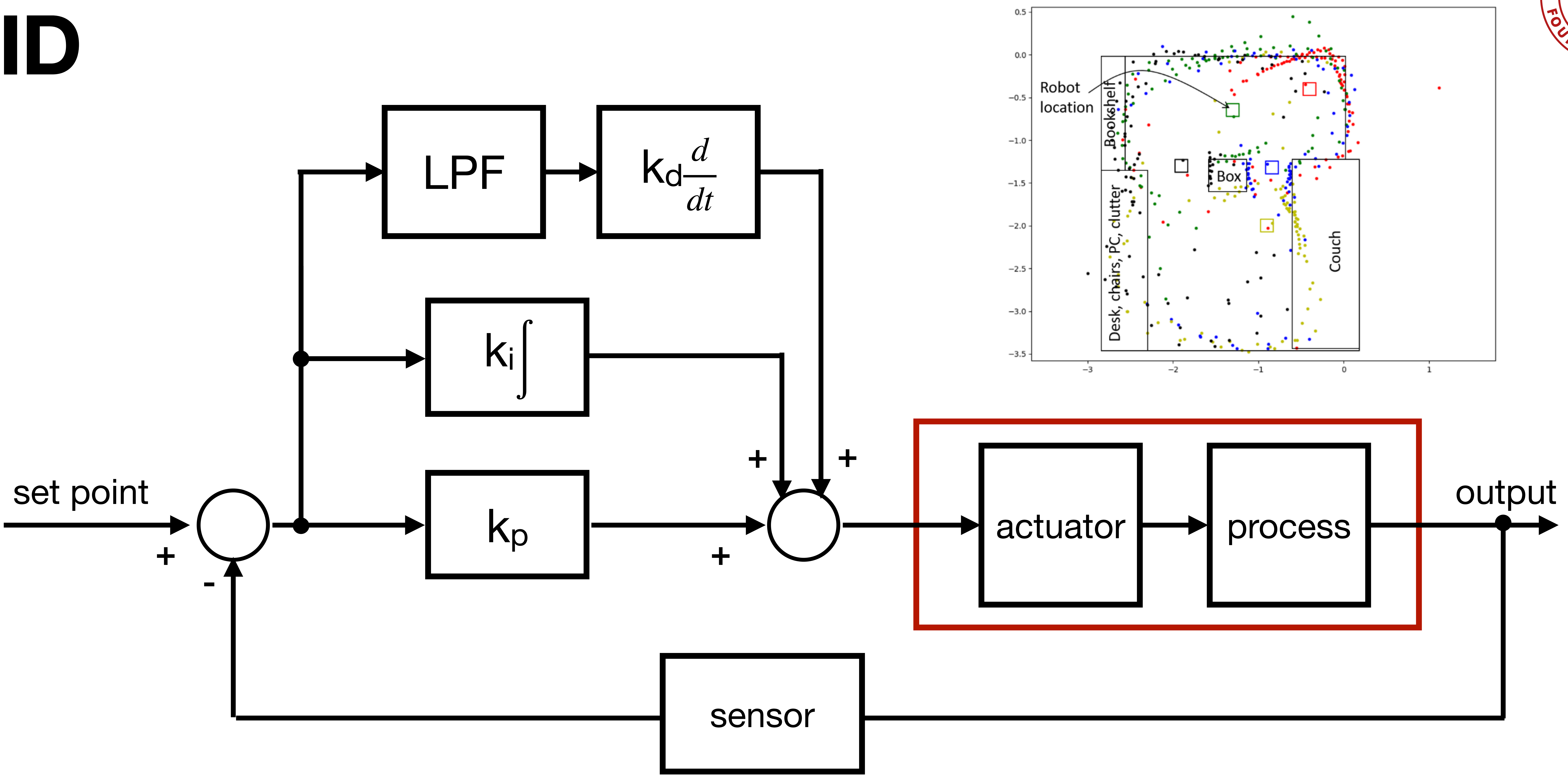
- Sampling time
- Control ~10 times faster than the system dynamics



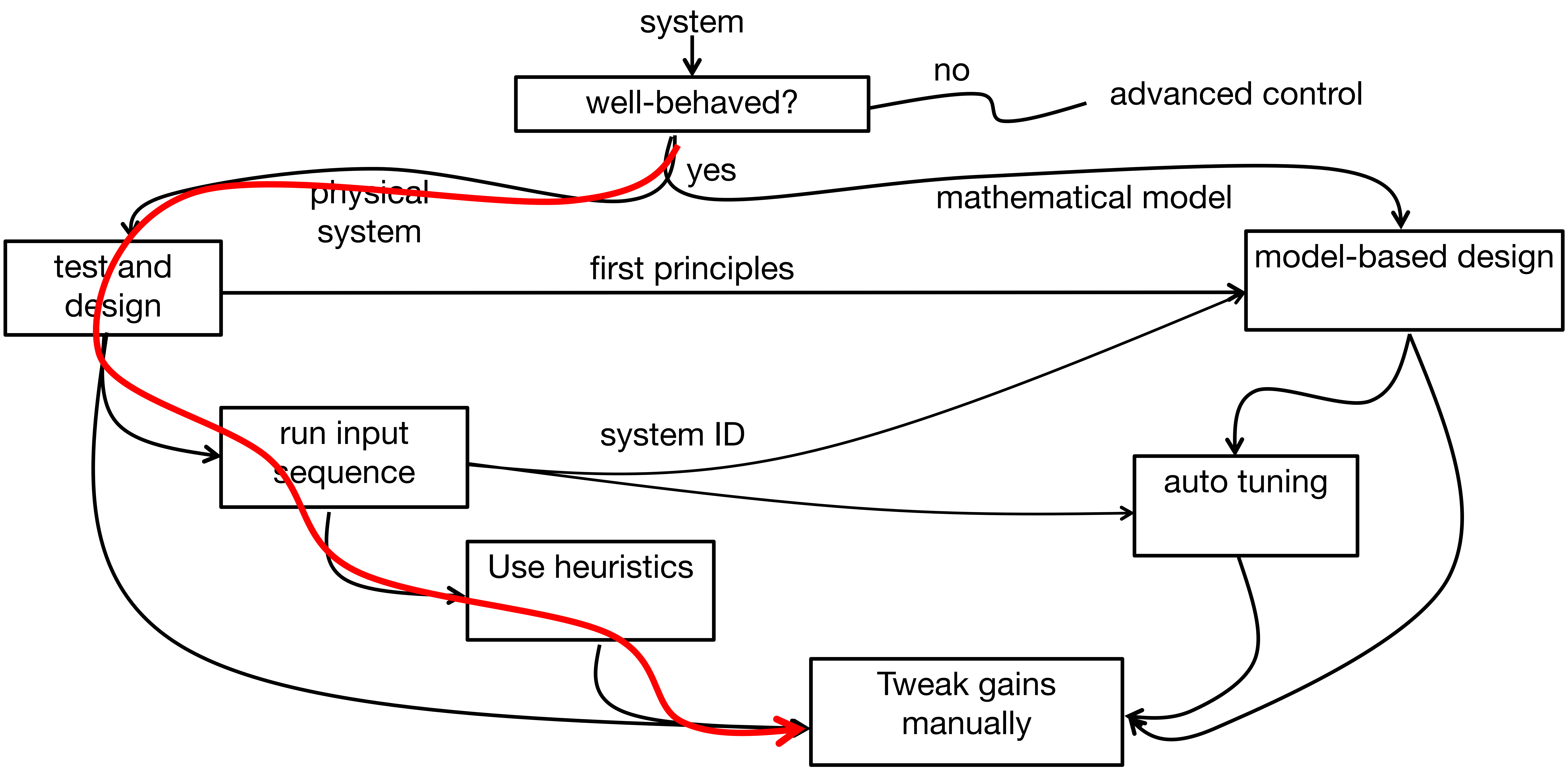
Cascaded Control Loops



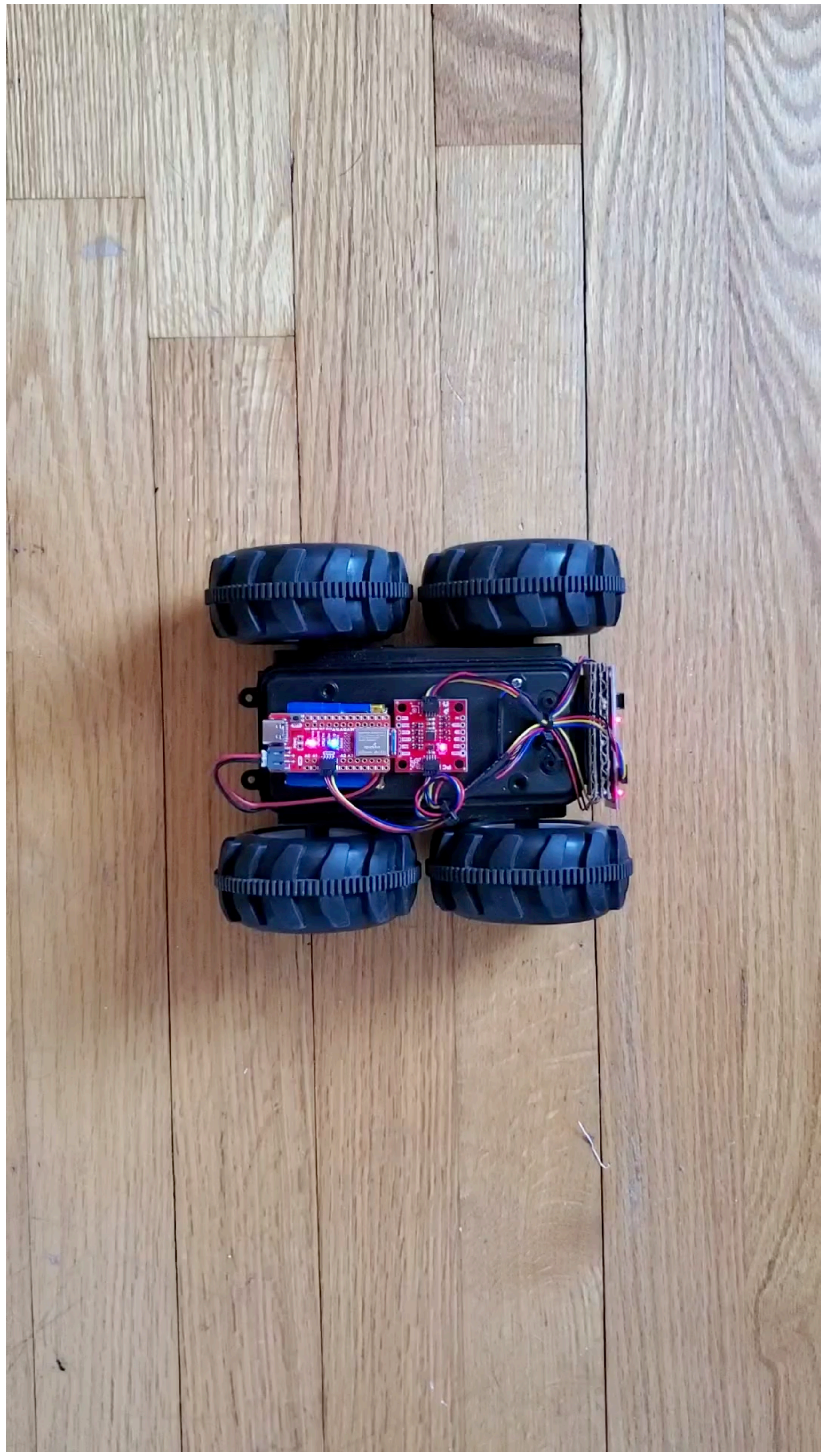
PID

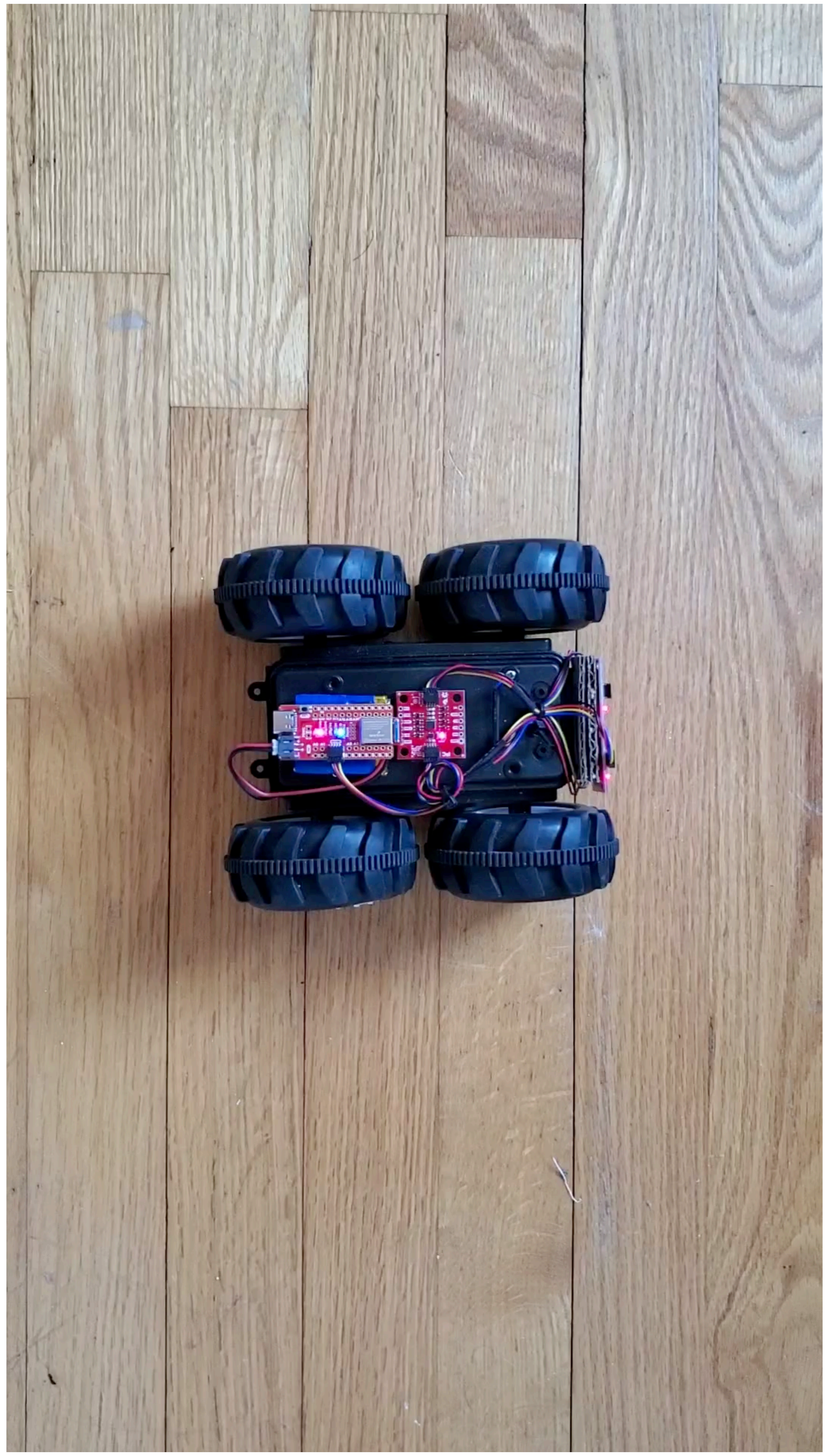

Robot
location
Bookshelf
Box
Desk, chairs, PC, clutter
Couch
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
−3.5
−3
−2
−1
0
1
LPF
$k_d\frac{d}{dt}$
$k_i\int$
k_p
set point
+
-
+
+
+
actuator
process
output
sensor

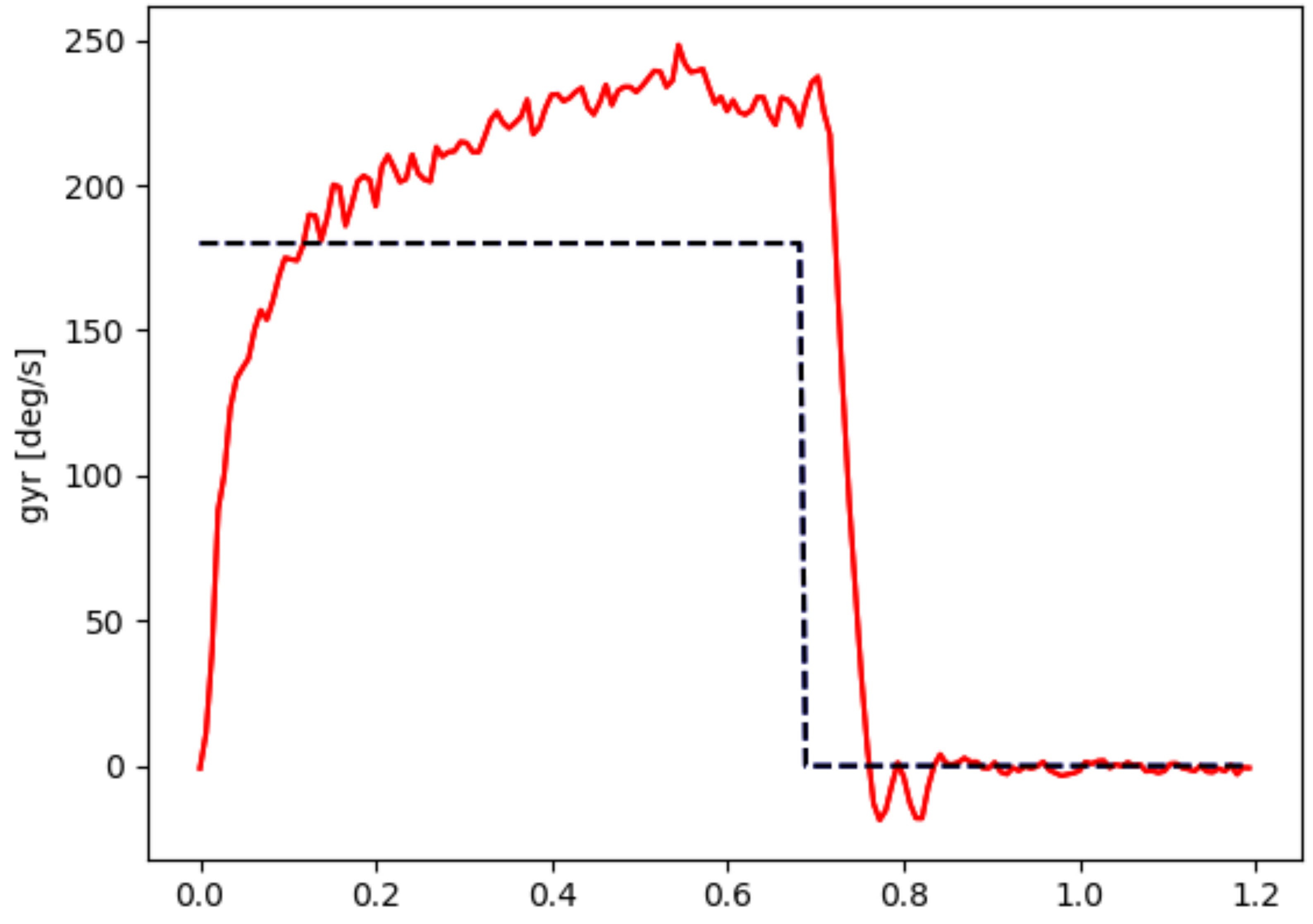
Tuning PID control

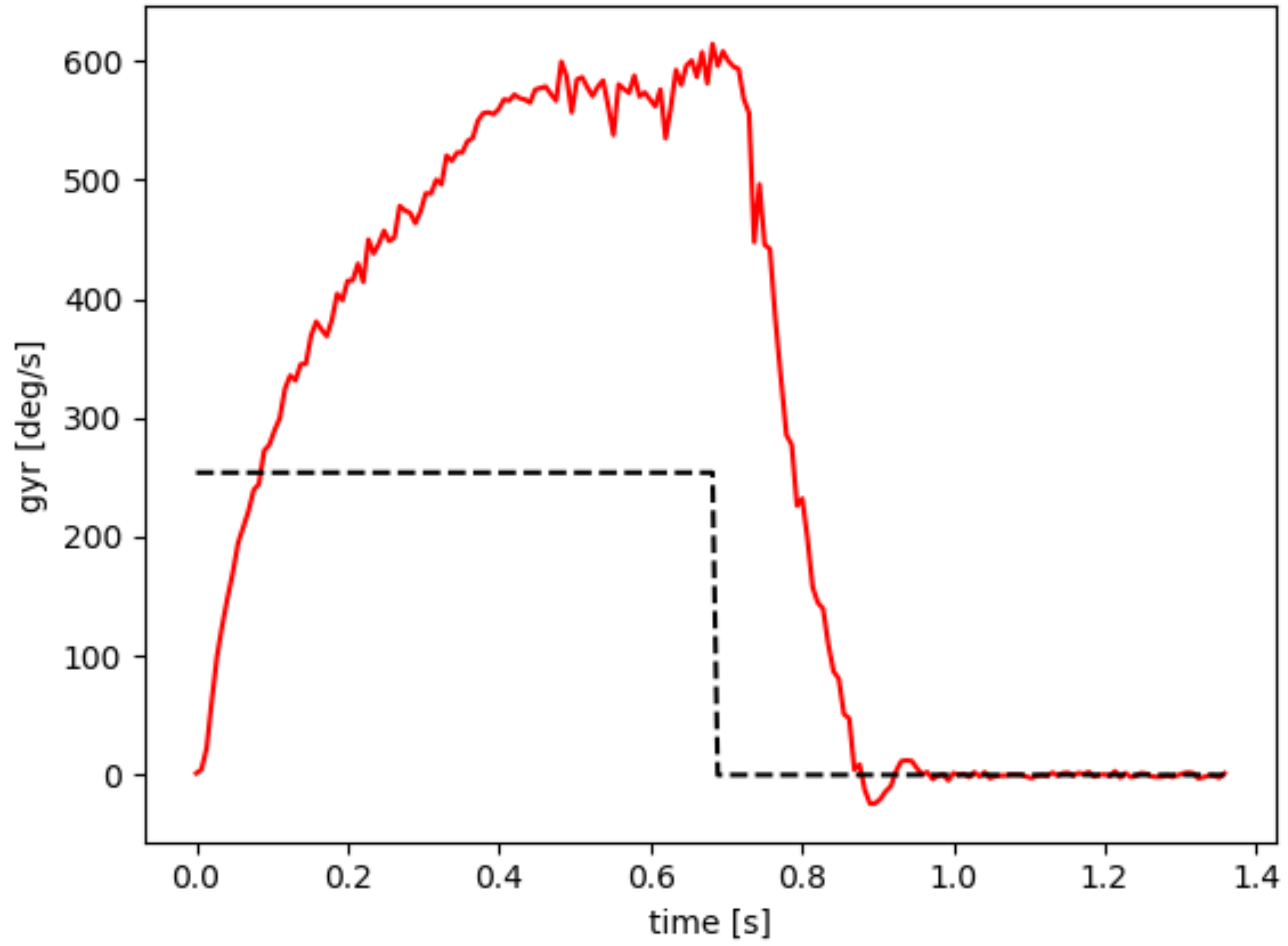


Tuning PID control









Tuning PID control

Chien, Hornes, and Reswick method

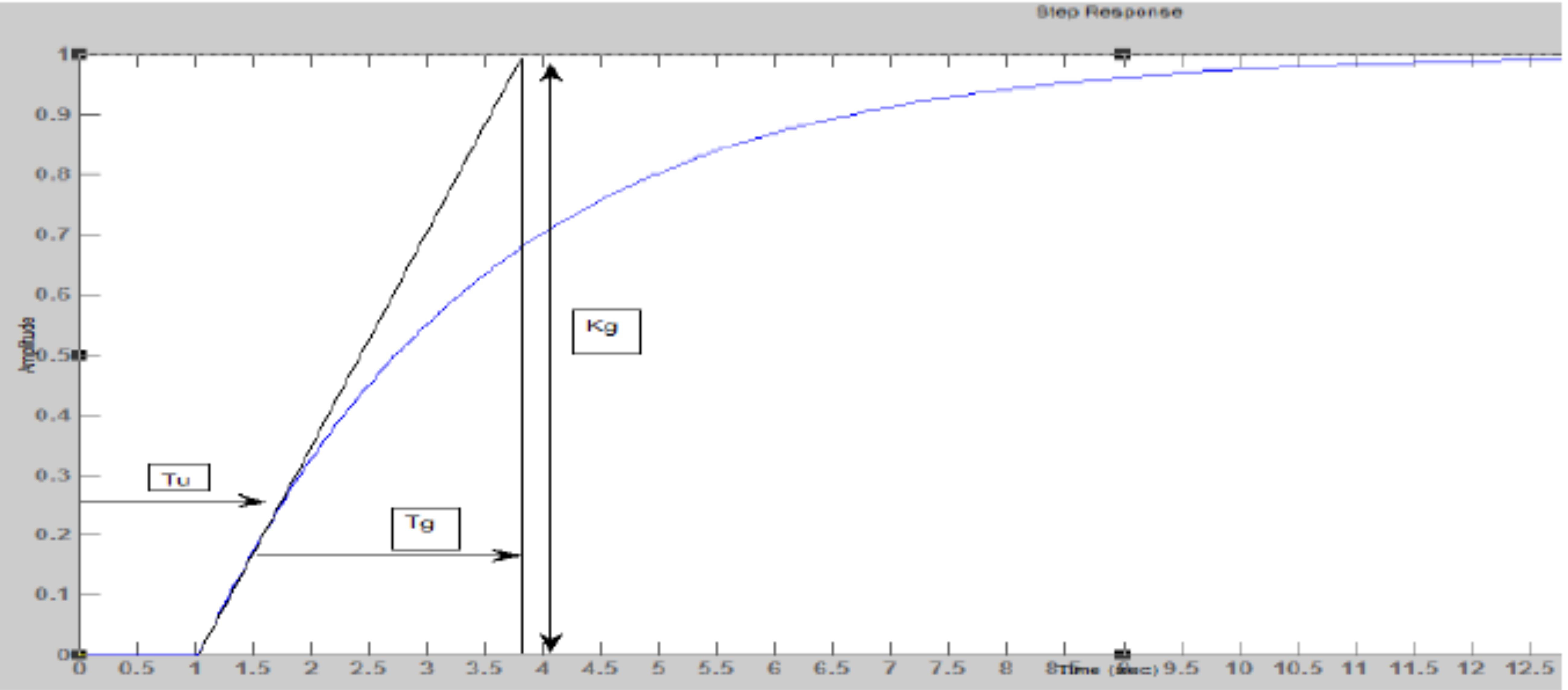
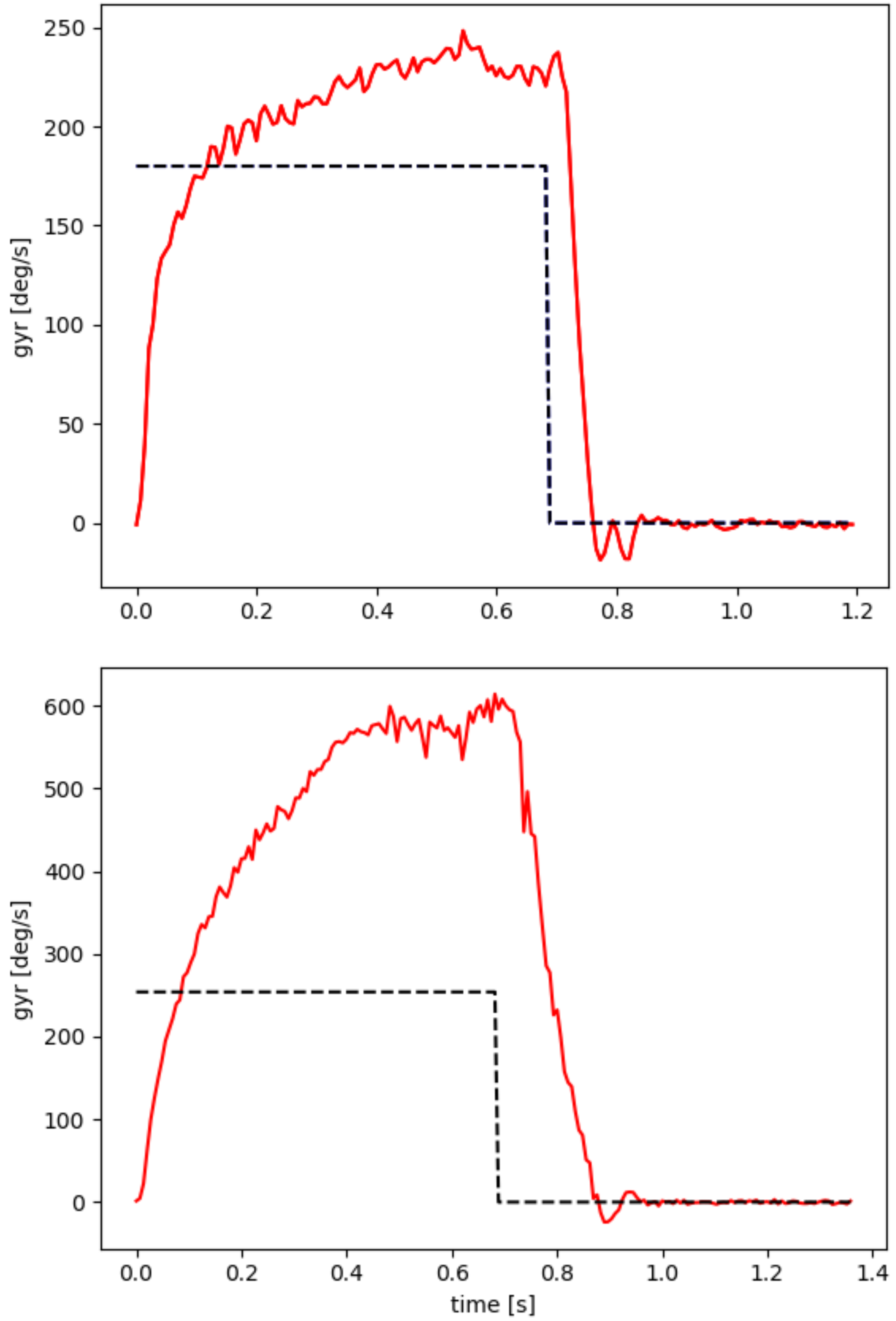


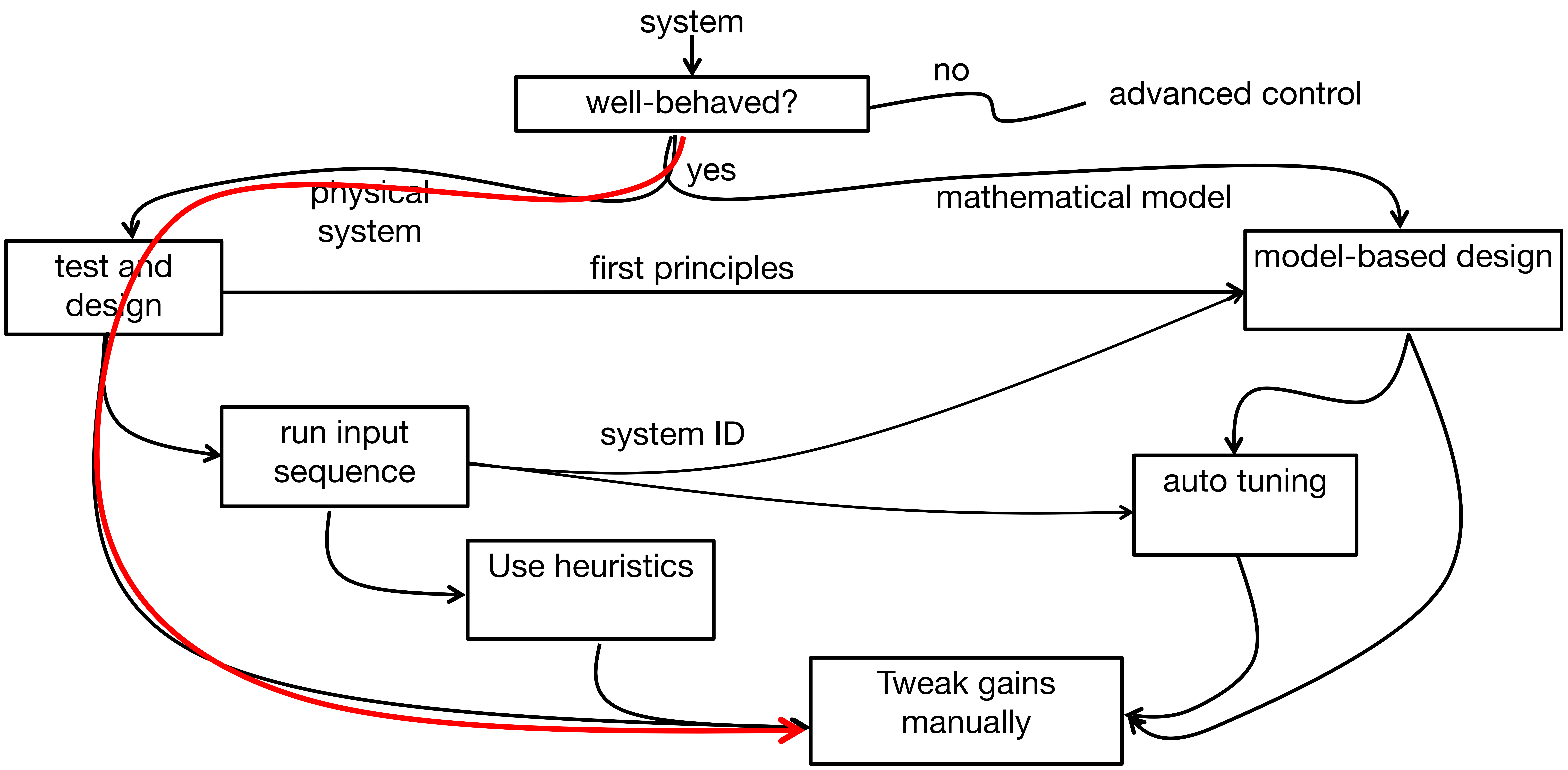
Fig.7. Open loop response of CHR method

Table.11. CHR Compensator

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



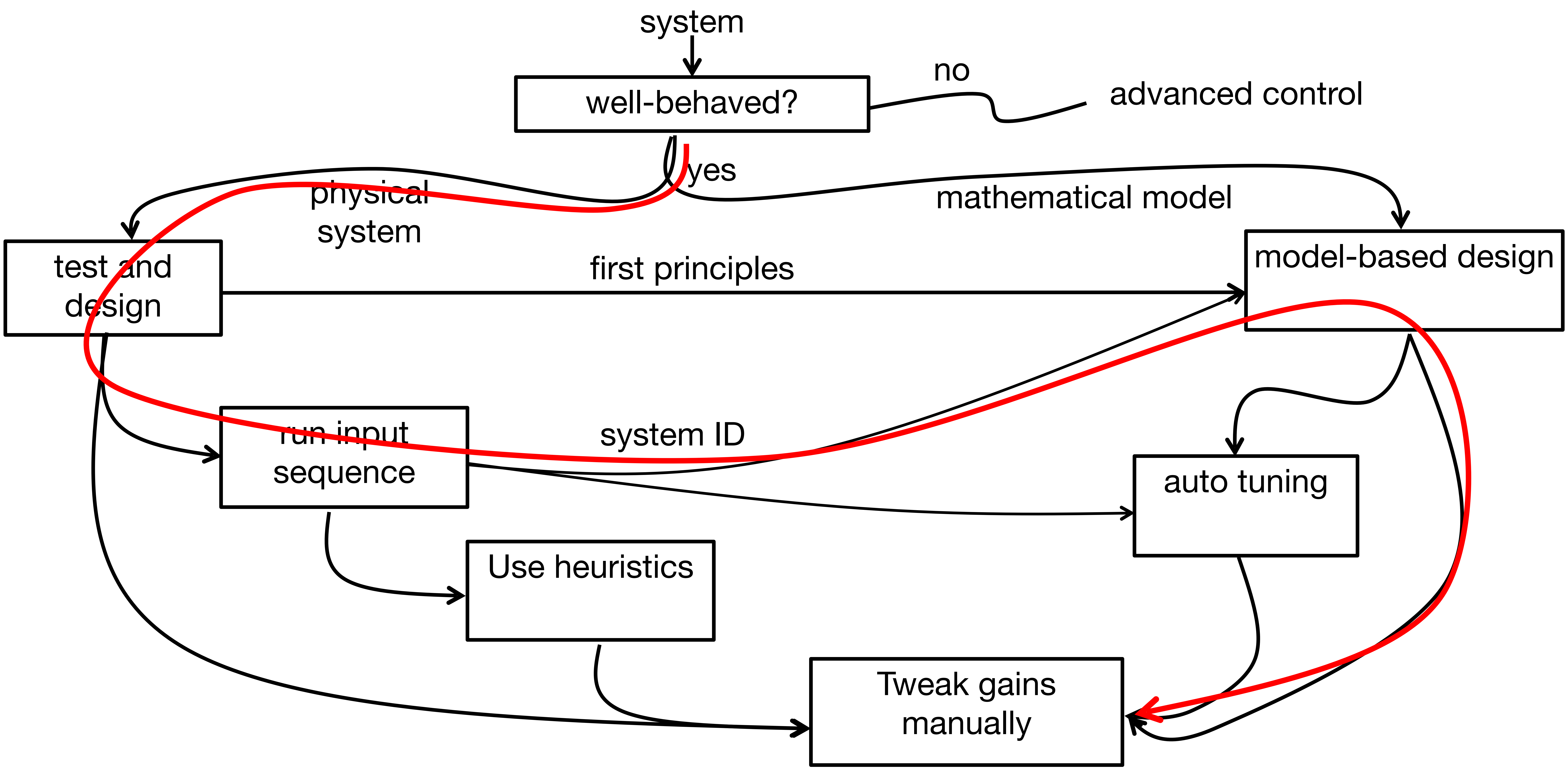
Tuning PID control



Tuning PID control

- Heuristic procedure #1:
  - Set k_p to small value, k_d and k_i to 0
  - Increase k_d until oscillation, then decrease by a factor of 2-4
  - Increase k_p until oscillation or overshoot, decreases by a factor of 2-4
  - Increase k_i until oscillation or overshoot
  - Iterate
- Heuristic procedure #2:
  - Set k_d and k_i to 0
  - Increase k_p until oscillation, then decrease by factor of 2-4
  - Increase k_i until loss of stability, then back off
  - Increase k_d to increase performance in response to disturbance
  - Iterate

Tuning PID control

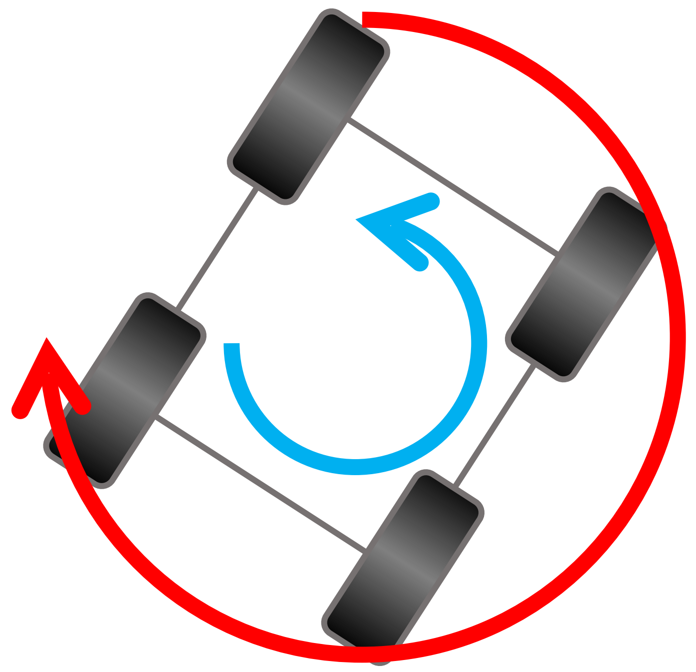


https://tinyurl.com/y67glgzk

Tuning PID control

Equations of motion

$$x = \begin{bmatrix} \theta \\ \dot{\theta} \end{bmatrix}$$



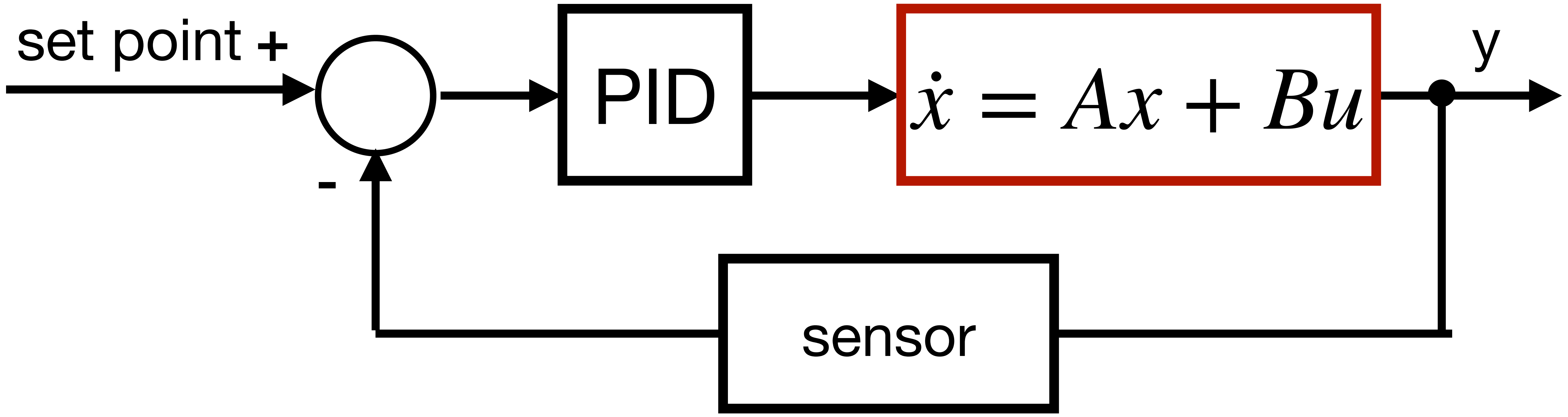
$$F = ma$$

$$\tau = I\alpha$$

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

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

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

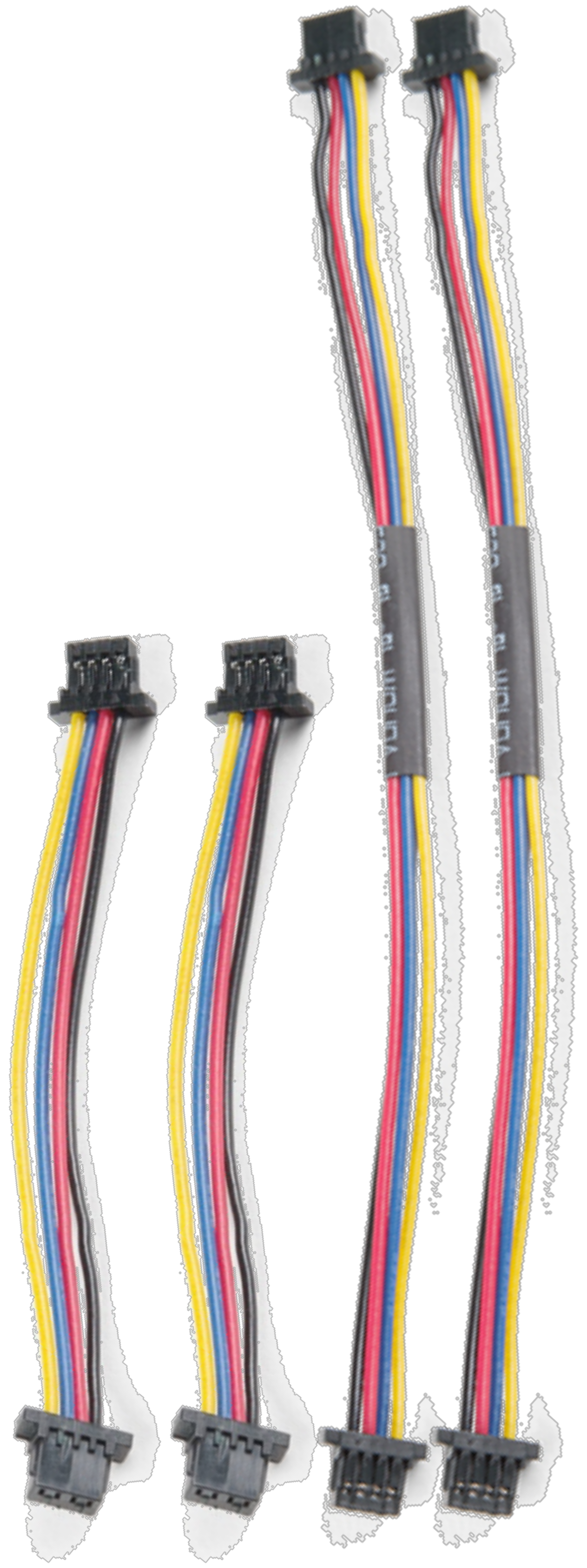


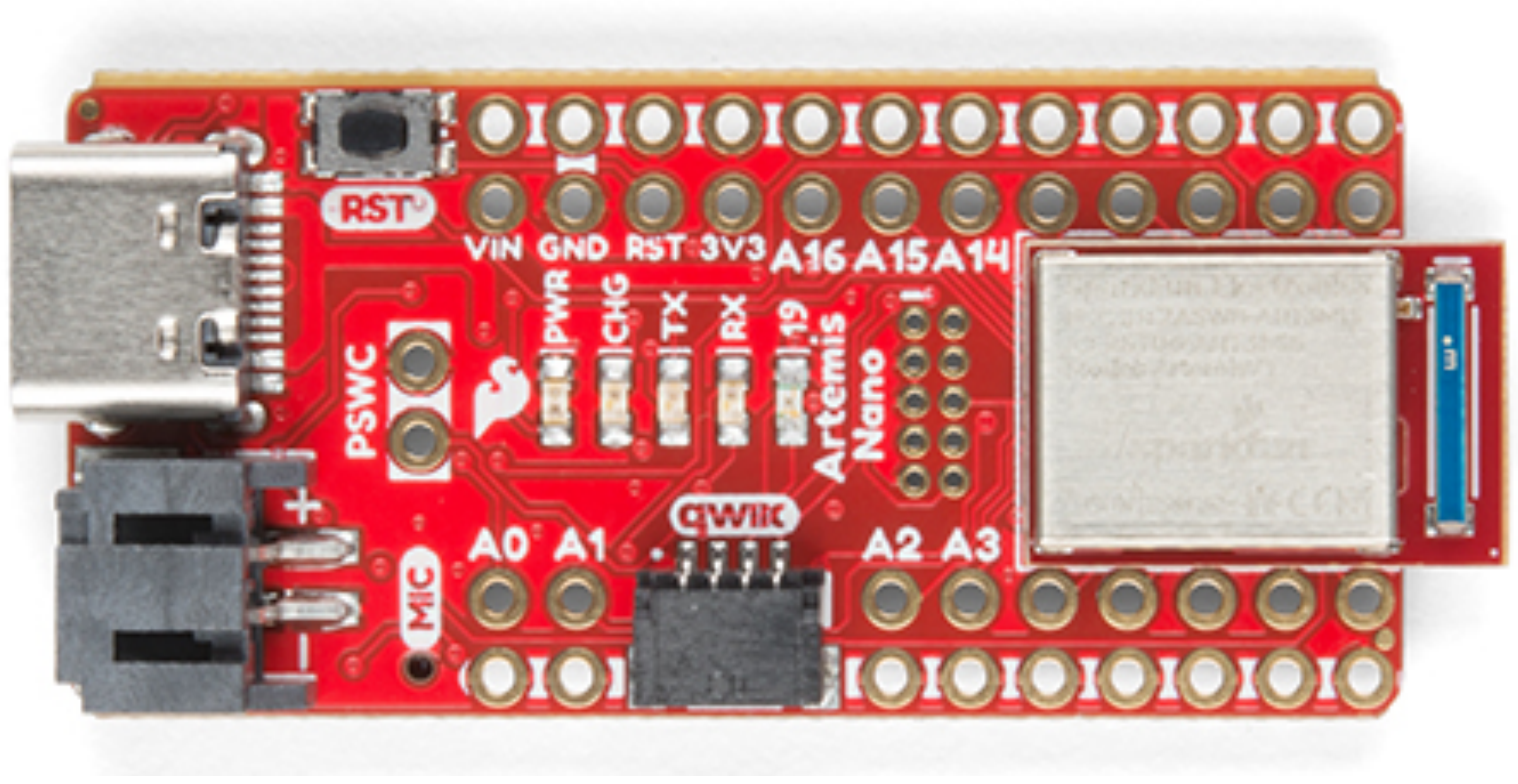
$$\begin{bmatrix} \dot{\theta} \\ \ddot{\theta} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & \frac{-c}{I} \end{bmatrix} \begin{bmatrix} \theta \\ \dot{\theta} \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{I} \end{bmatrix} u$$

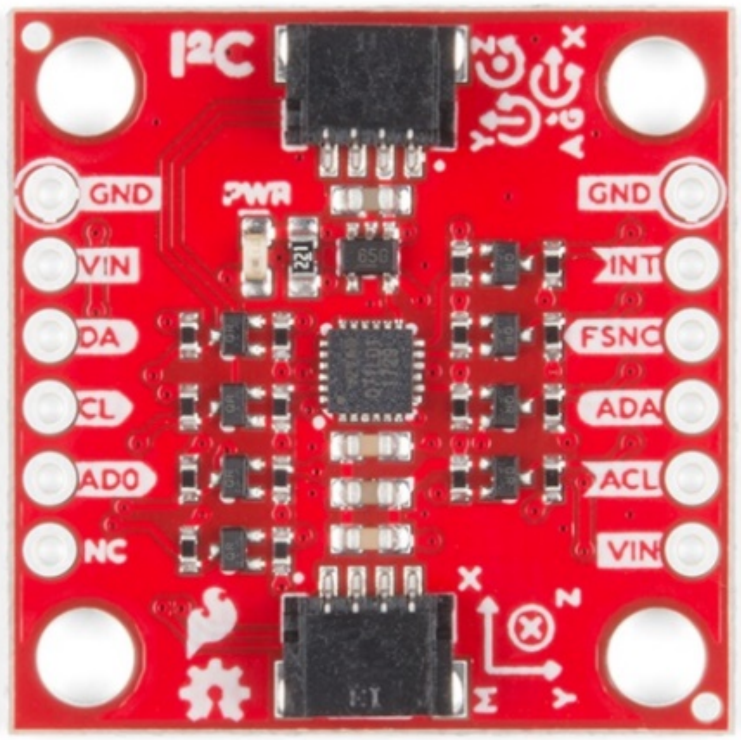
Lab 3

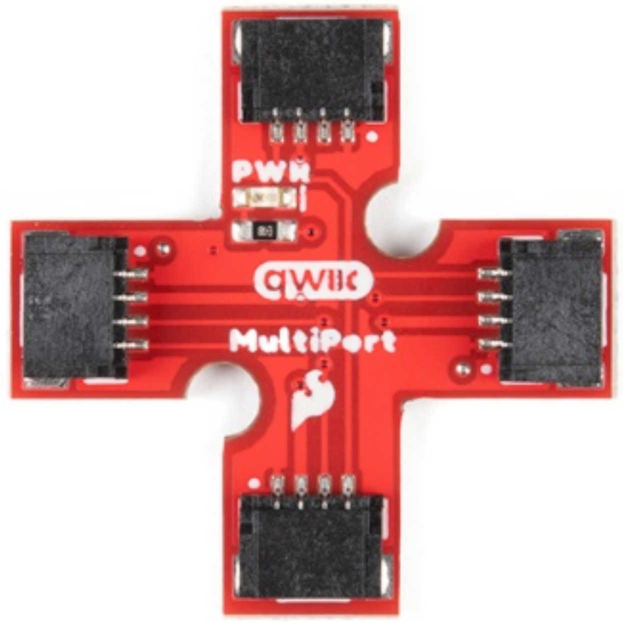
https://mavisfu.github.io/lab3.html

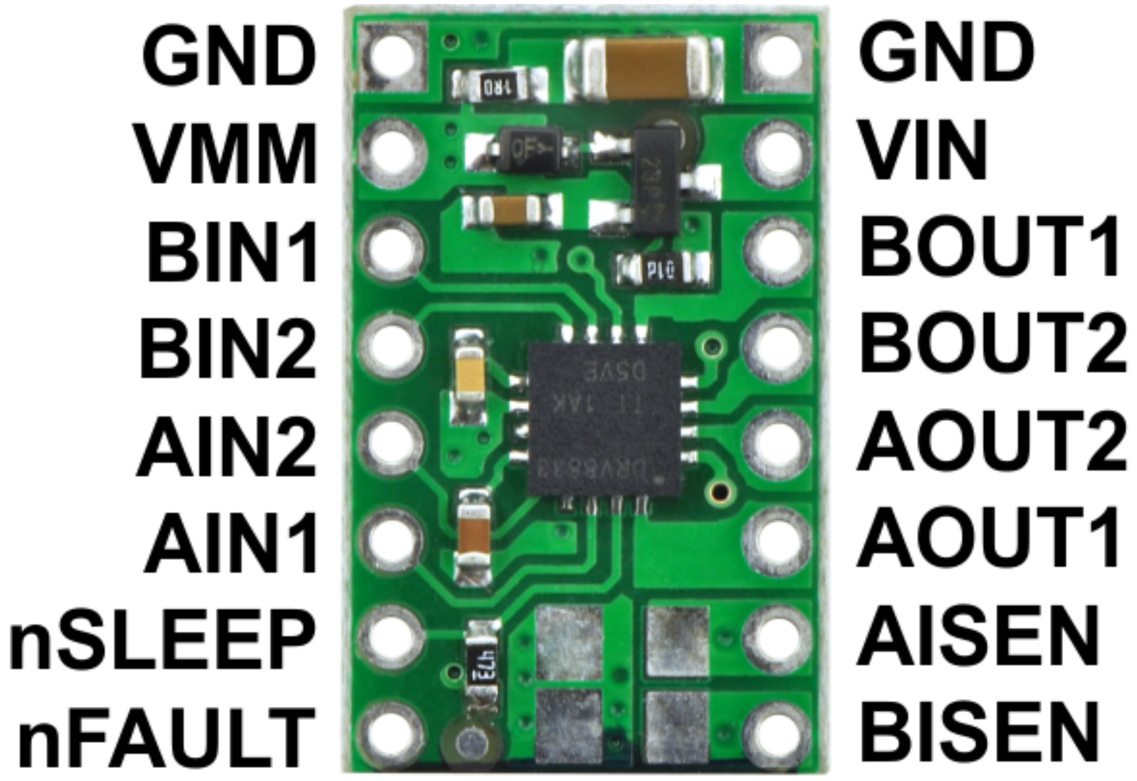
Hardware

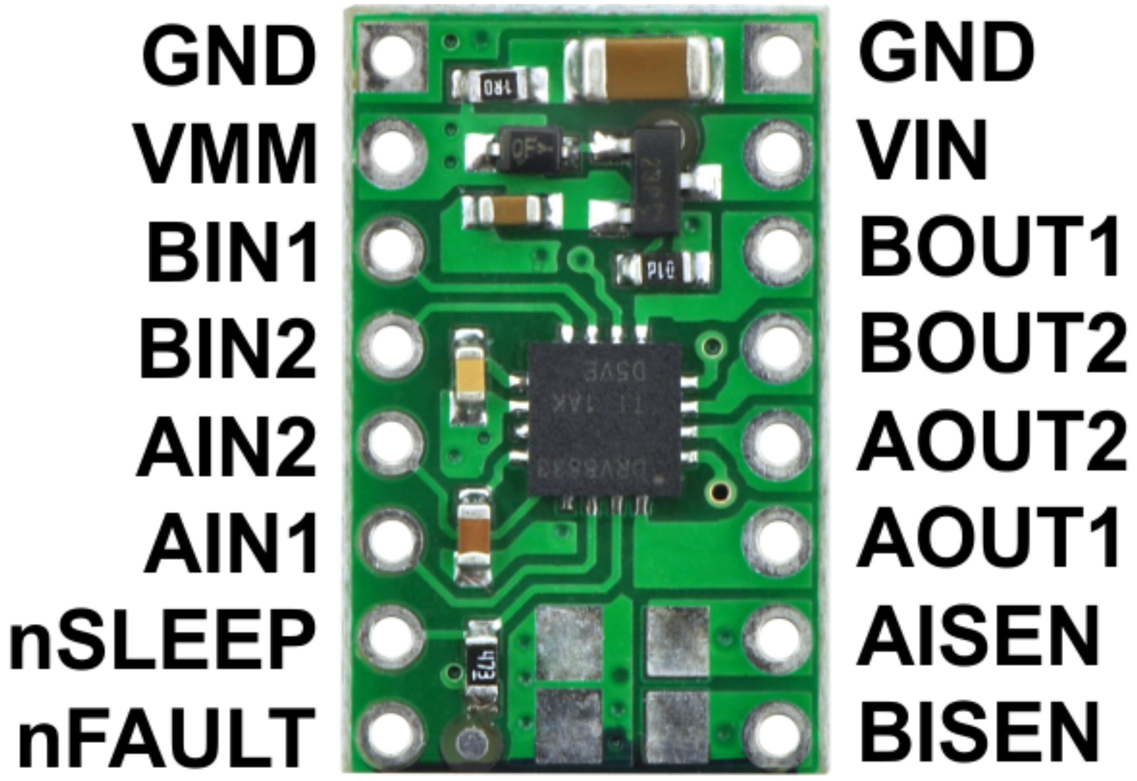


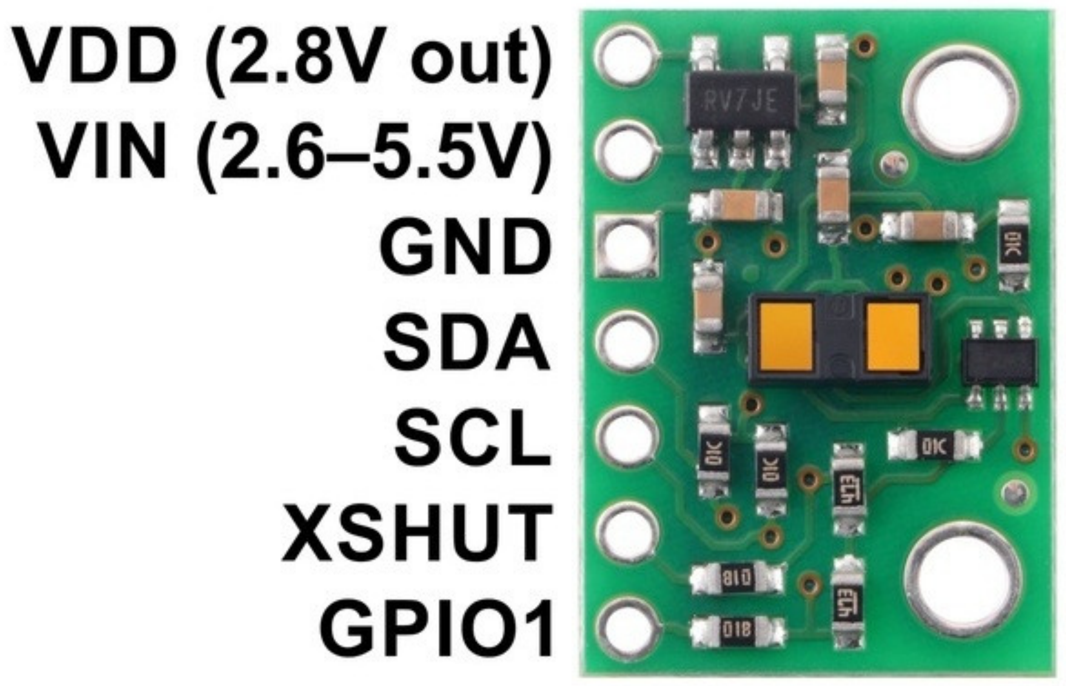

RST
VIN GND RST 3V3 A16 A15 A14
PSWC
PWR CHG TX RX 19
Artemis Nano
qwiic
A0 A1
A2 A3
MIC

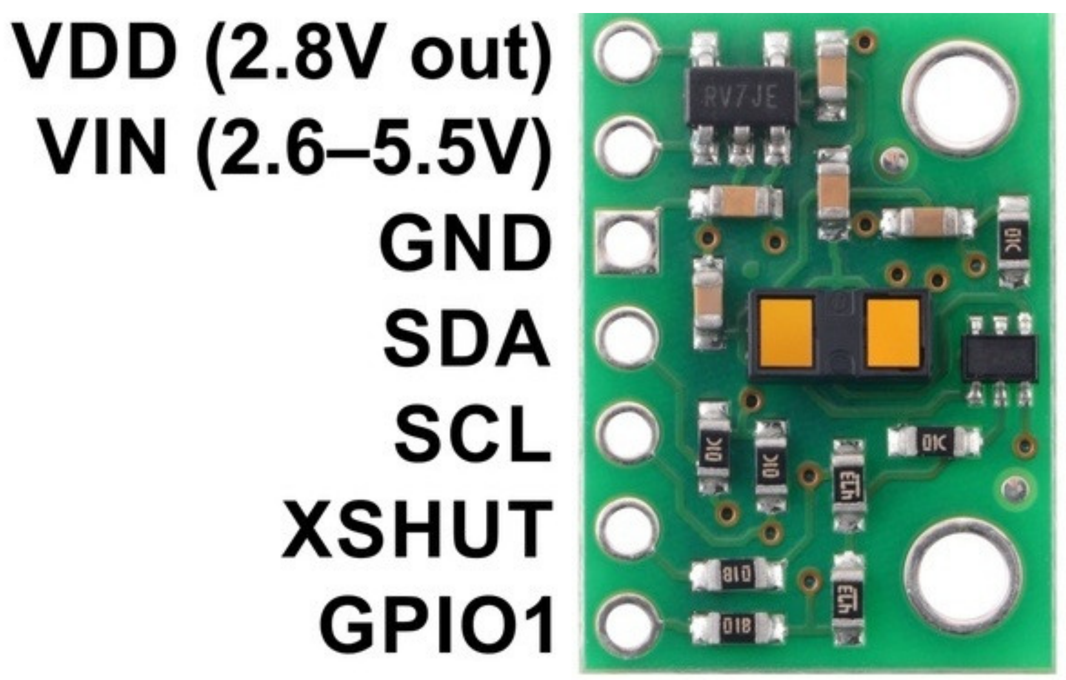

I2C
GND
VIN
GND
INT
FSNC
ADA
ACL
VIN
NC


PWR
qwiic
MultiPort


GND
VMM
BIN1
BIN2
AIN2
AIN1
nSLEEP
nFAULT
GND
VIN
BOUT1
BOUT2
AOUT2
AOUT1
AISEN
BISEN


GND
VMM
BIN1
BIN2
AIN2
AIN1
nSLEEP
nFAULT
GND
VIN
BOUT1
BOUT2
AOUT2
AOUT1
AISEN
BISEN


VDD (2.8V out)
VIN (2.6–5.5V)
GND
SDA
SCL
XSHUT
GPIO1

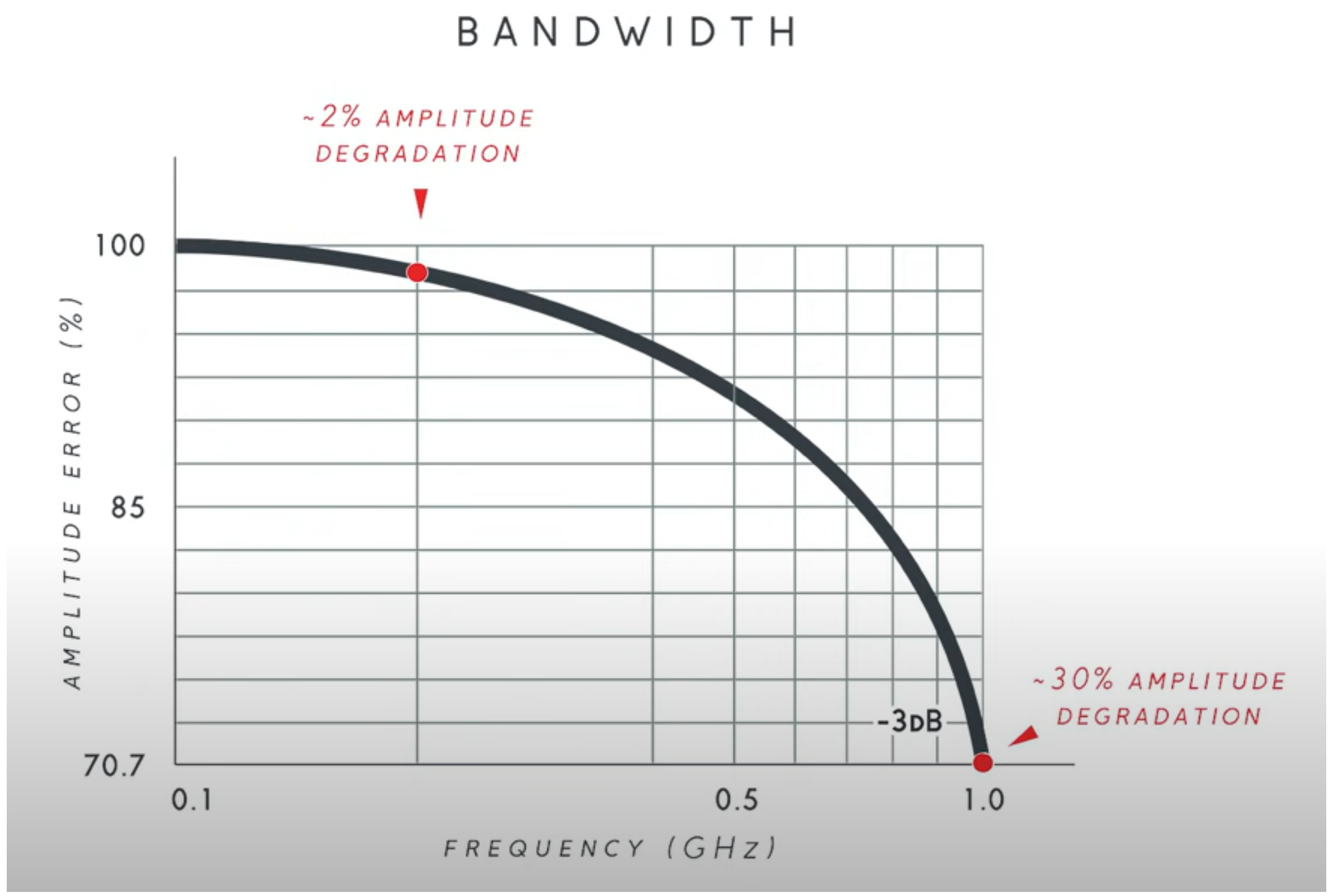

VDD (2.8V out)
VIN (2.6–5.5V)
GND
SDA
SCL
XSHUT
GPIO1

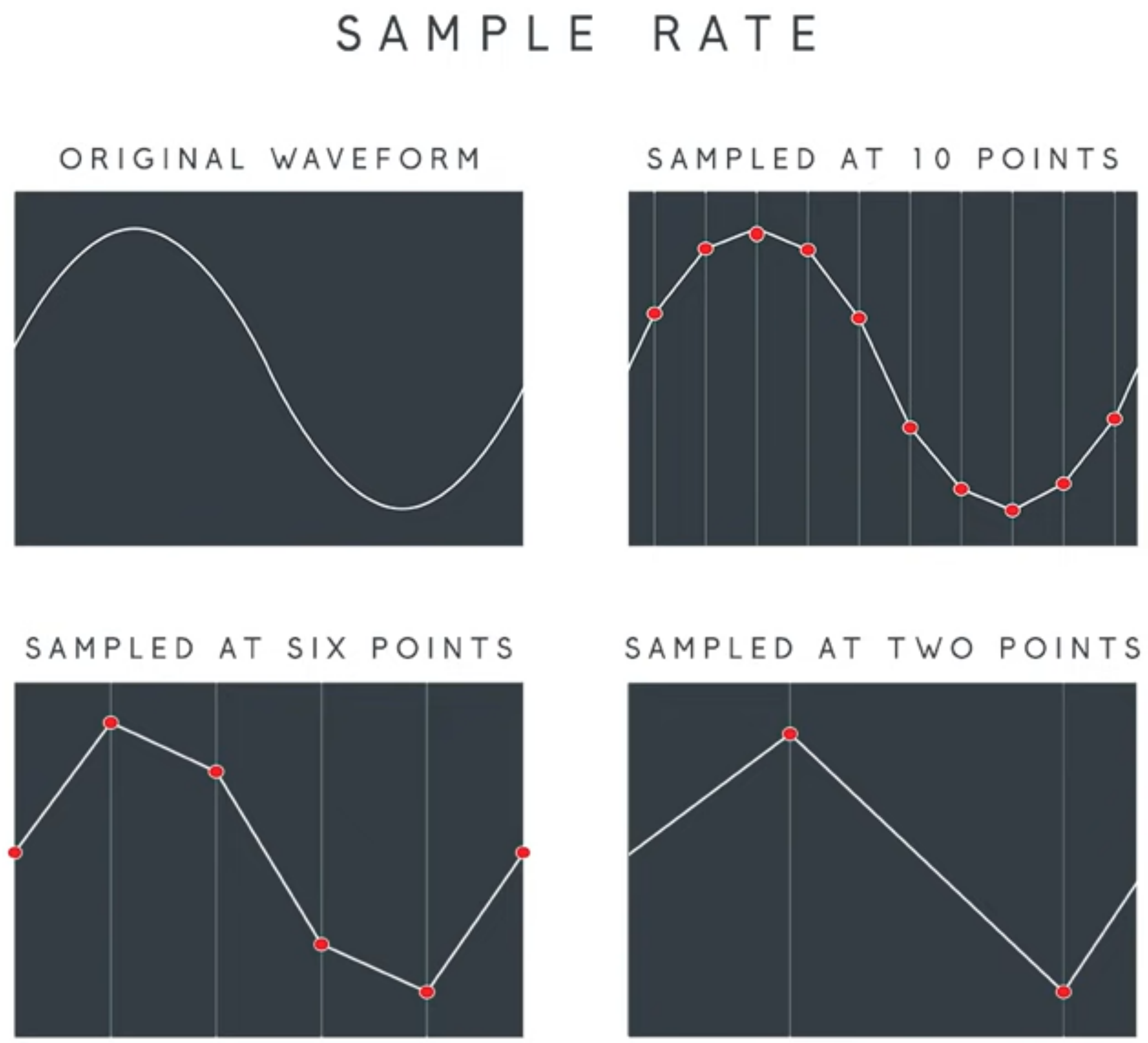
Oscilloscopes

Oscilloscope setup

Oscilloscope setup

- Bandwidth
- Sample rate
- Resolution

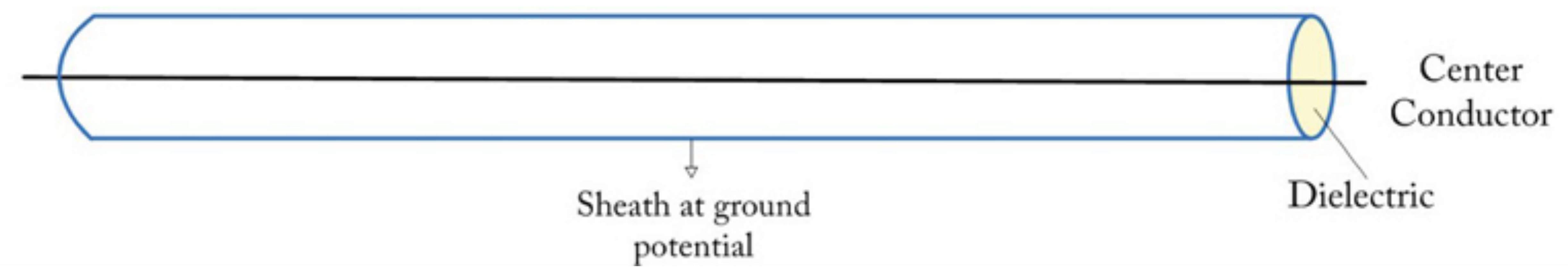




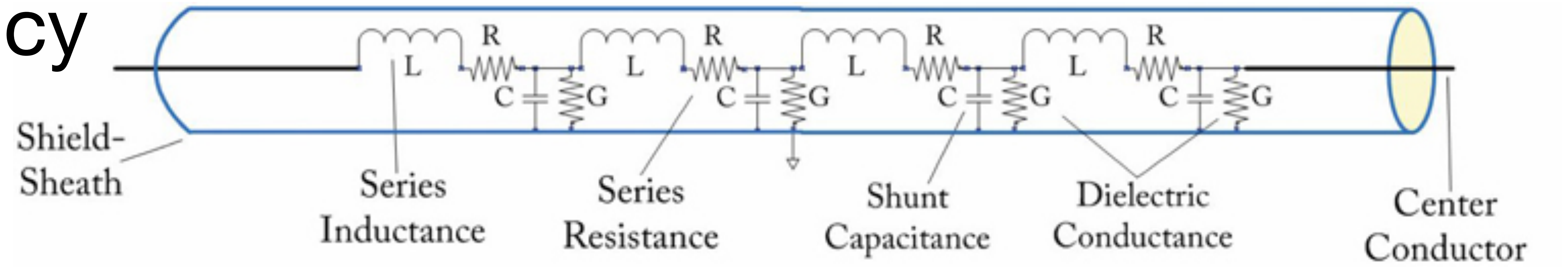
Oscilloscope Probes

- Scope inputs resemble a 16pF capacitor in parallel with a 1MOhm resistor
- At high frequencies the coax cable acts as a low pass filter
- 1x attenuation for low amplitude, low frequency signals
- 10x attenuation for load-sensitive circuits, high-frequency or high-amplitude signals

Low frequency coax cable



High frequency circuit



Oscilloscope Probes

- Scope inputs resemble a 16pF capacitor in parallel with a 1MOhm resistor
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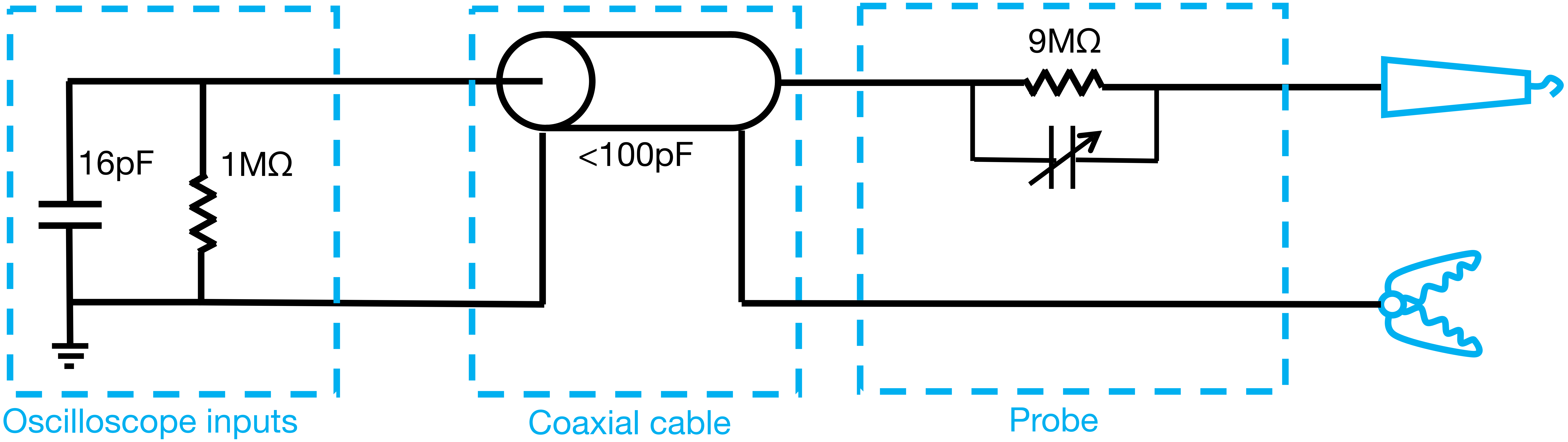
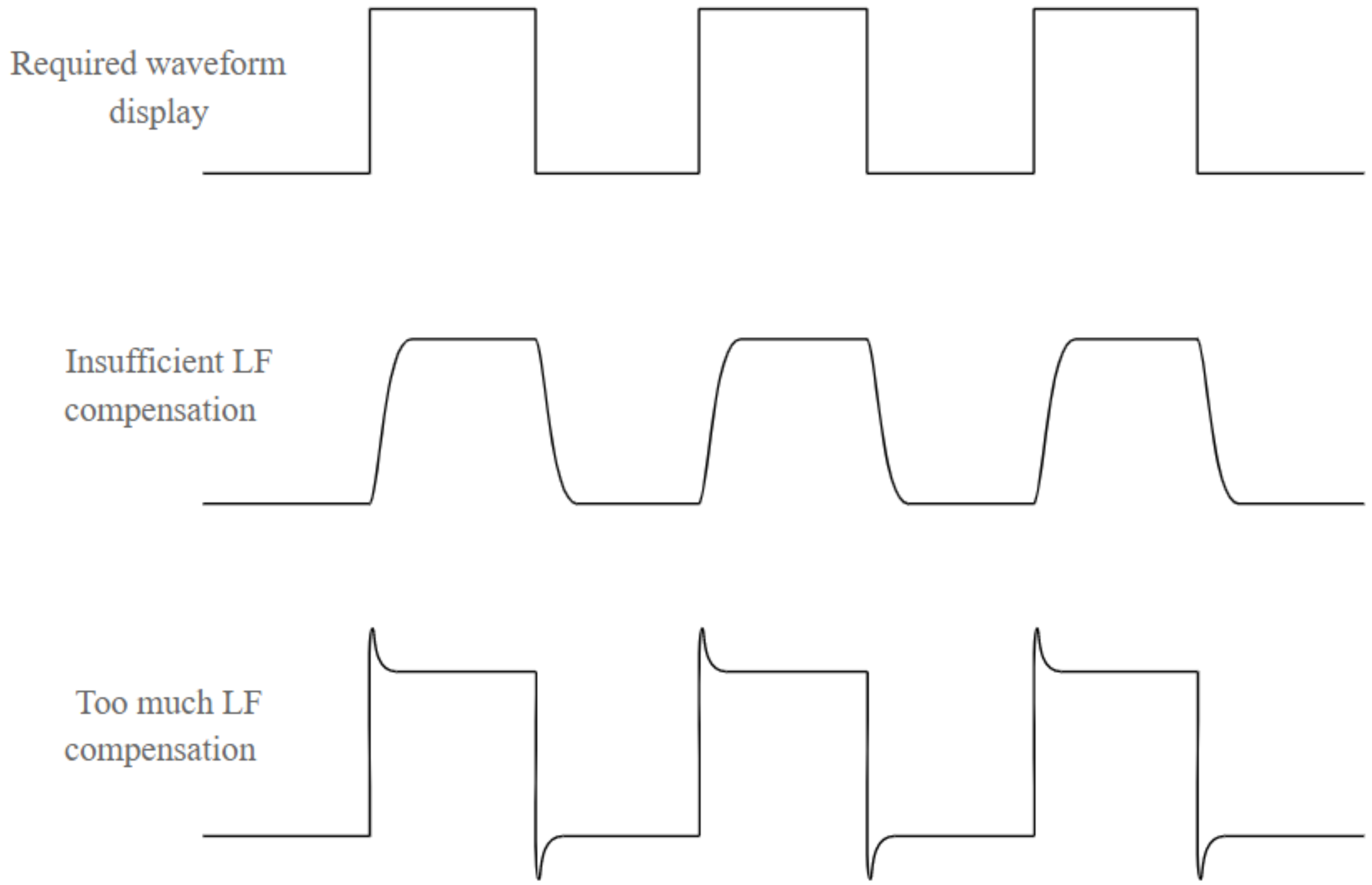


Oscilloscope Probes

- 10x probe calibration
  - Use the built-in square wave generator
  - Adjust capacitor until the square wave looks square!



Oscilloscope setup

Class Action Items

- Lab 3 starts today! Please aim to get your soldering done first!
  - Not everyone can solder at the same time (we only have 8 soldering irons)
  - If you have access to another soldering iron, feel free to use it.
- There is no lab next week and lab 3 is not due until Feb. 25-26.
- Lab 4 also has a significant soldering component, please if you can, work on this early (i.e., next week after February break)
- A really good Lab 3 from last year: https://mavisfu.github.io/lab3.html