ECE 4960

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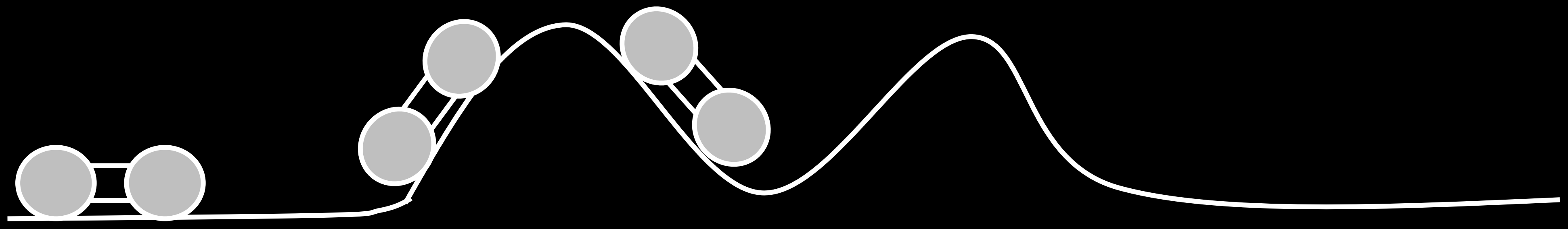
Fast Robots

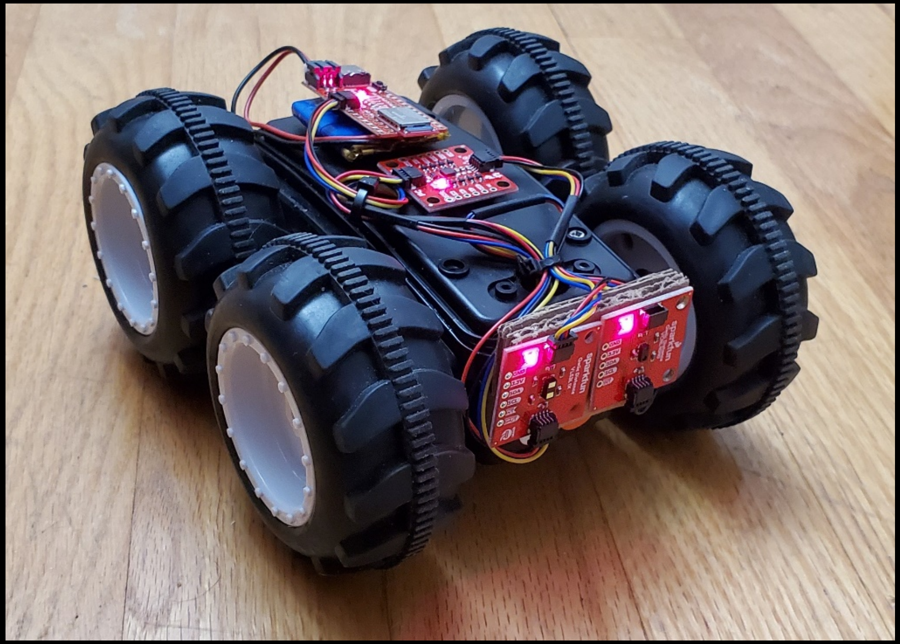
Feedback Control

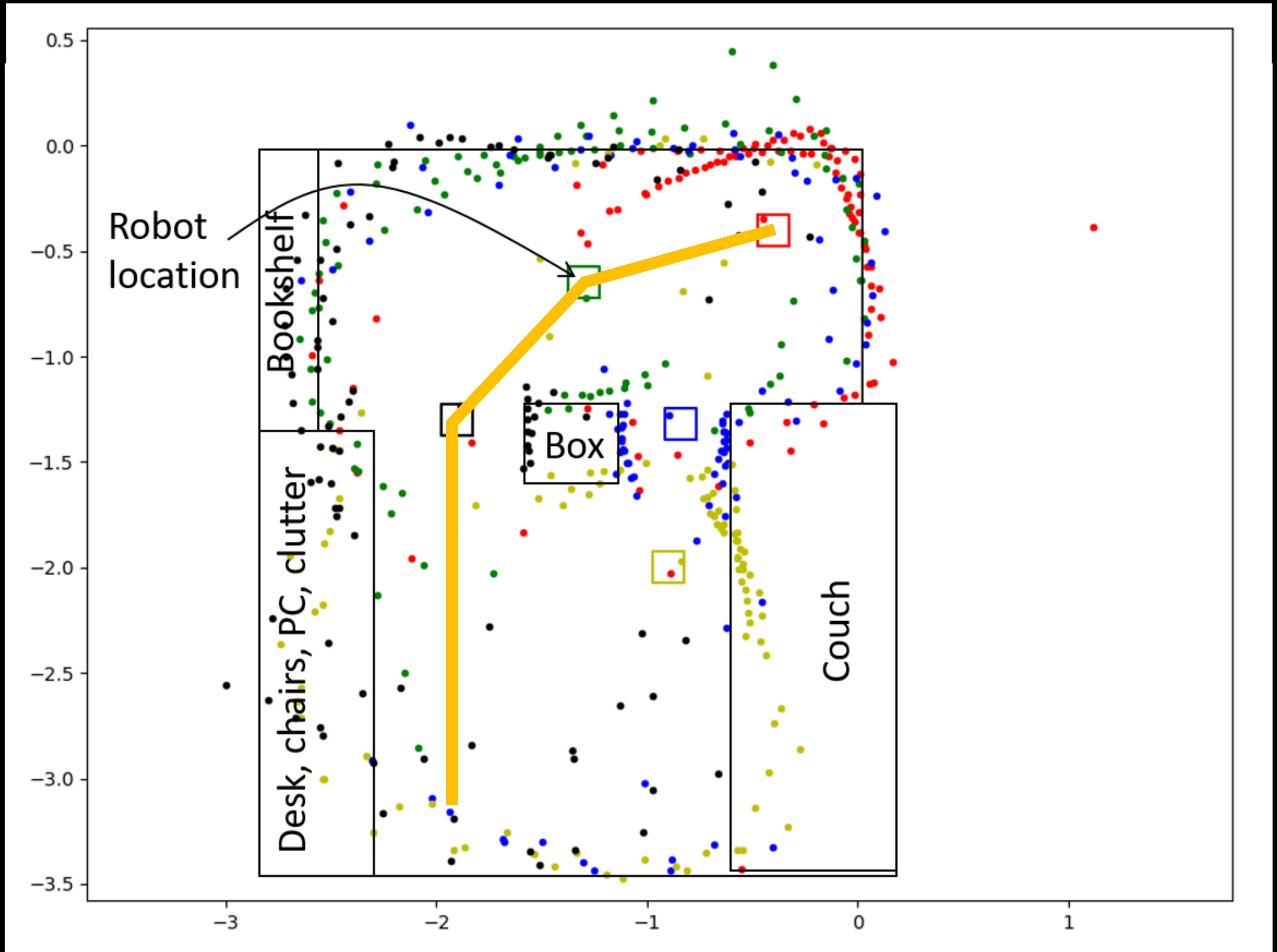
- Maintain speed prediction at different battery levels



Feedback Control

- Maintaining speed prediction at different battery levels
- Mapping: evenly spaced out sensor readings
- Path execution: adhere to generated path plans

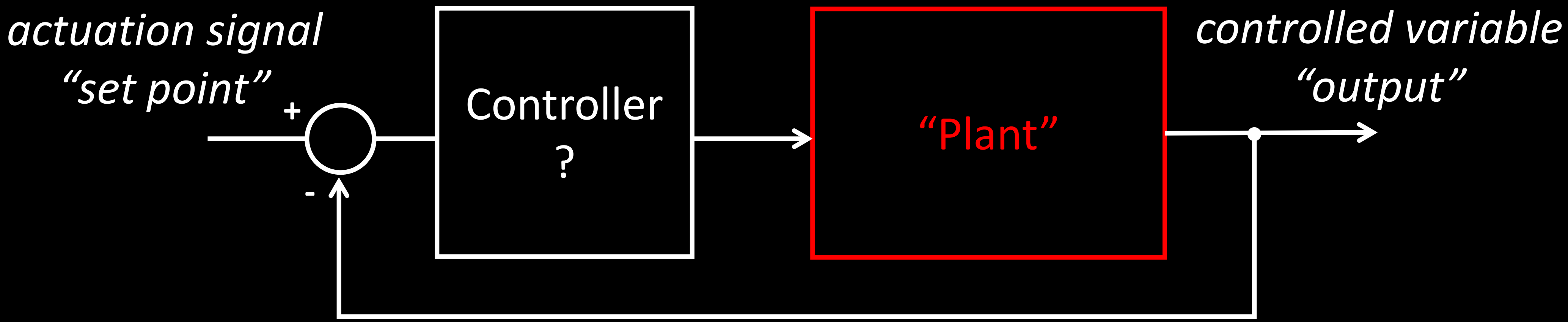




PID control

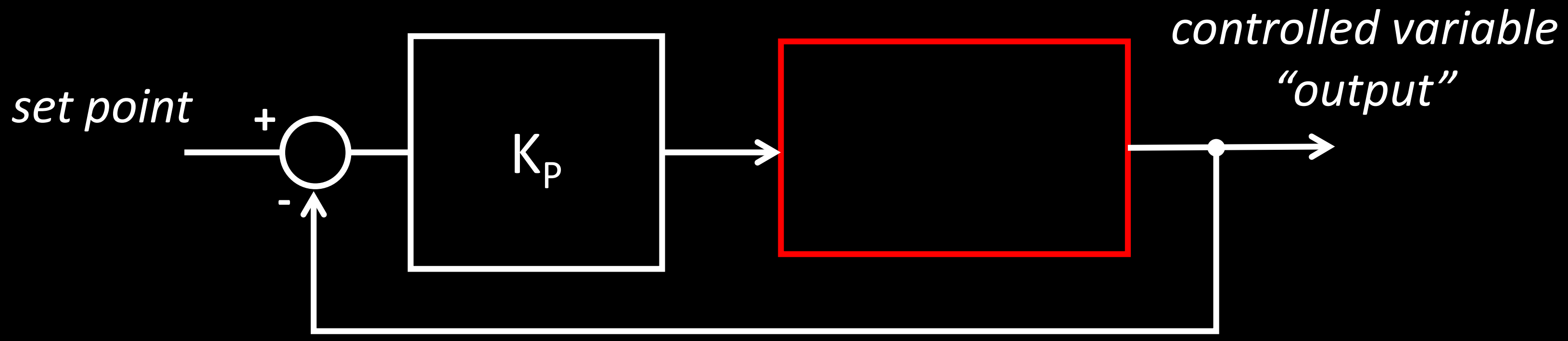
Heavily inspired by a Matlab Tech Talk: Understanding PID Control

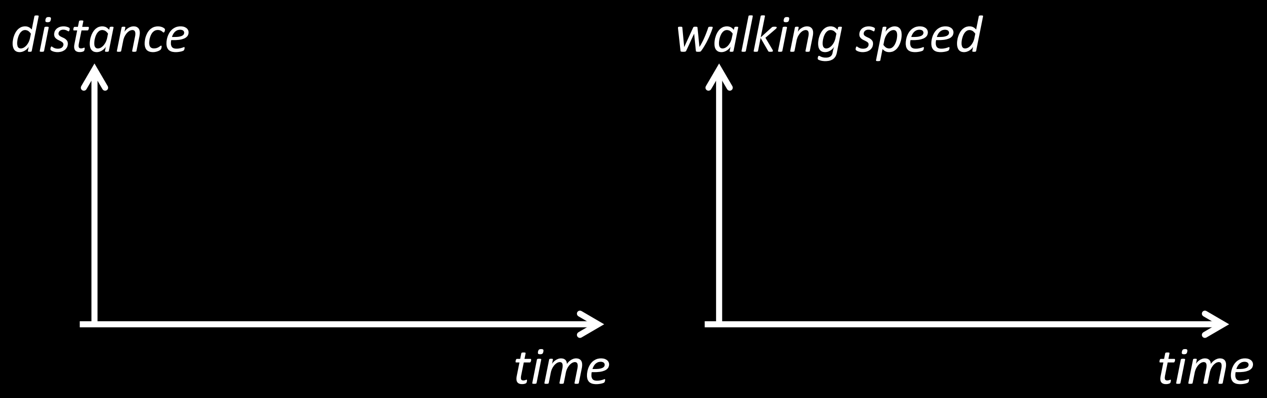
$$u(t) = K_P e(t) + K_I \int_0^t e(t) dt + K_D \frac{de(t)}{dt}$$



PID control

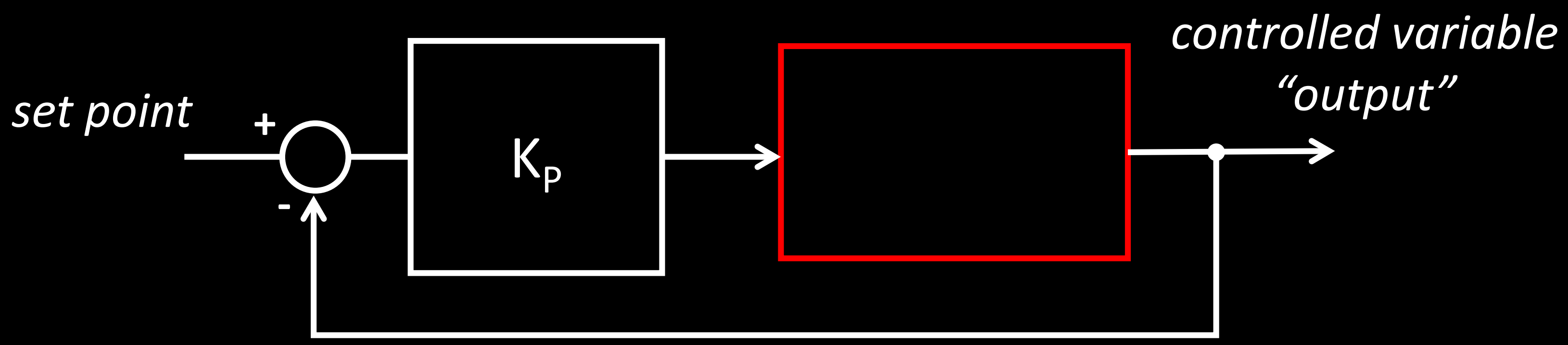
- Soccer field example





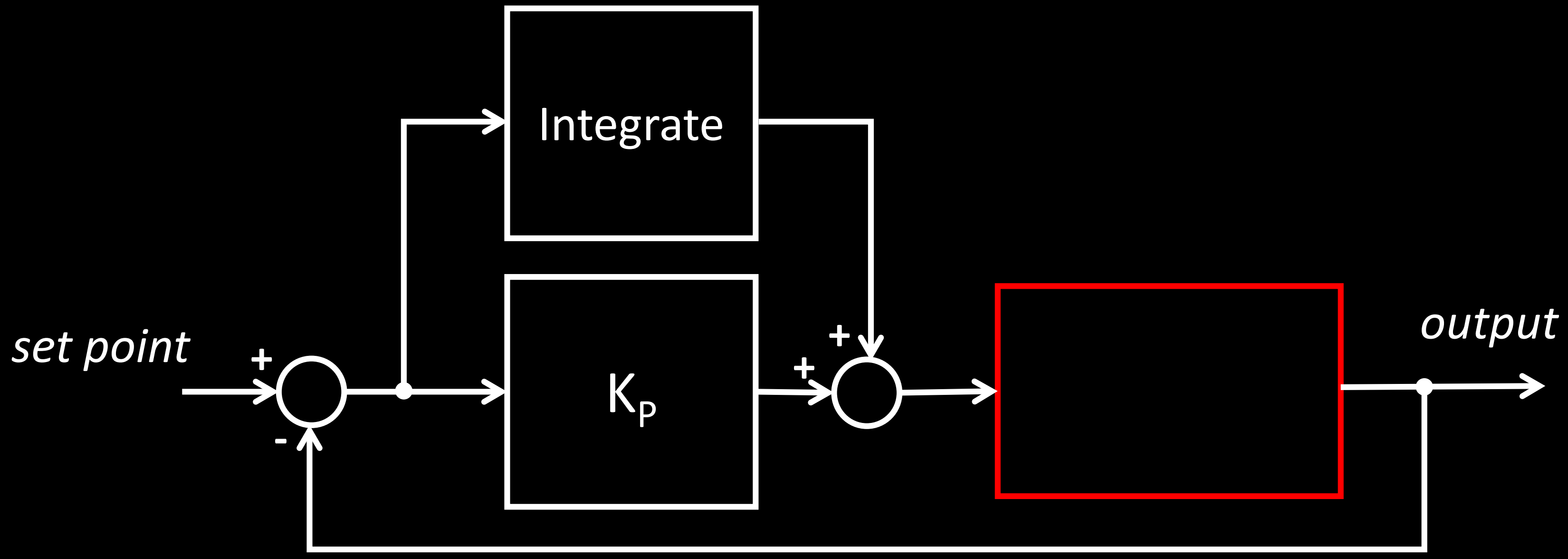
PID control

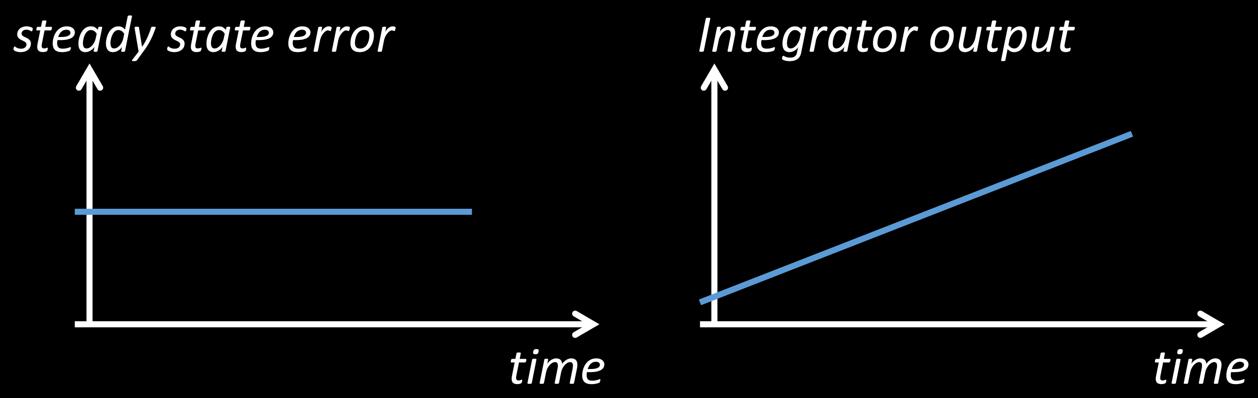
- Drone example



PID control

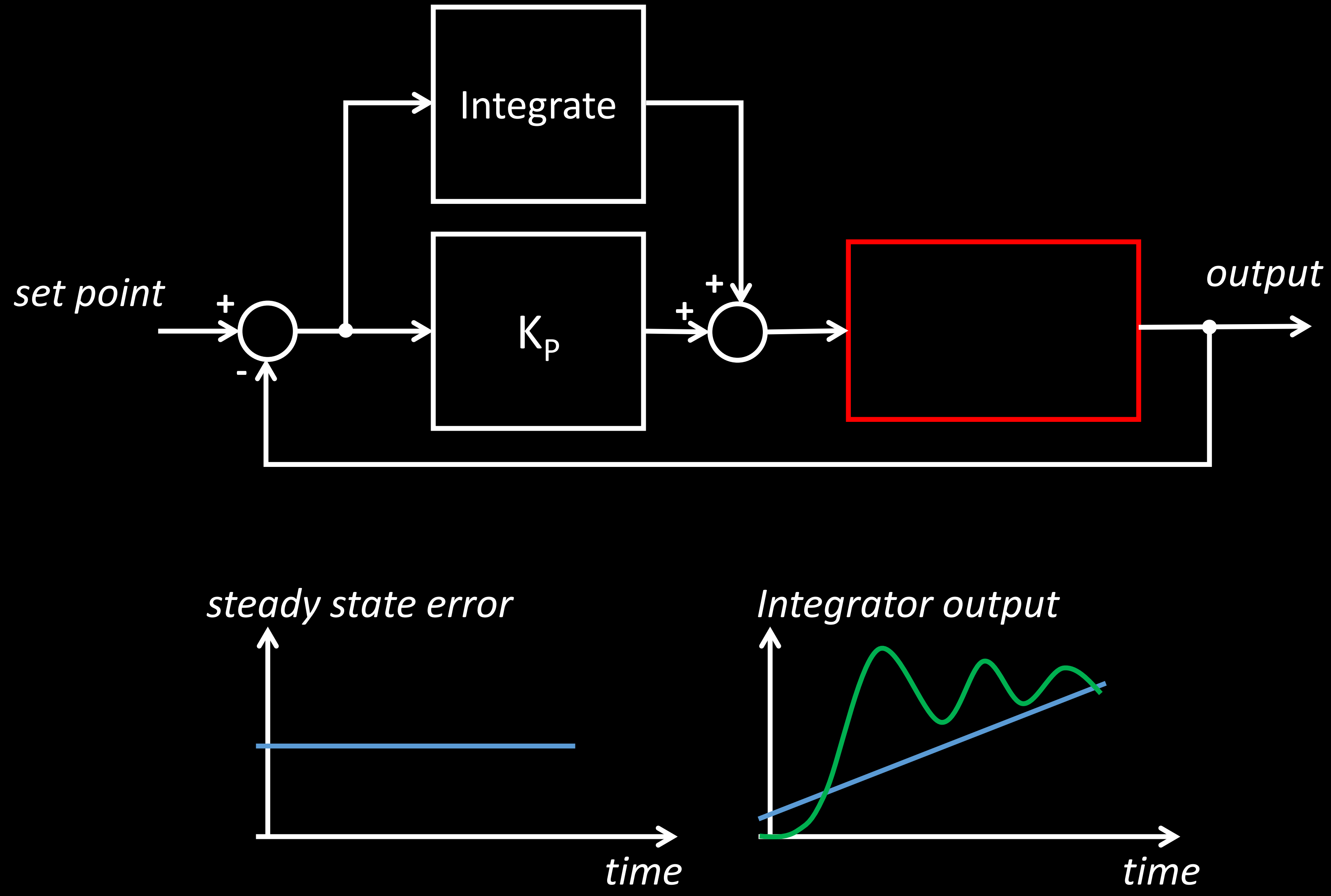
- Drone example





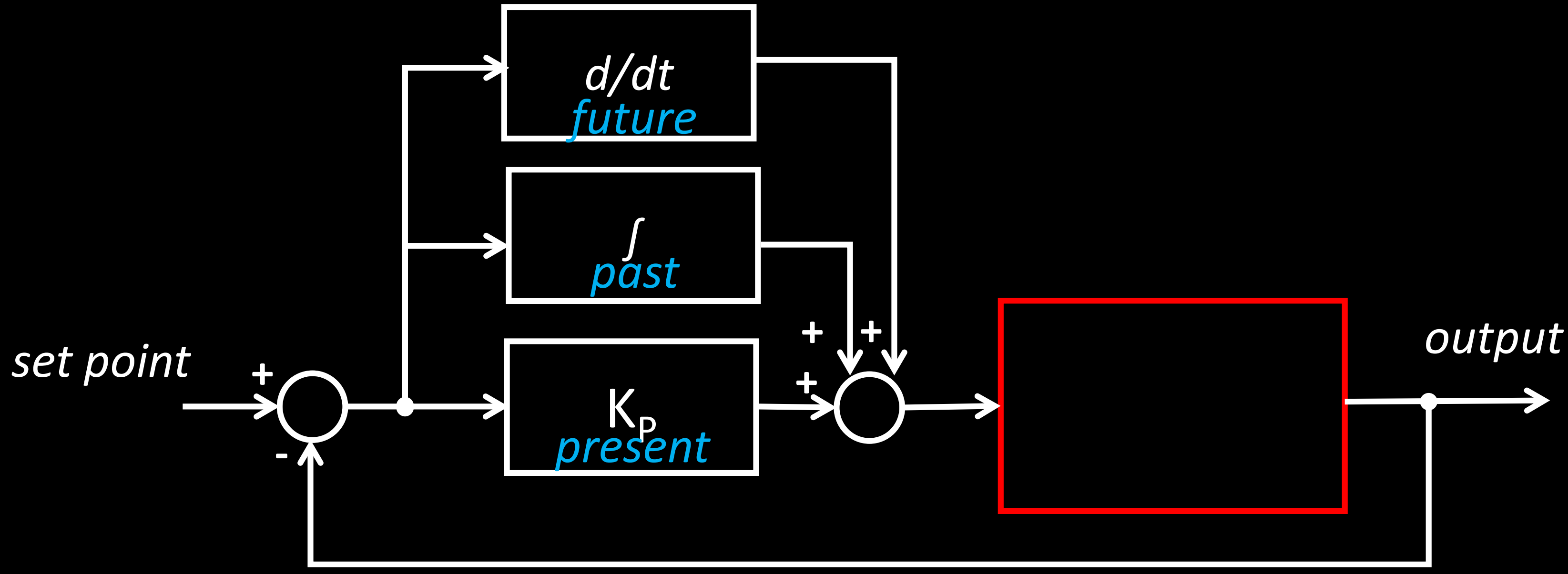
PID control

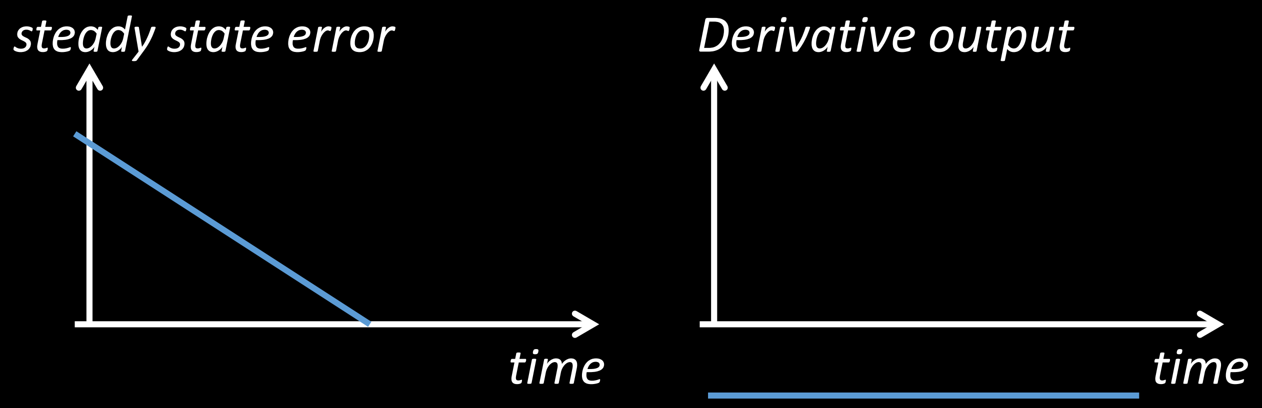
- Drone example



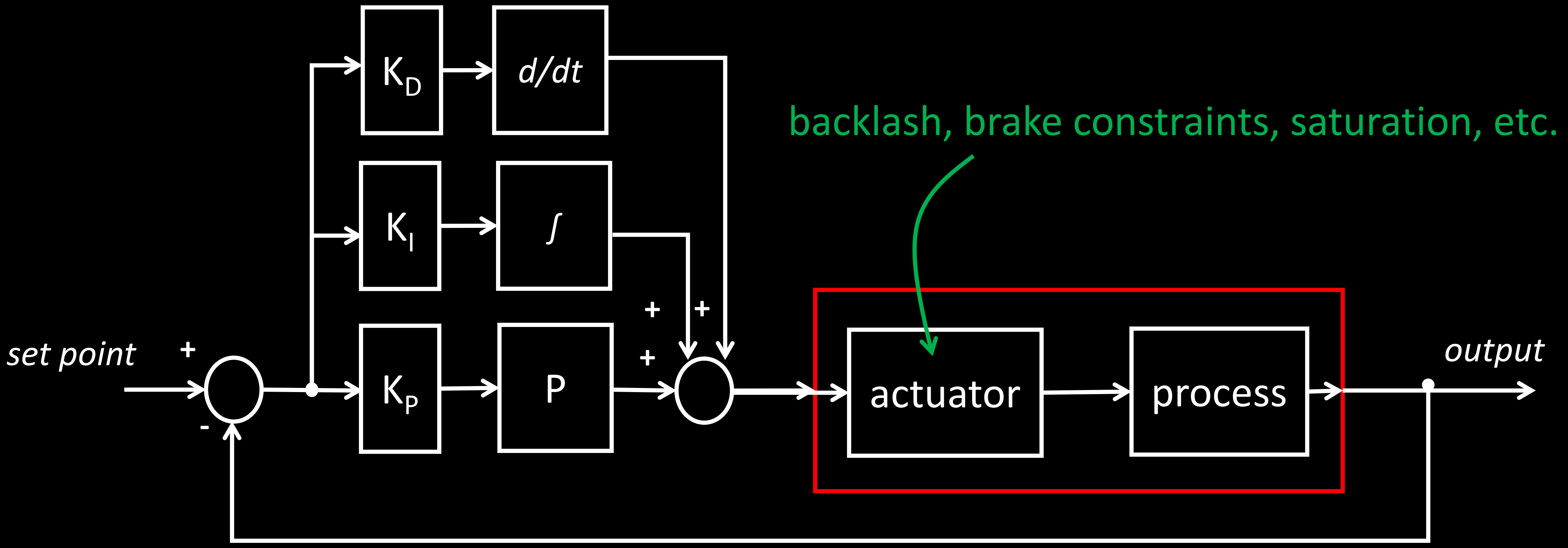
PID control

- Drone example

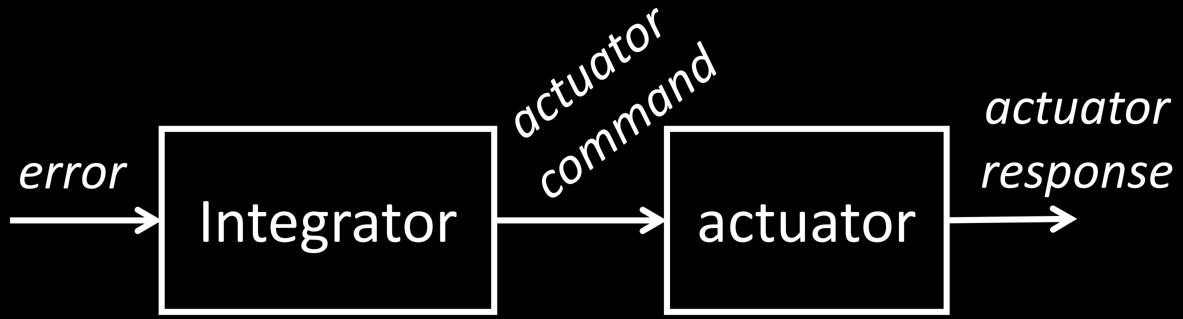


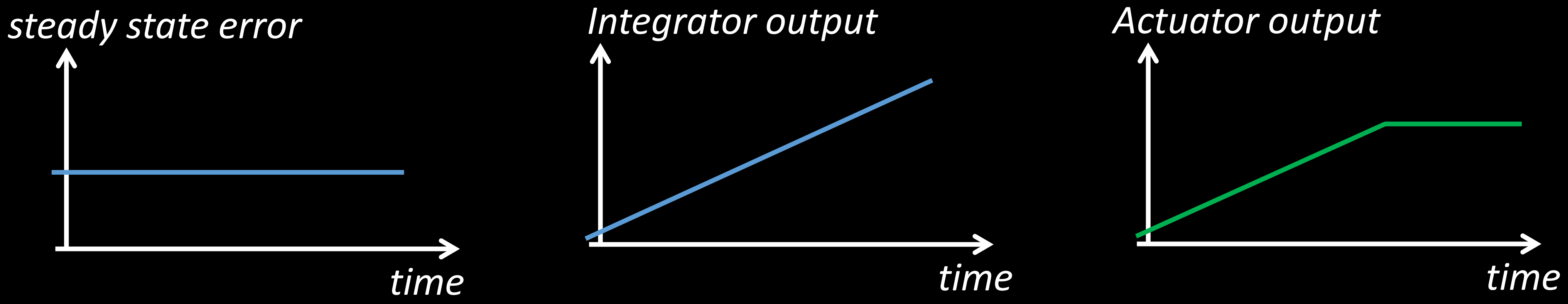


Real Systems are not linear!



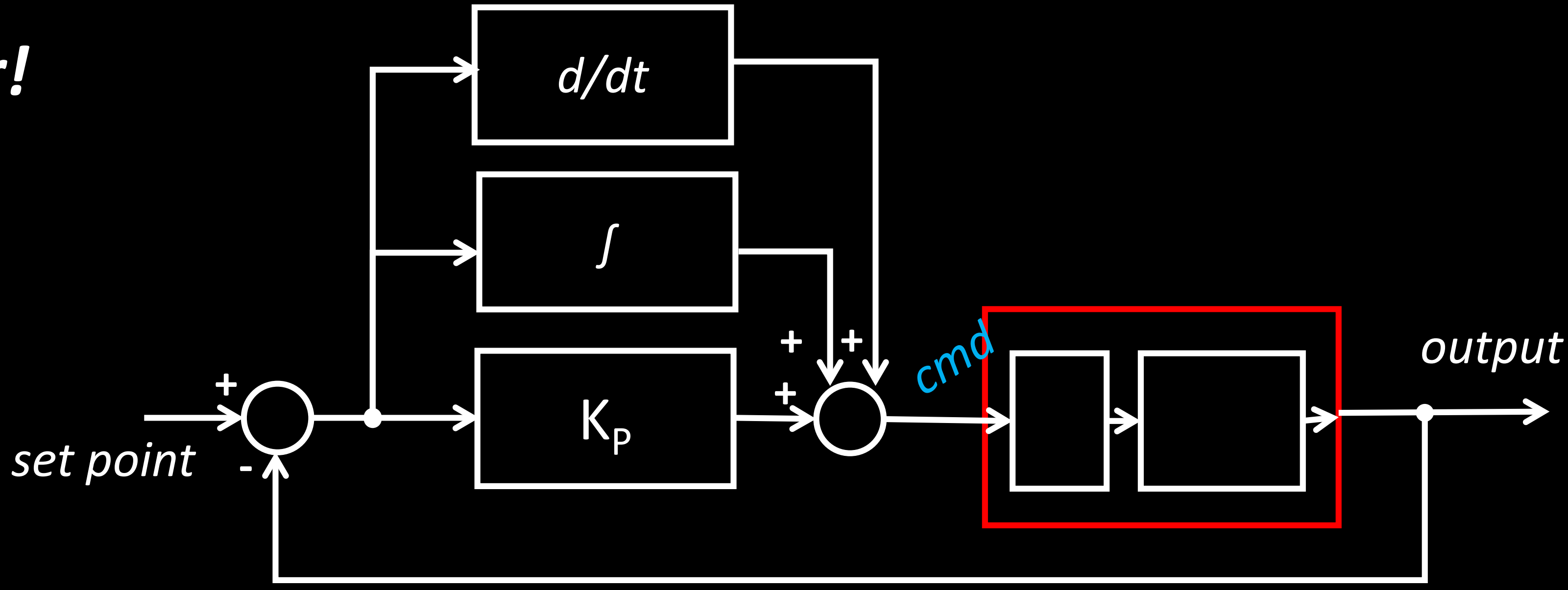
Real Systems are not linear!

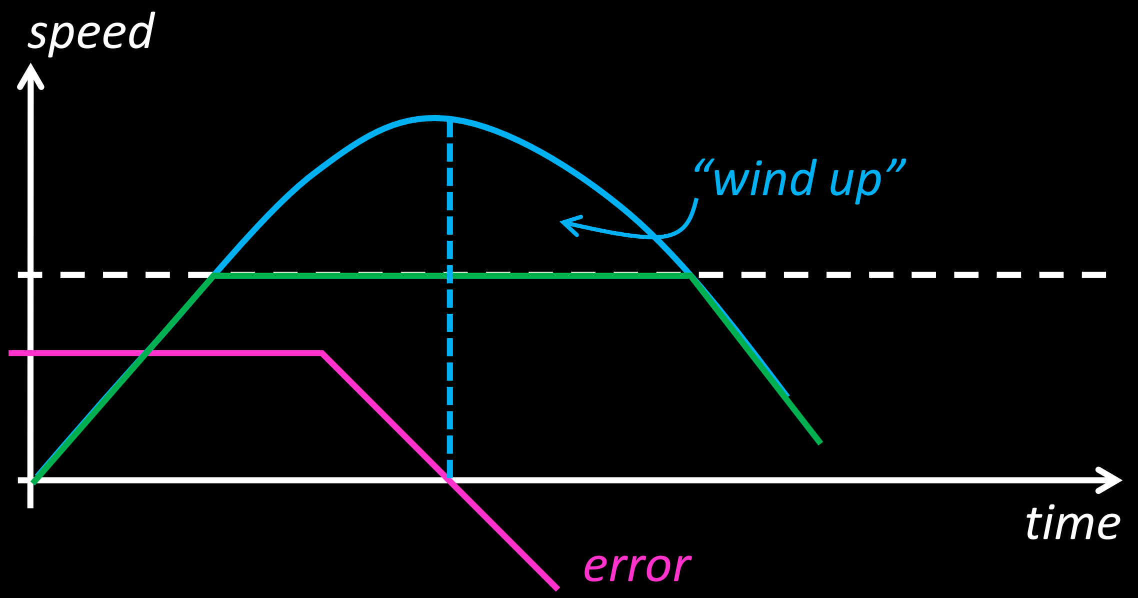




Real systems are not linear!

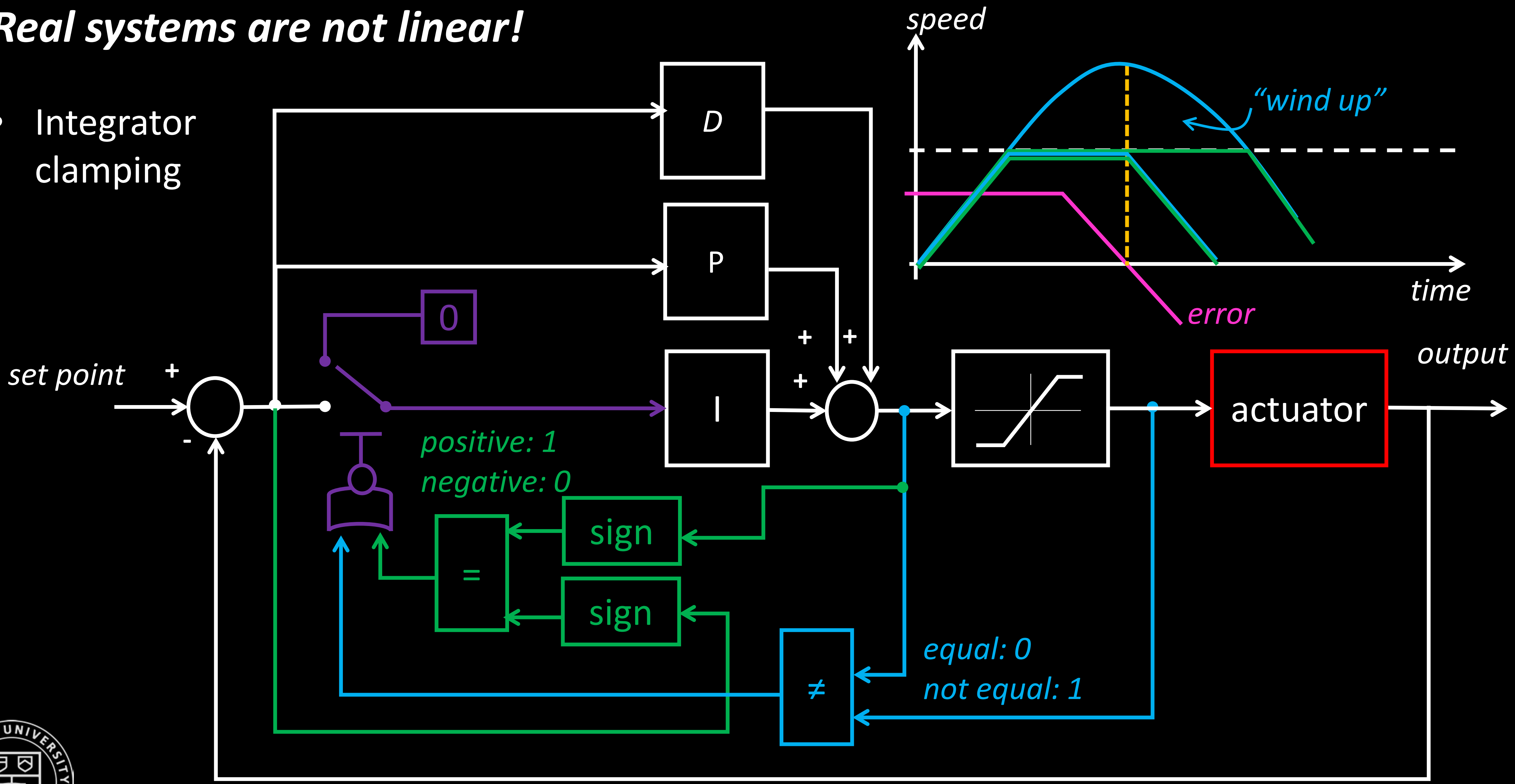
- Drone example
  - "Integral wind-up"
    - Clamping





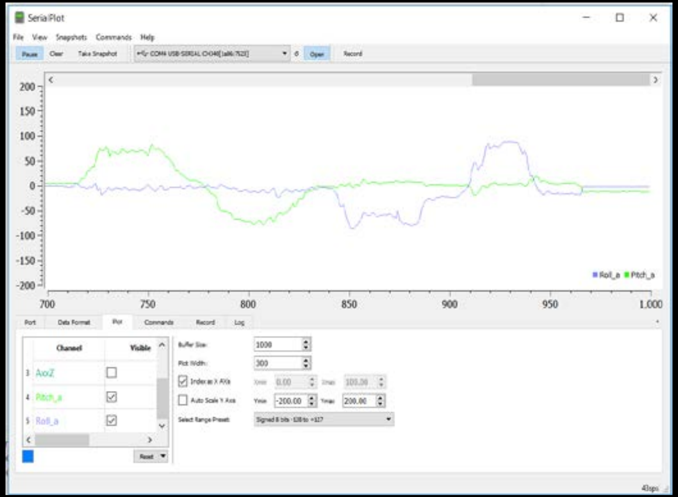
Real systems are not linear!

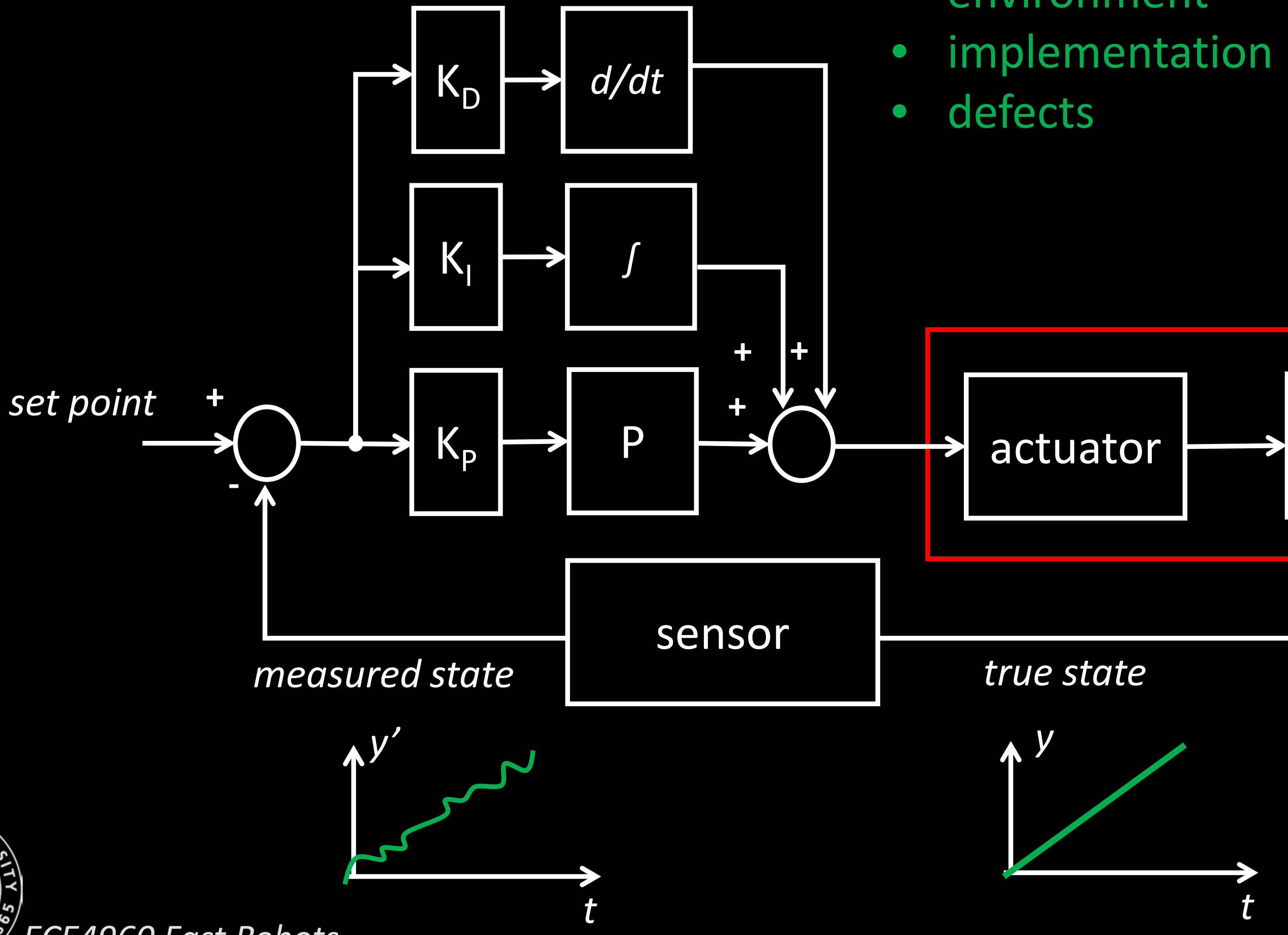
- Integrator clamping

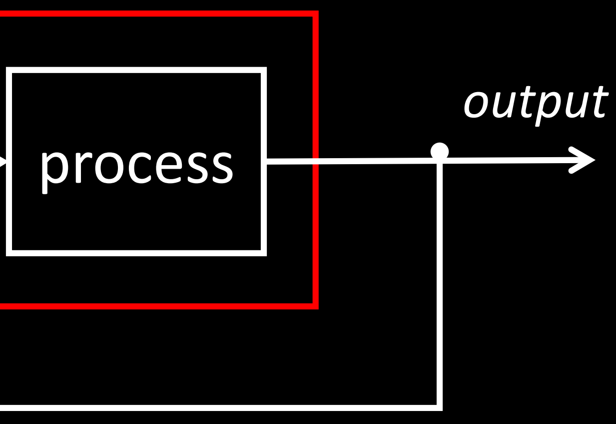


PID and Sensor noise

"noise":
- environment
- implementation
- defects

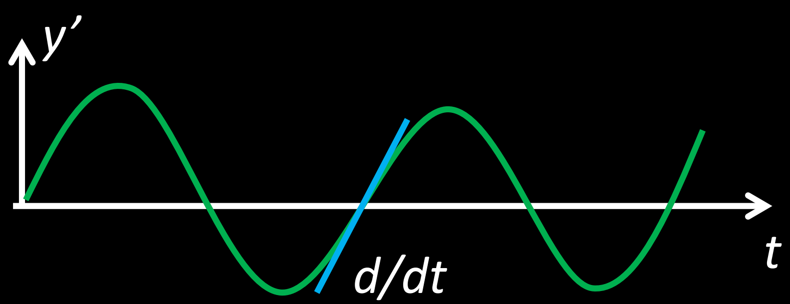


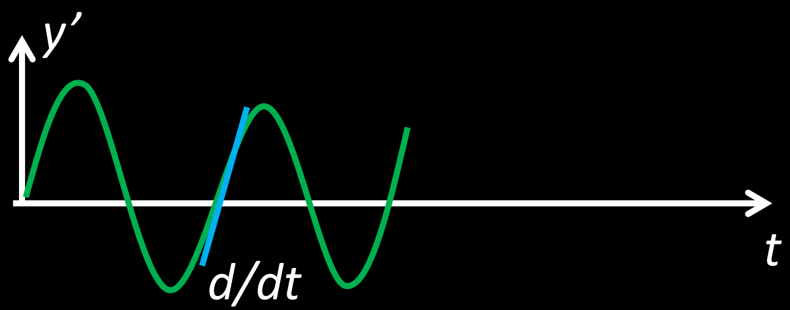


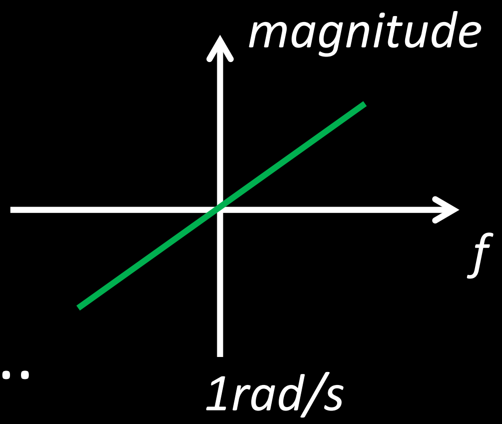


PID and Sensor noise

- Derivatives amplify HF signals more than LF signals





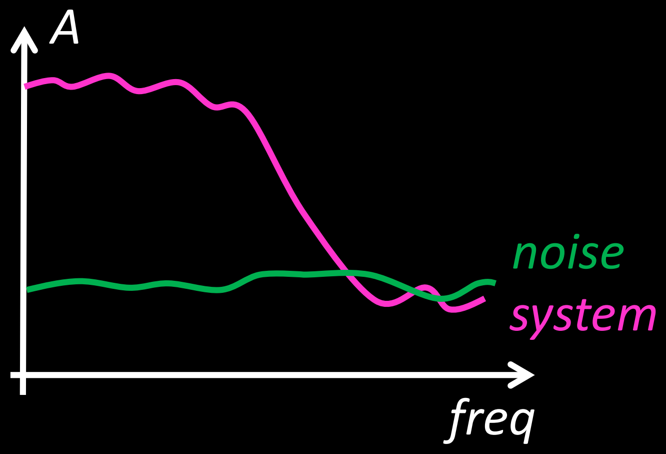


$$y(t) = A\sin(\omega_a t+\phi_a) + B\sin(\omega_b t+\phi_b) + \ldots$$

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

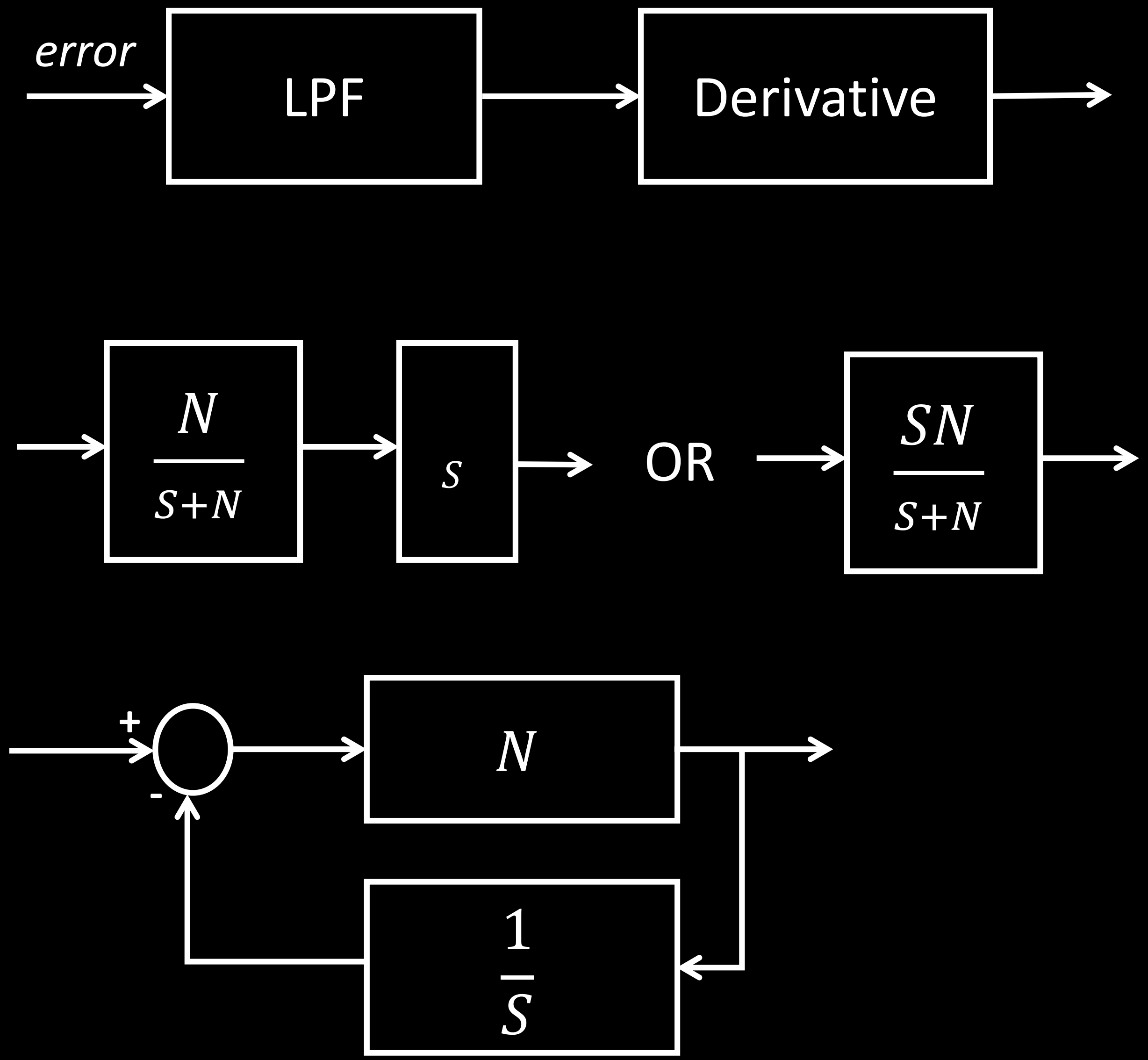
- if ω_a > 1rad/s, the amplitude will increase
- if ω_a < 1rad/s, the amplitude will decrease

PID and Sensor noise



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

1st order LPF $\quad \frac{N}{S+N} = \frac{1}{\frac{1}{N}S+1} = \frac{1}{\tau S+1}$



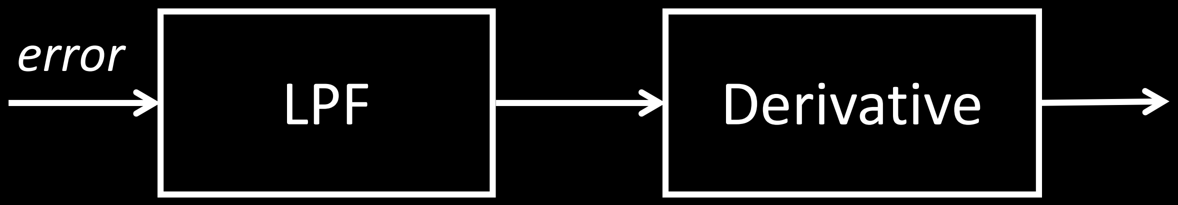
PID and Sensor noise

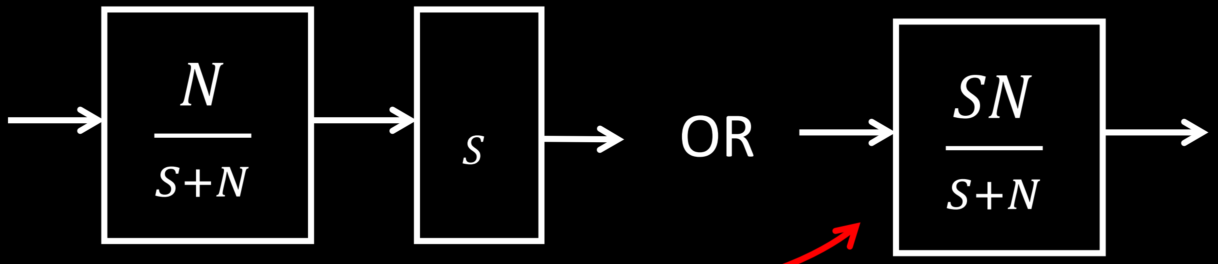
$$y = N\left(u - \frac{y}{s}\right)$$

$$y + \frac{Ny}{s} = Nu$$

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

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





Time	Laplace
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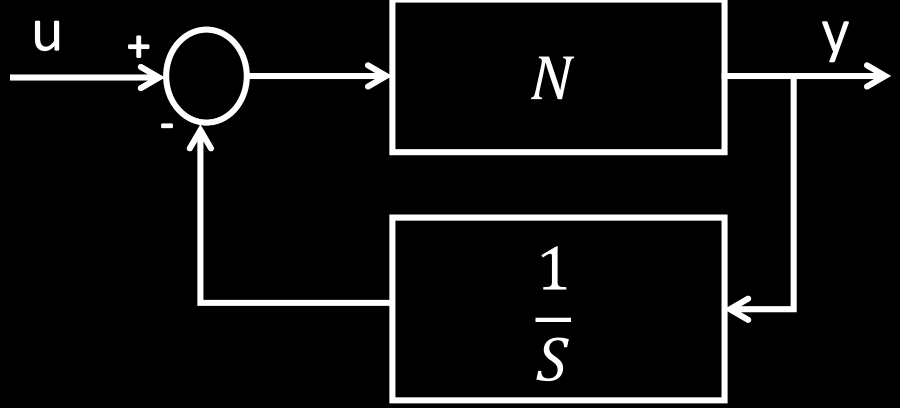
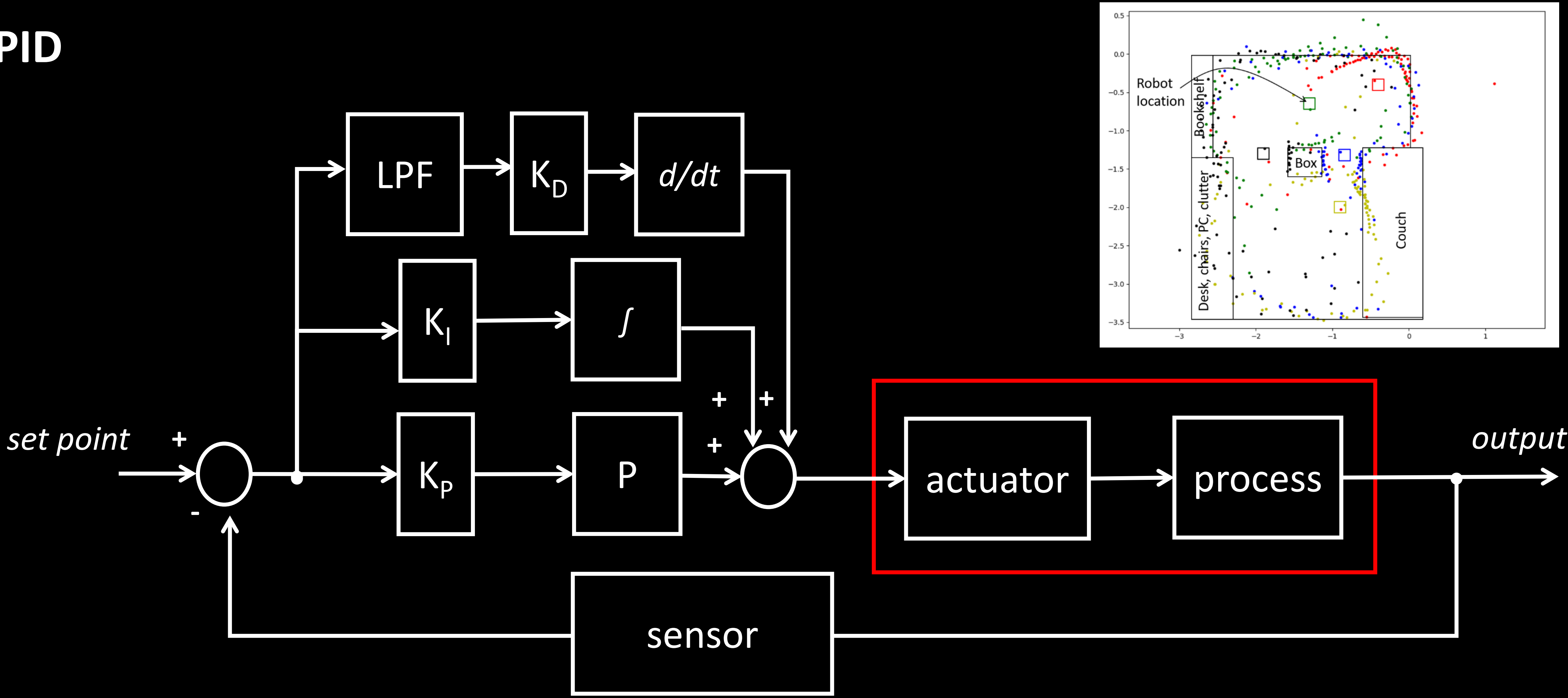
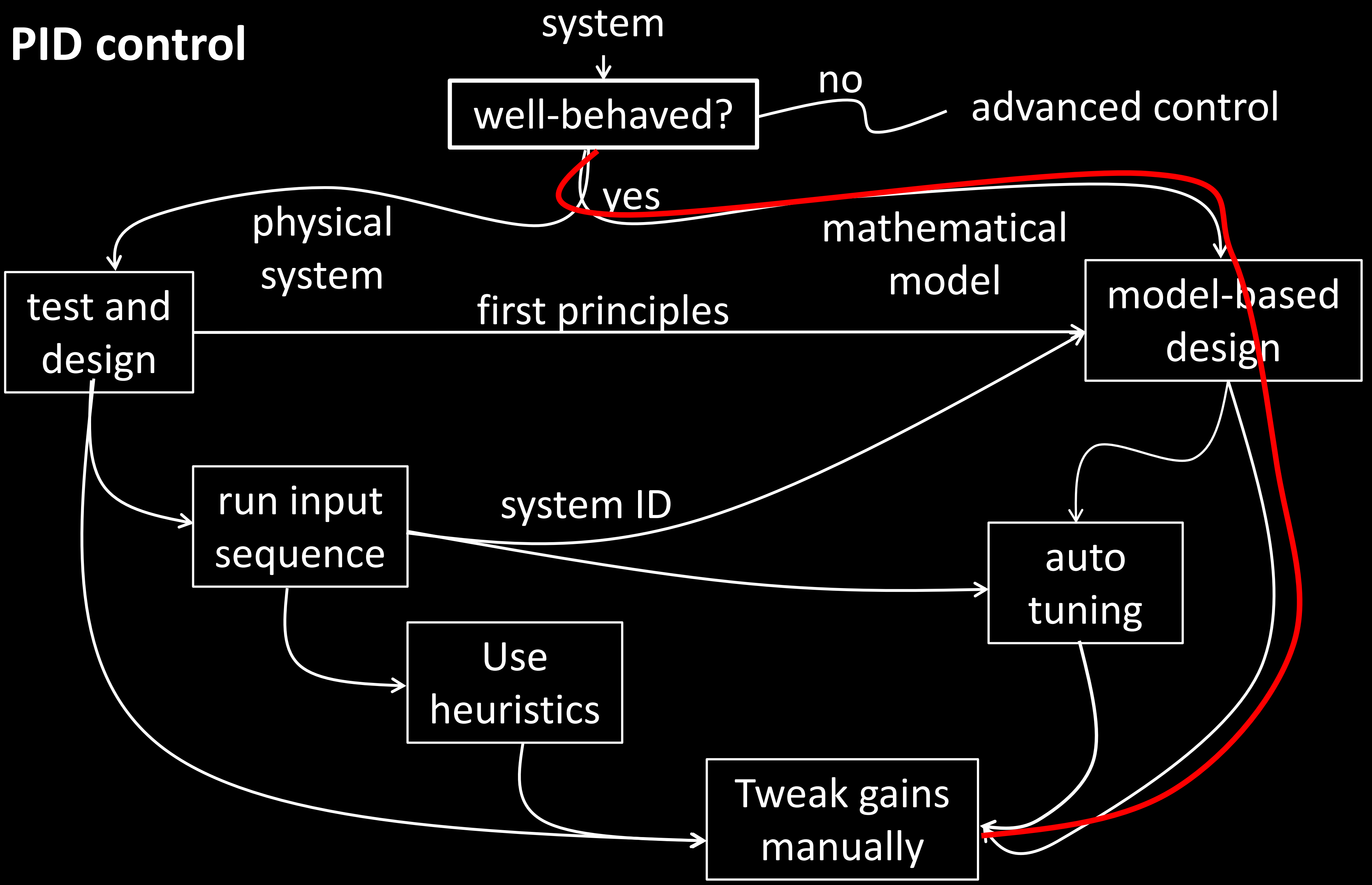


PID

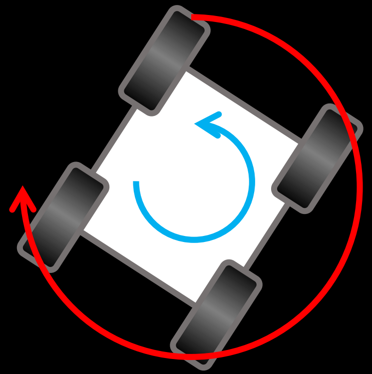

set point
+
-
LPF
K_D
d/dt
K_I
∫
K_P
P
+
+
+
actuator
process
output
sensor
Robot
location
Bookshelf
Box
Desk, chairs, PC, clutter
Couch

Tuning PID control



Tuning PID control

- PID on turning speed
  - Equations of motion
  - $\dot{x} = \begin{bmatrix} \theta \\ \dot{\theta} \end{bmatrix}$
  - https://tinyurl.com/y67glgzk



$$F = ma$$

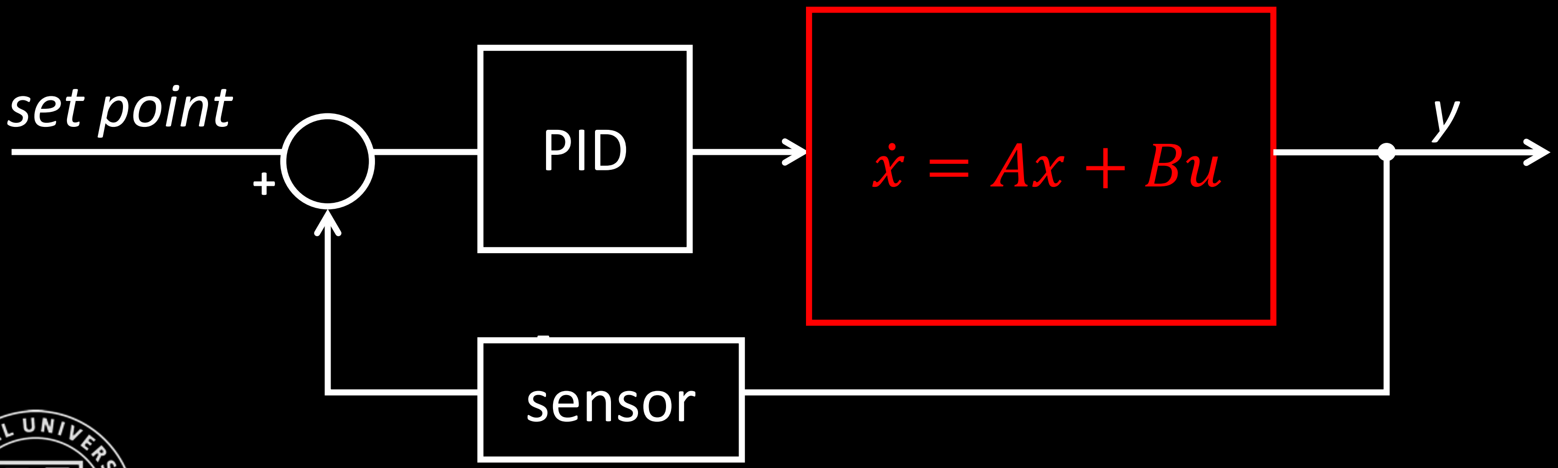
$$\tau = I\alpha$$

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

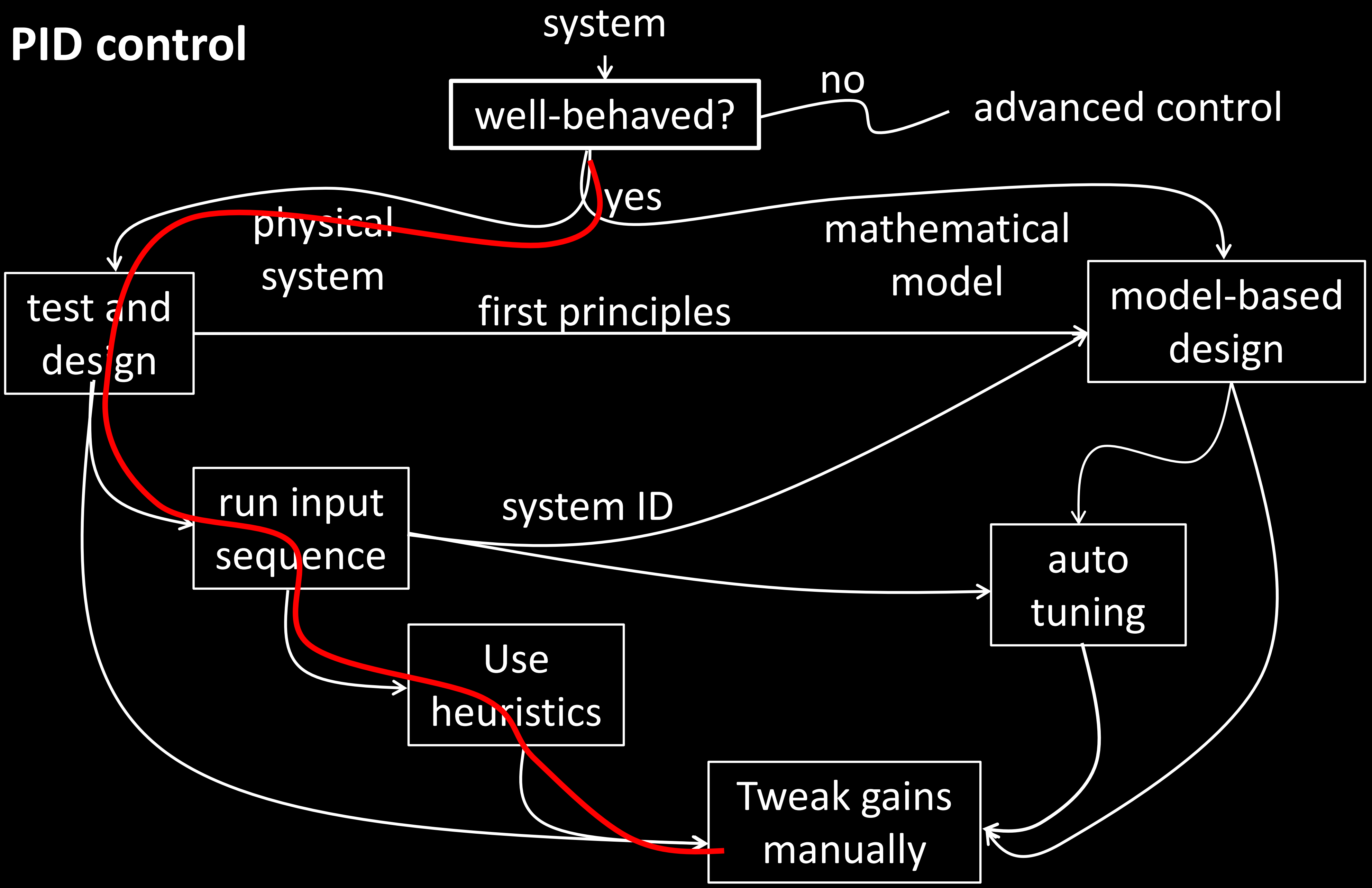
$$u - \dot{\theta}c = I\ddot{\theta}$$

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

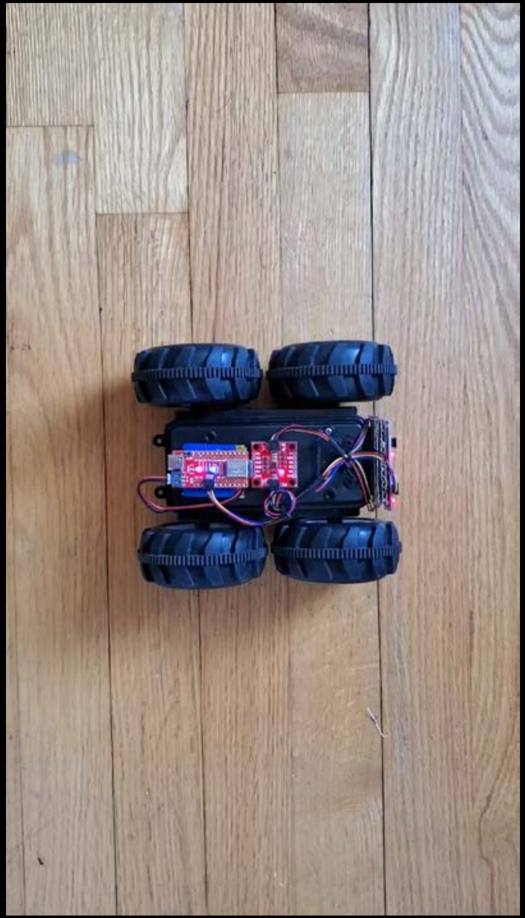
$$\begin{bmatrix} \dot{\theta} \\ \ddot{\theta} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & \frac{-c}{I} \end{bmatrix} \begin{bmatrix} \theta \\ \dot{\theta} \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{I} \end{bmatrix} u$$

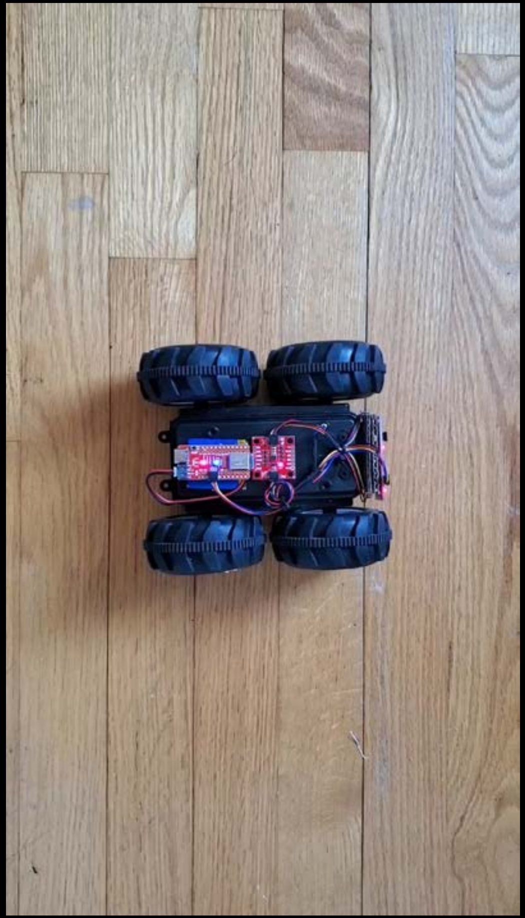


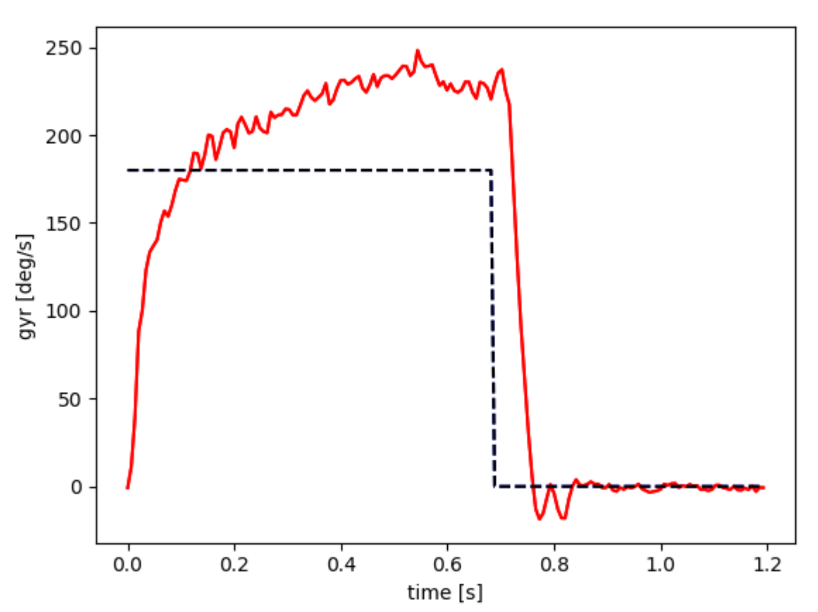
Tuning PID control

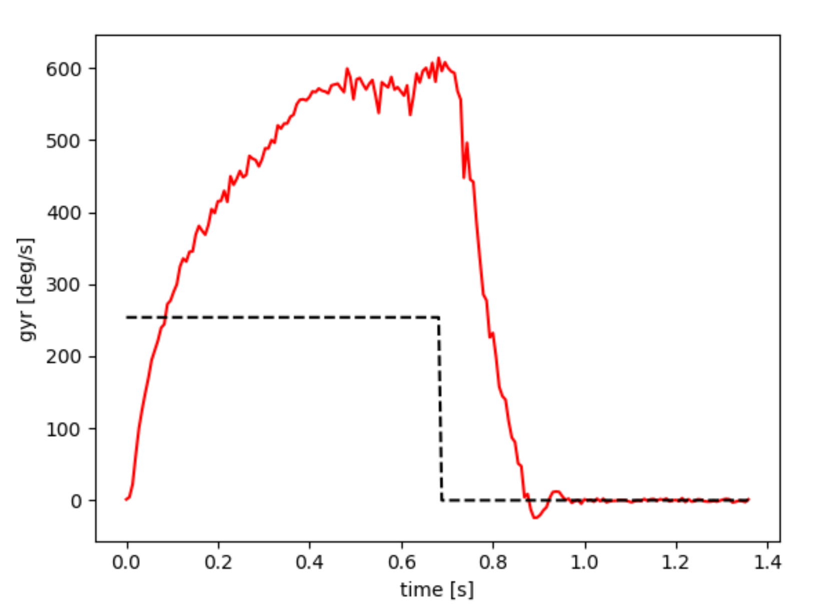


Tuning PID control









Tuning PID control

- Chien, Hornes, and Reswick method

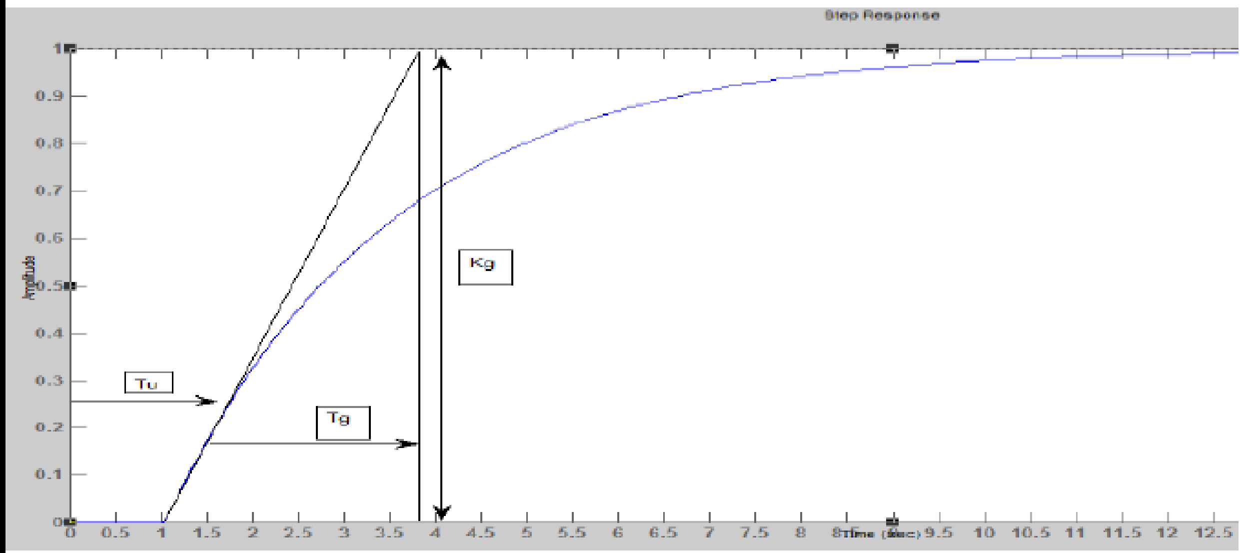
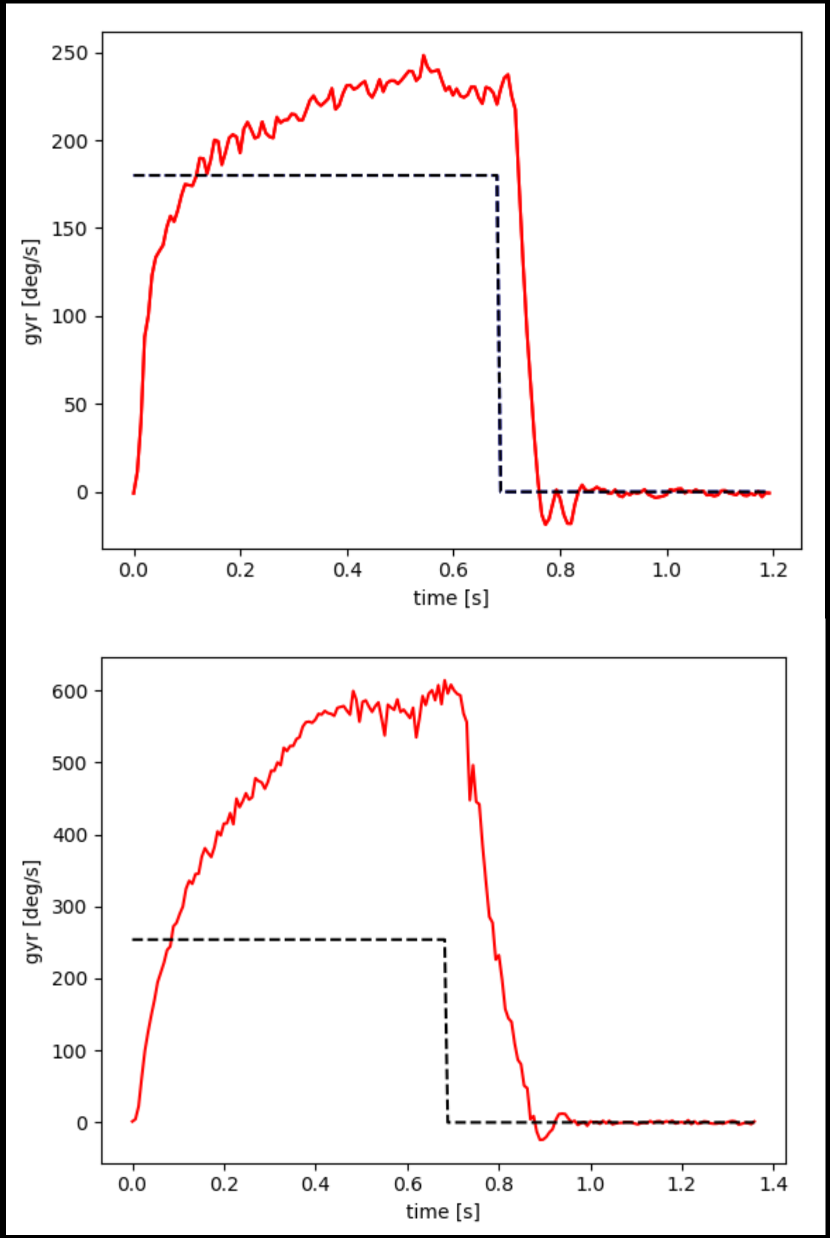


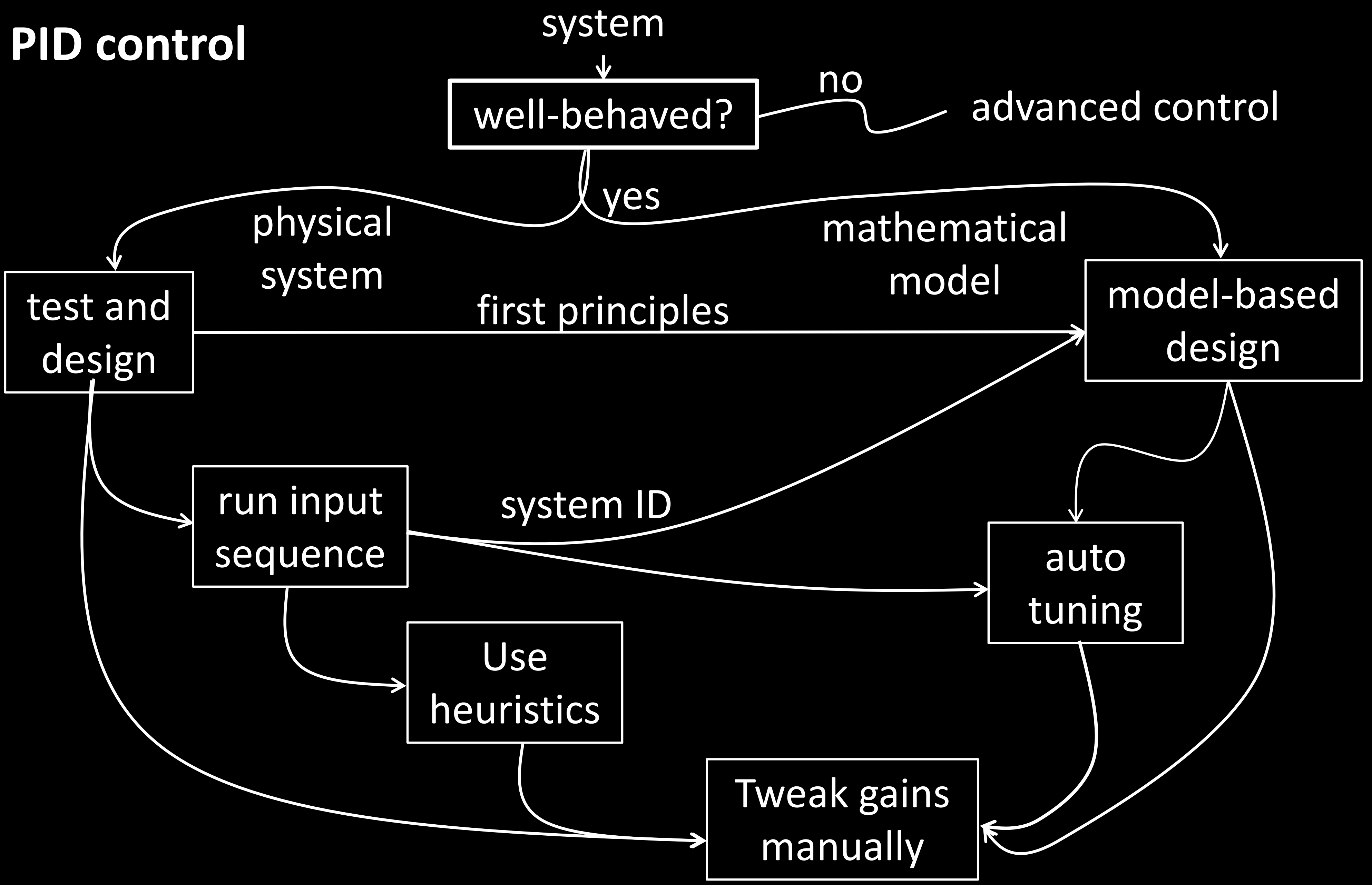
Fig.7. Open loop response of CHR method

Table.11. CHR Compensator

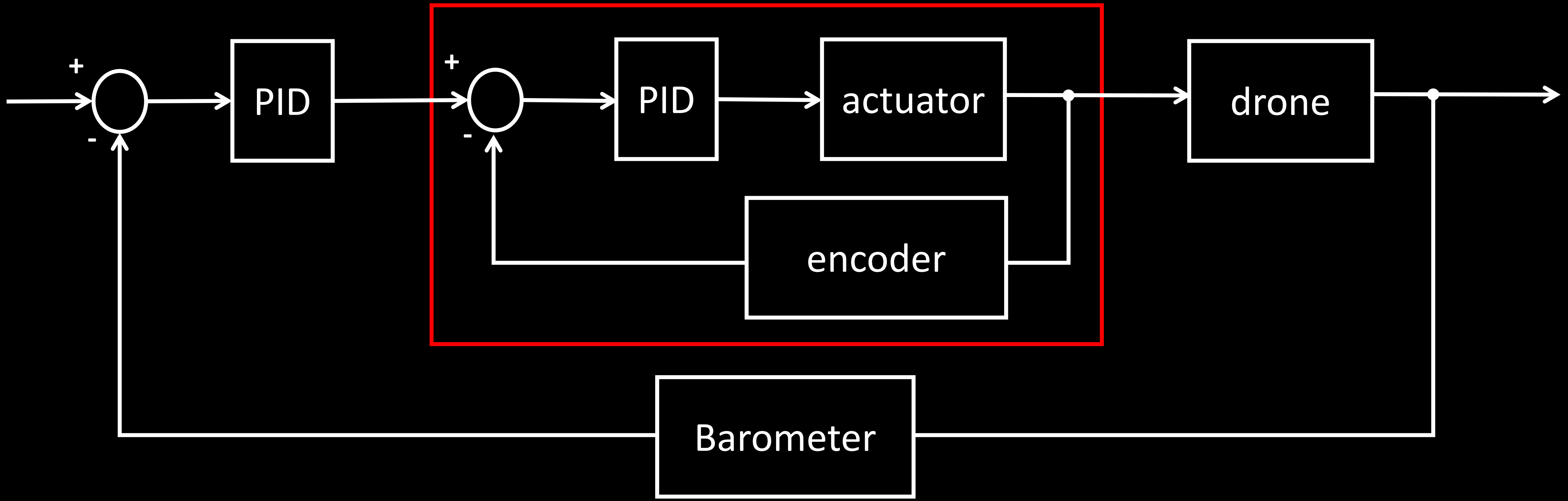
Type of controller	K_p	T_i	T_d
PID	$0.6T_g/T_uKg$	T_g	$0.5T_u$



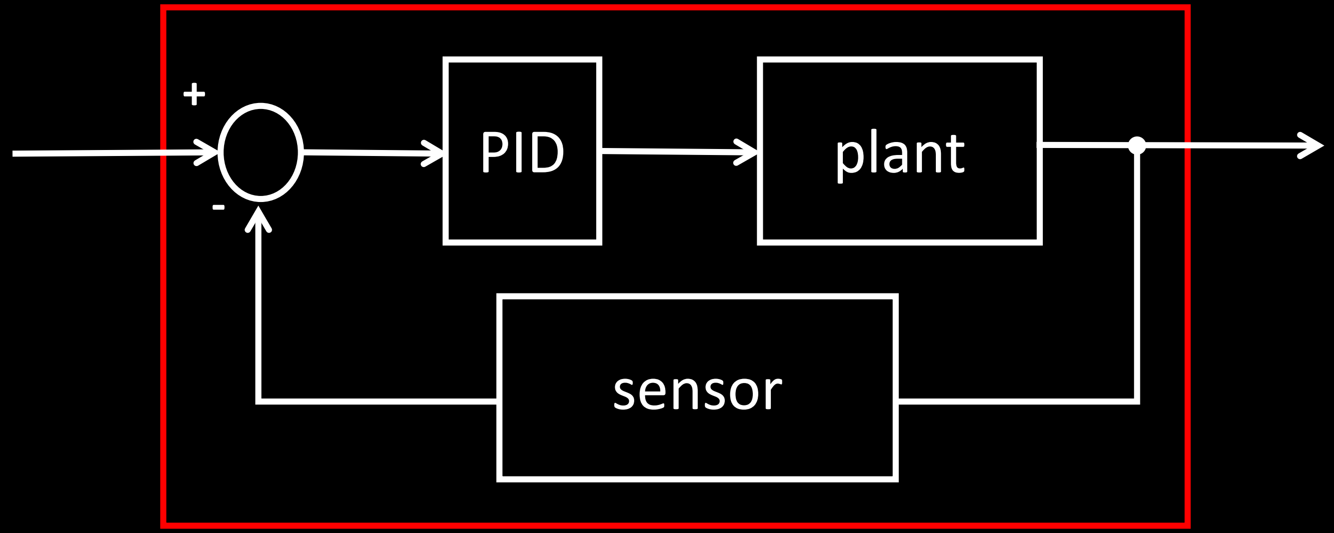
Tuning PID control



Cascaded Control Loops



Discrete PID Control



$$c(s) = K_P + K_I \frac{1}{s} + K_D \frac{N}{1 + N\frac{1}{s}}$$

$$c(z) = K_P + K_I T_s \frac{1}{z-1} + K_D \frac{N}{1 + NT_s\frac{1}{z-1}}$$