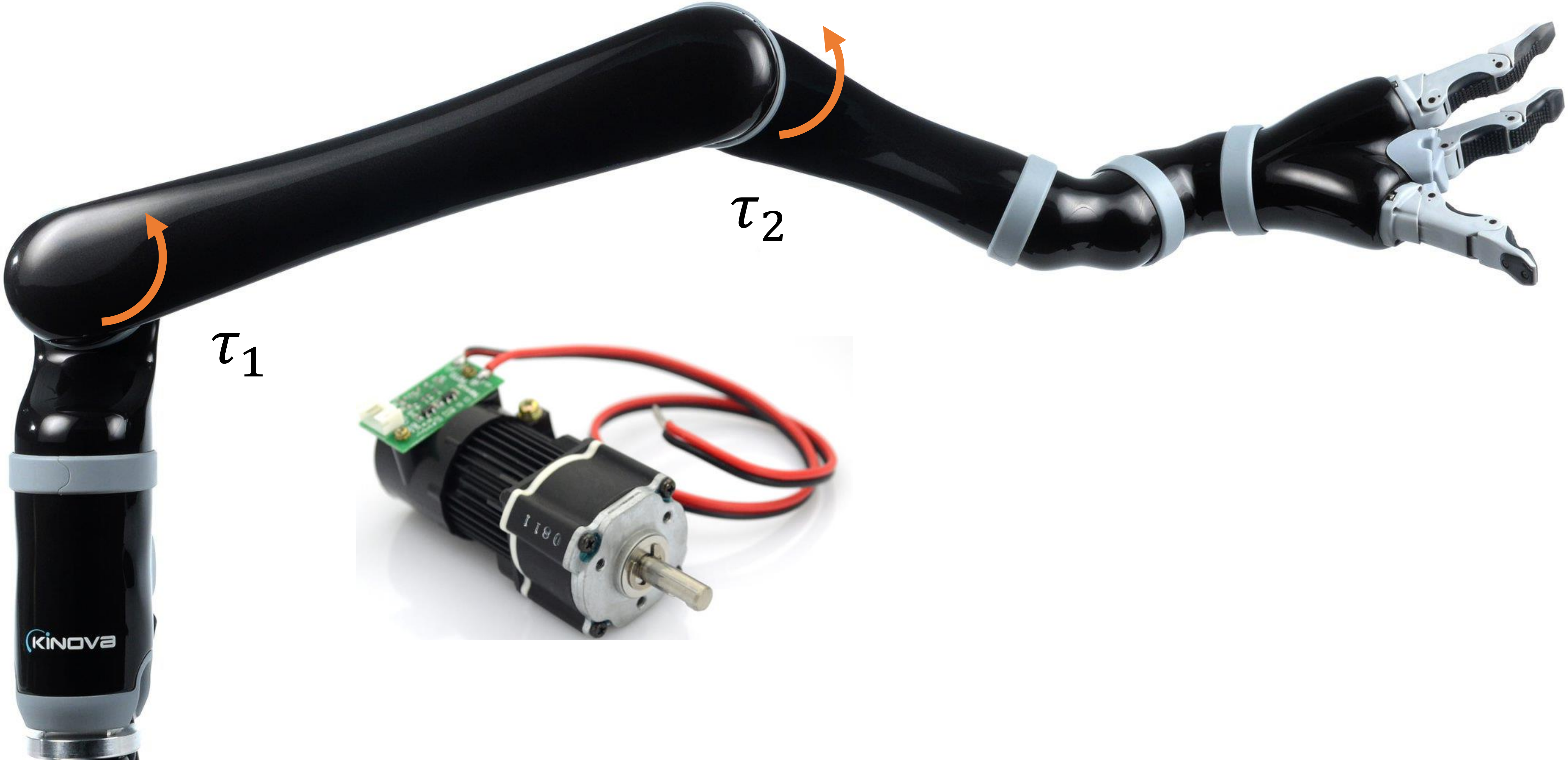
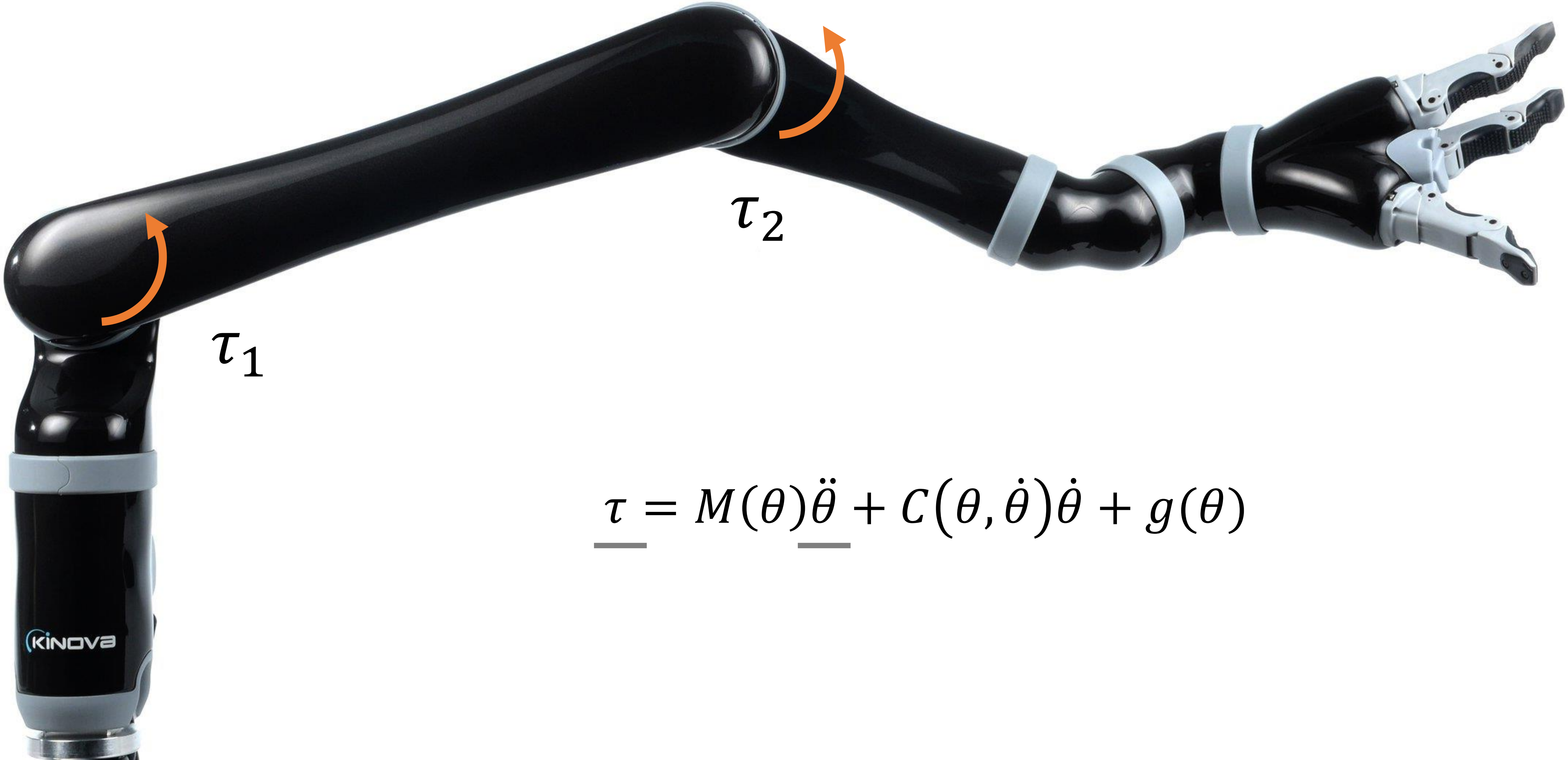
Control Review

Reading: Robot Modeling and Control 6.2, 6.3, 6.4

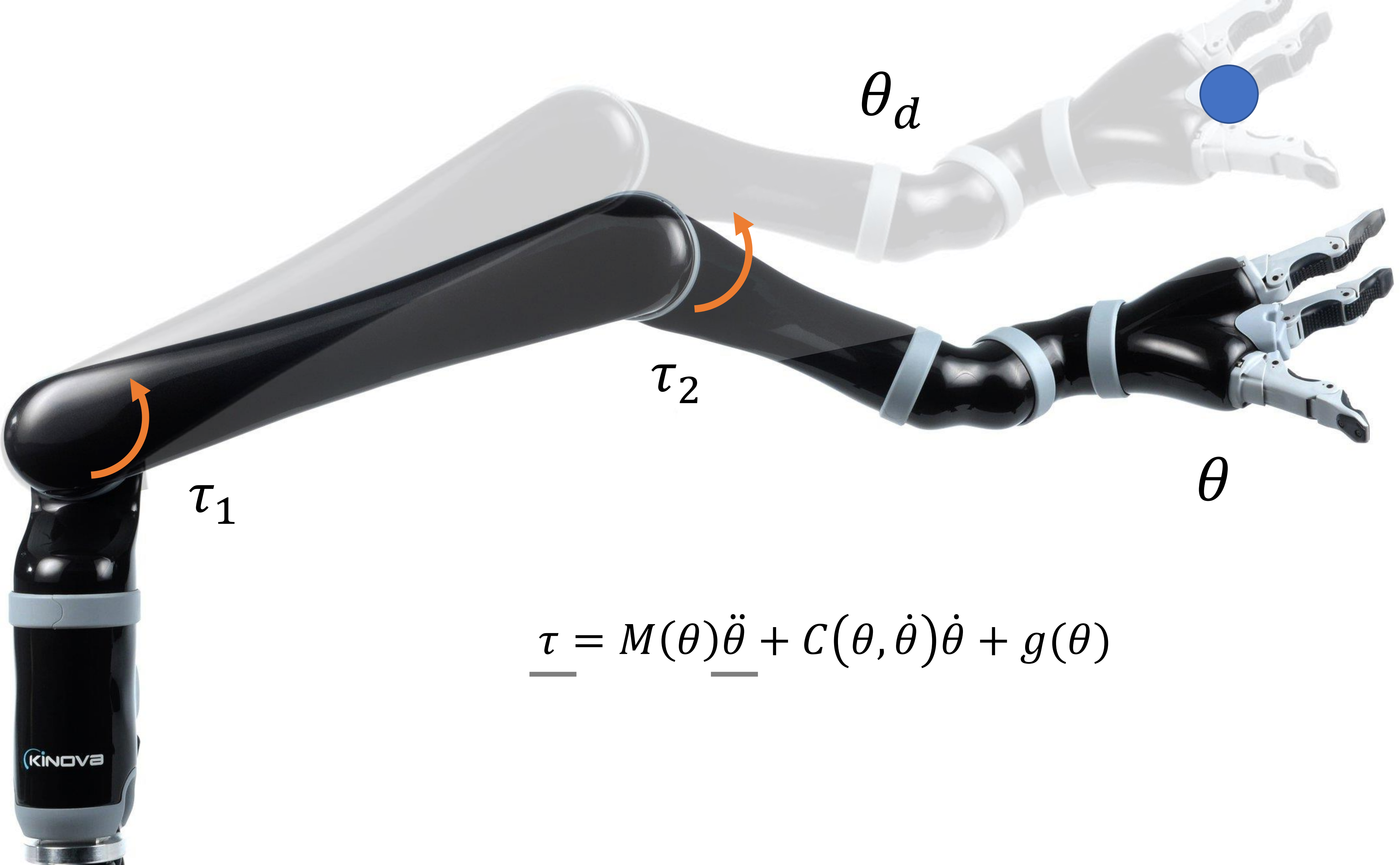
This Lecture

- Why use control?
- What are open-loop and closed-loop control?
- How do we start choosing a controller?

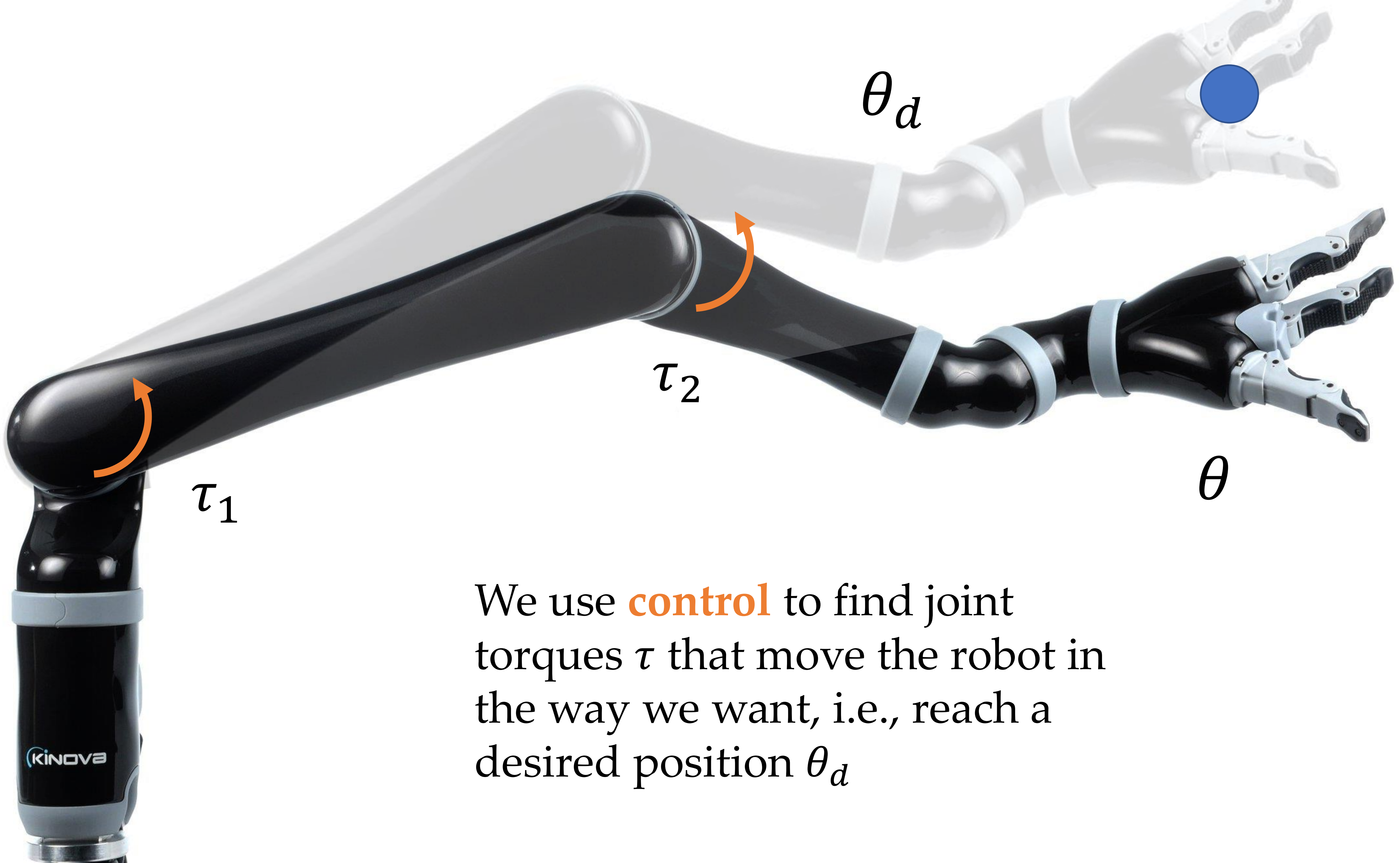

τ_1
τ_2
KINOVA



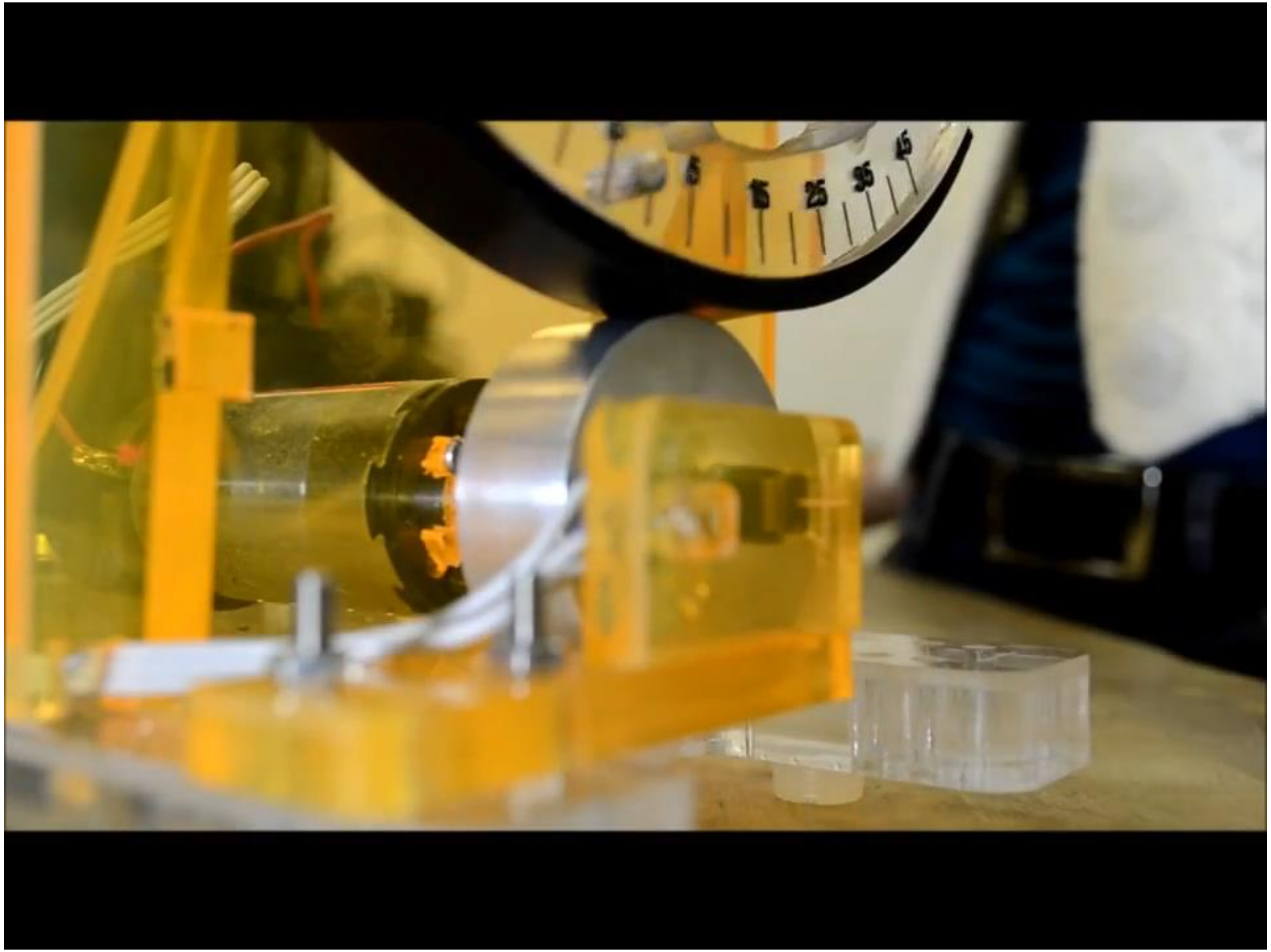
$$\underline{\tau} = M(\theta)\underline{\ddot{\theta}} + C(\theta, \dot{\theta})\dot{\theta} + g(\theta)$$



$$\underline{\tau} = M(\theta)\underline{\ddot{\theta}} + C(\theta, \dot{\theta})\dot{\theta} + g(\theta)$$



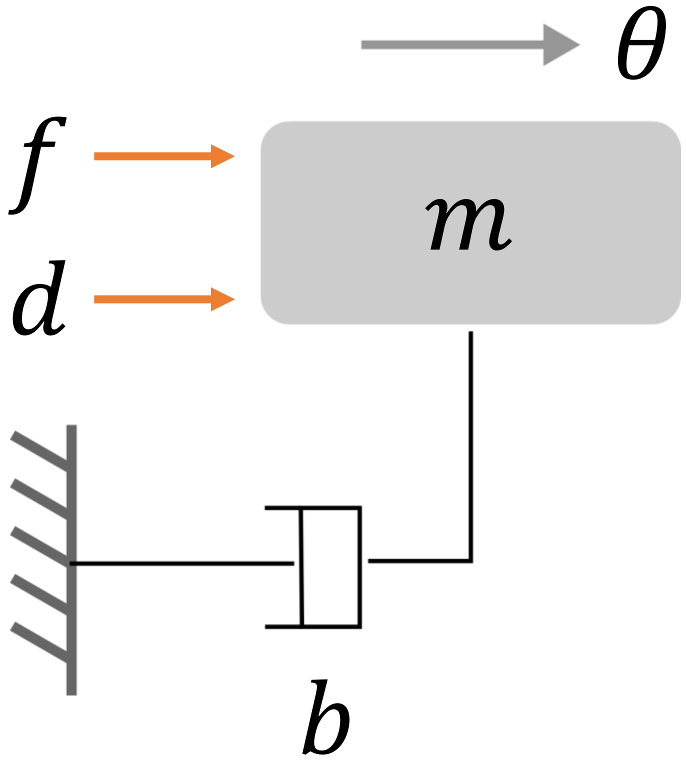
We use **control** to find joint torques τ that move the robot in the way we want, i.e., reach a desired position θ_d



Example

- 1-DoF Robot
- Model as a **mass-damper**
- f is the force applied by the actuator
- d is a disturbance force

What are the dynamics of this robot?

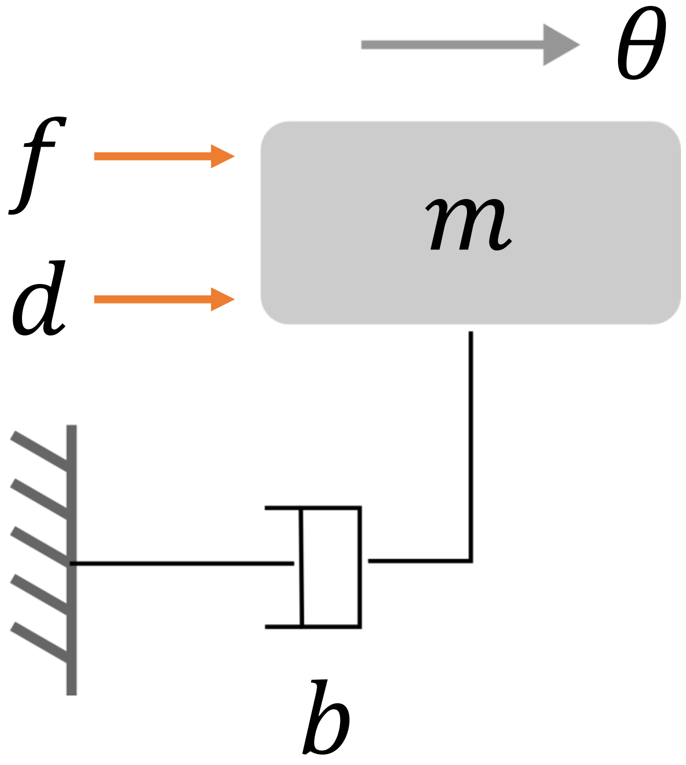


Example

- 1-DoF Robot
- Model as a **mass-damper**
- f is the force applied by the actuator
- d is a disturbance force

$$f(t) + d(t) = m\ddot{\theta}(t) + b\dot{\theta}(t)$$

Convert to Laplace domain

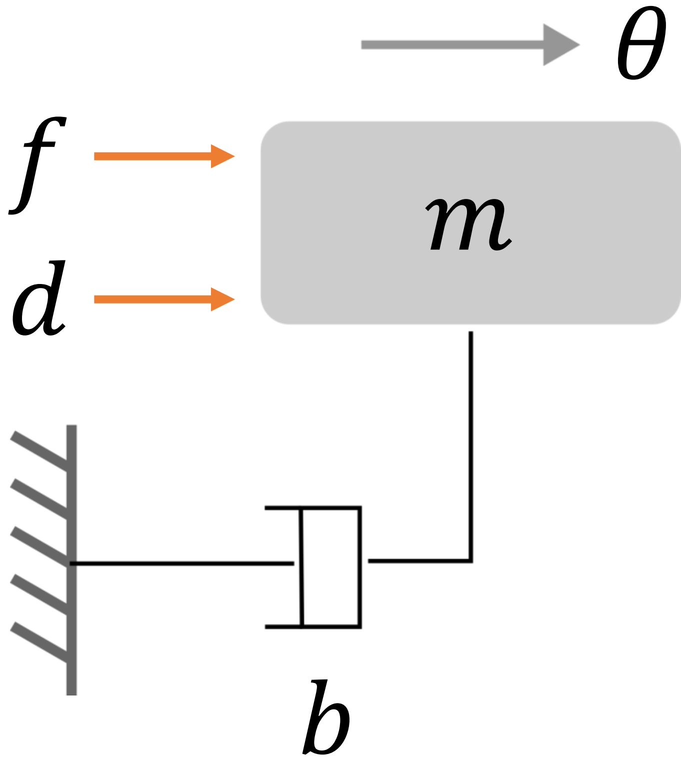


Example

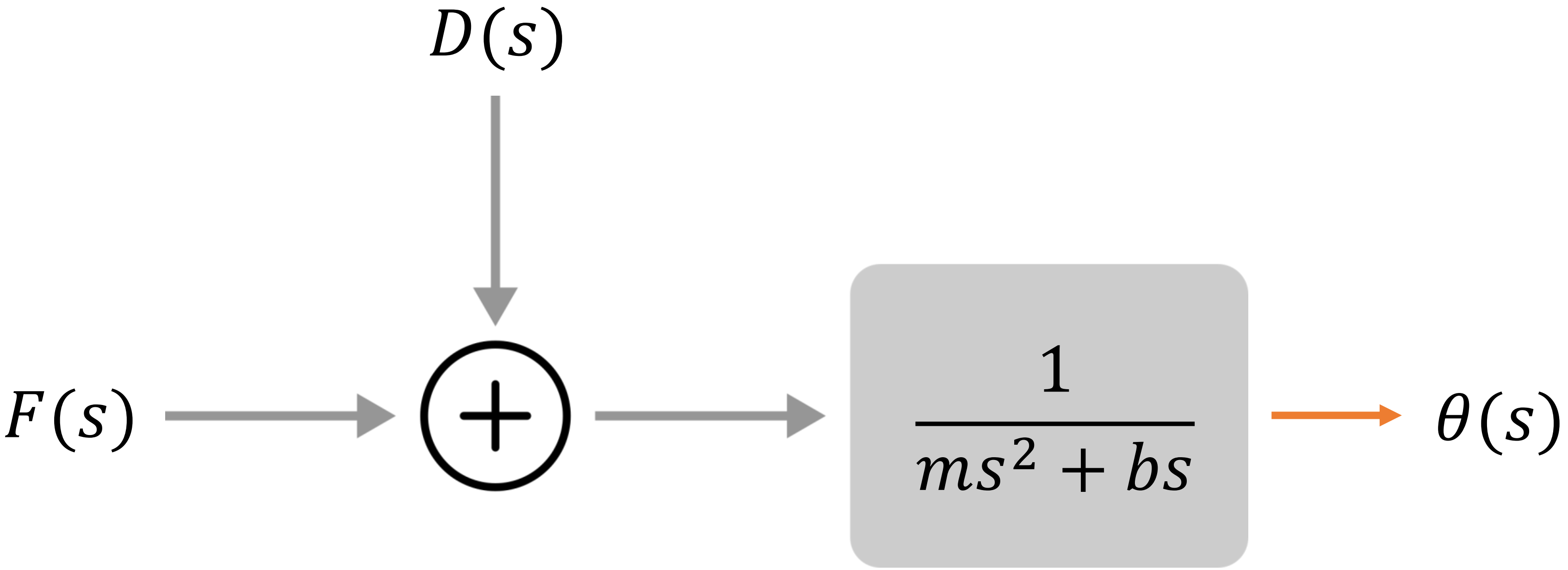
- 1-DoF Robot
- Model as a **mass-damper**
- f is the force applied by the actuator
- d is a disturbance force

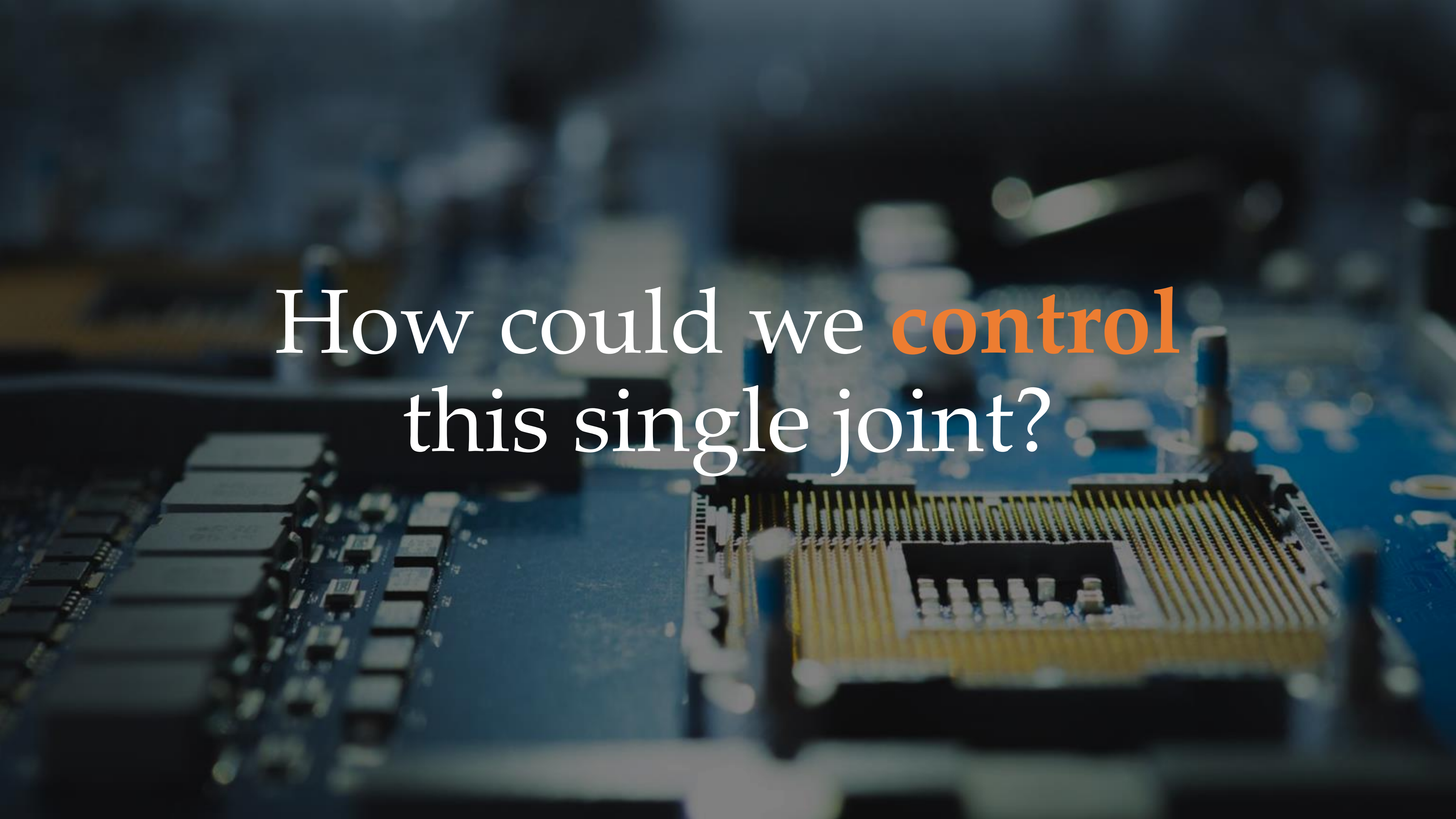
$$F(s) + D(s) = ms^2\theta(s) + bs\theta(s)$$

Convert to block diagram



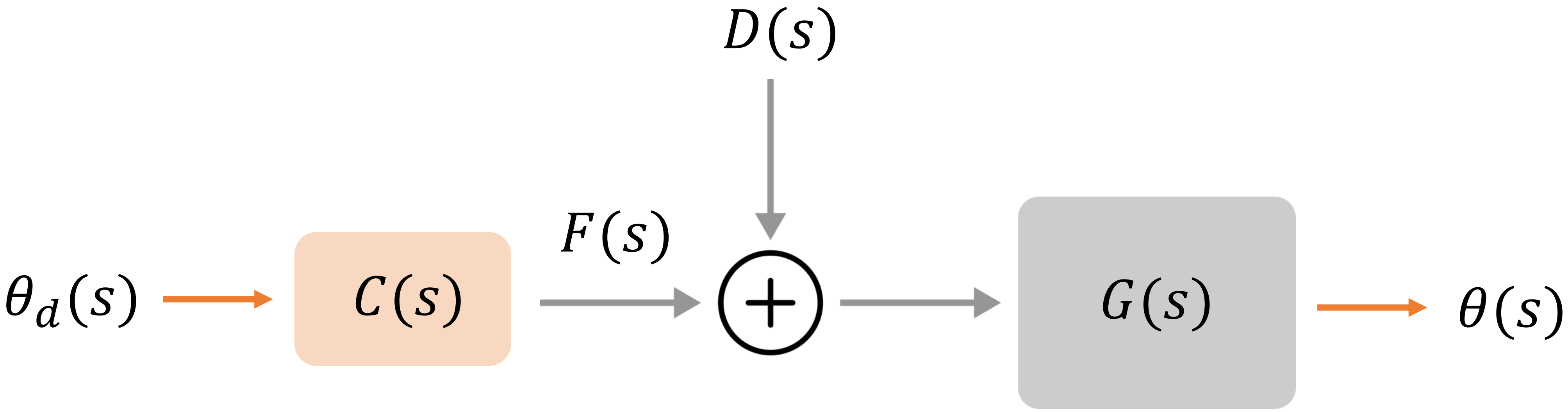
Example





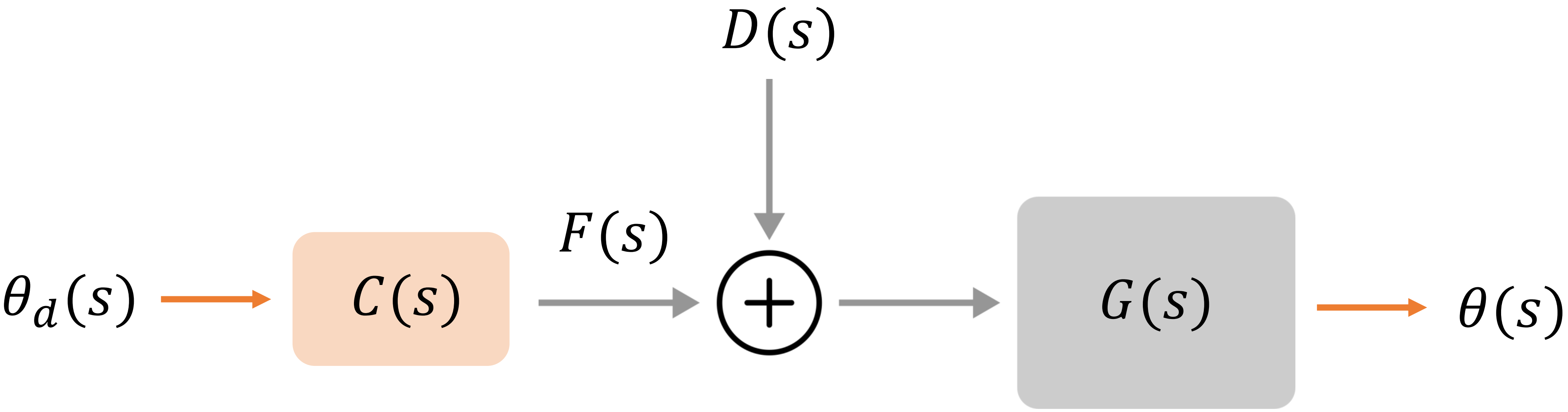
How could we **control** this single joint?

Open-Loop Control



$$\theta_d(s)C(s)G(s) + D(s)G(s) = \theta(s)$$

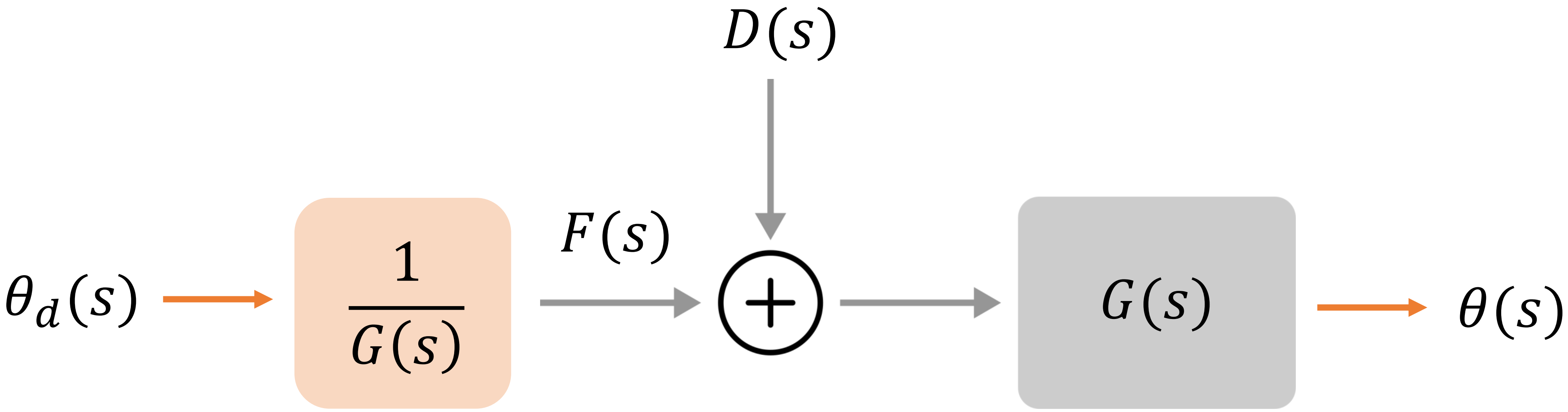
Open-Loop Control



$$\underbrace{\theta_d(s)C(s)G(s)}_{\text{Pick } C(s) \text{ so } \theta = \theta_d} + \cancel{D(s)G(s)} = \theta(s)$$

For the moment, assume $D = 0$

Open-Loop Control



$$\underline{\theta_d(s)} + D(s)G(s) = \theta(s)$$

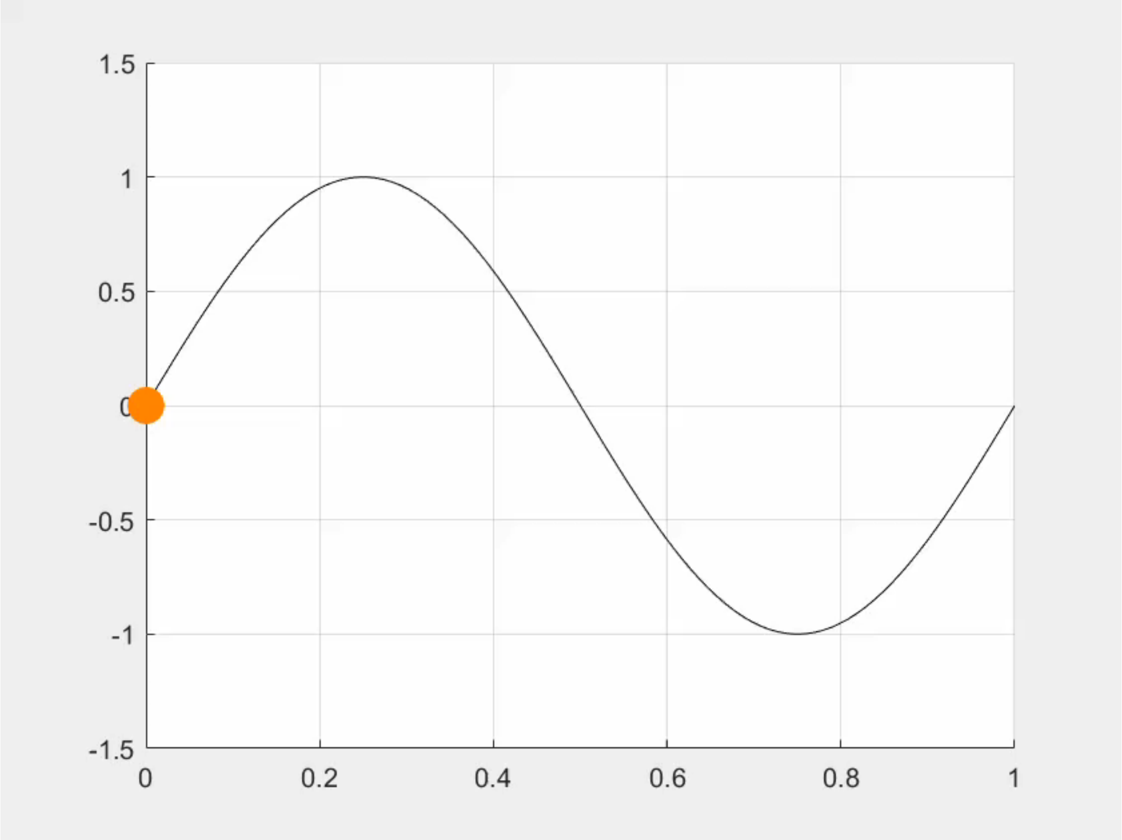
Pick $C(s) = \frac{1}{G(s)}$ *to cancel dynamics*

Open-Loop Control

1. Need accurate **model** of system.

$$C(s) = \frac{1}{G(s)} = ms^2 + bs$$

For 1-DoF robot example, need m and b exactly.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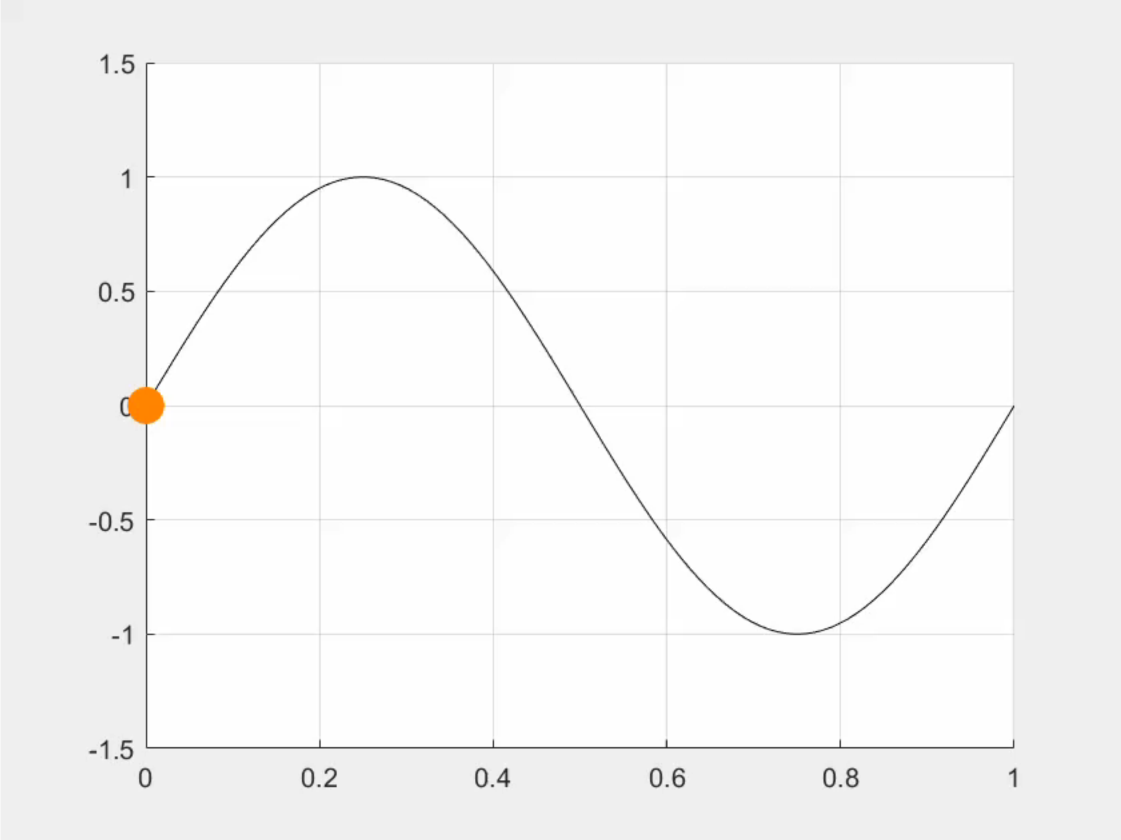
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Open-Loop Control

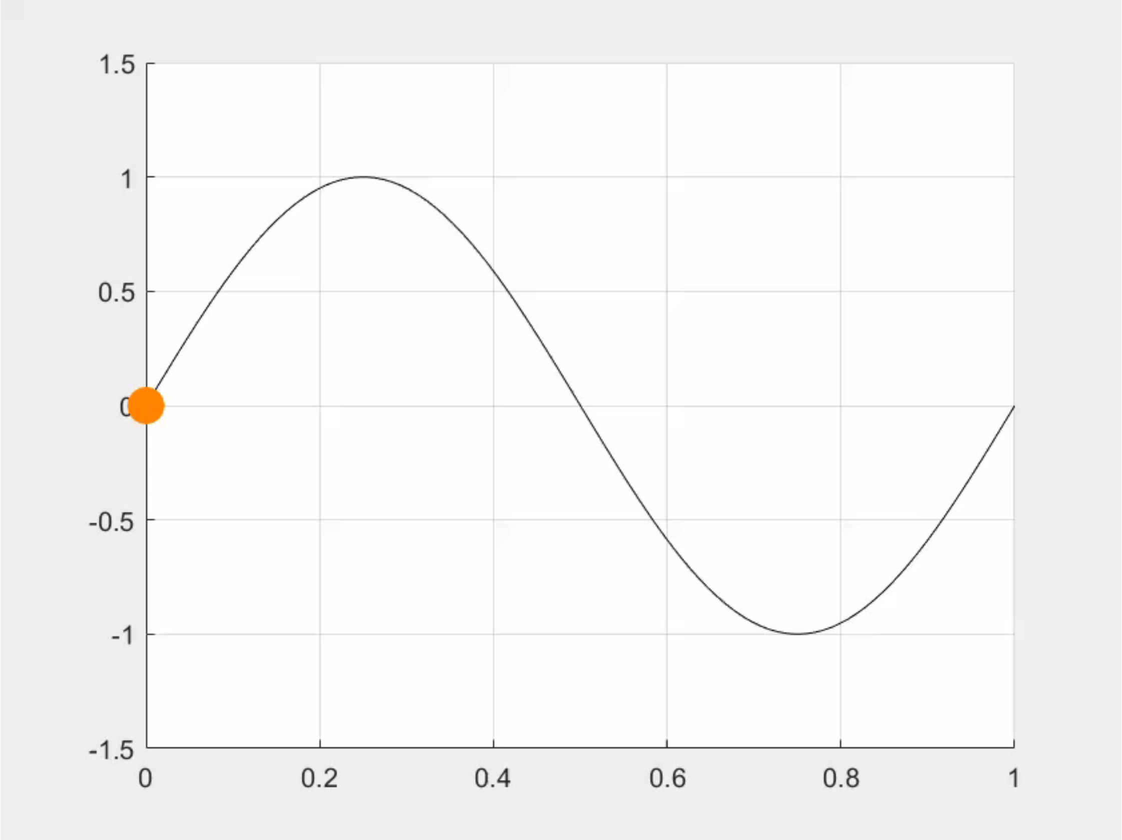
1. Need accurate **model** of system.

$$C(s) = \frac{1}{G(s)} = ms^2 + bs$$

2. Cannot deal with a **disturbance**.

$$\theta_d(s) \boxed{+ D(s)G(s)} = \theta(s)$$

External force moves system away from desired position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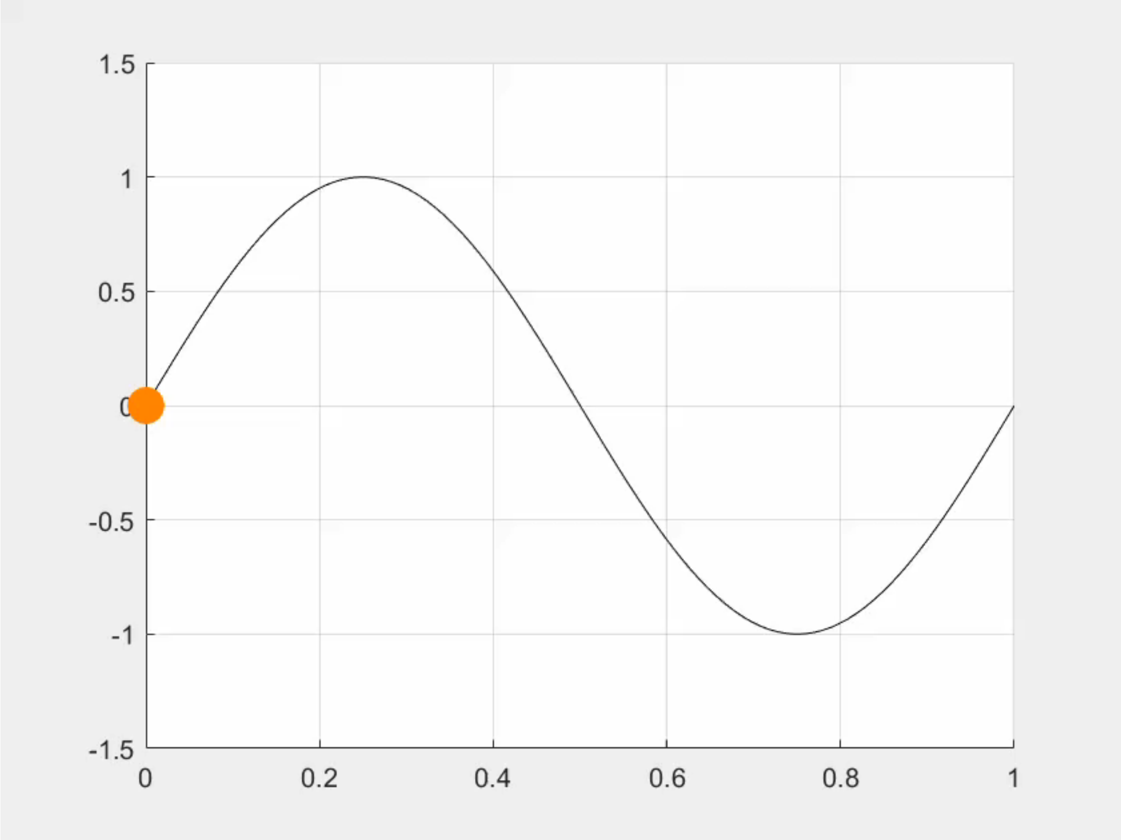
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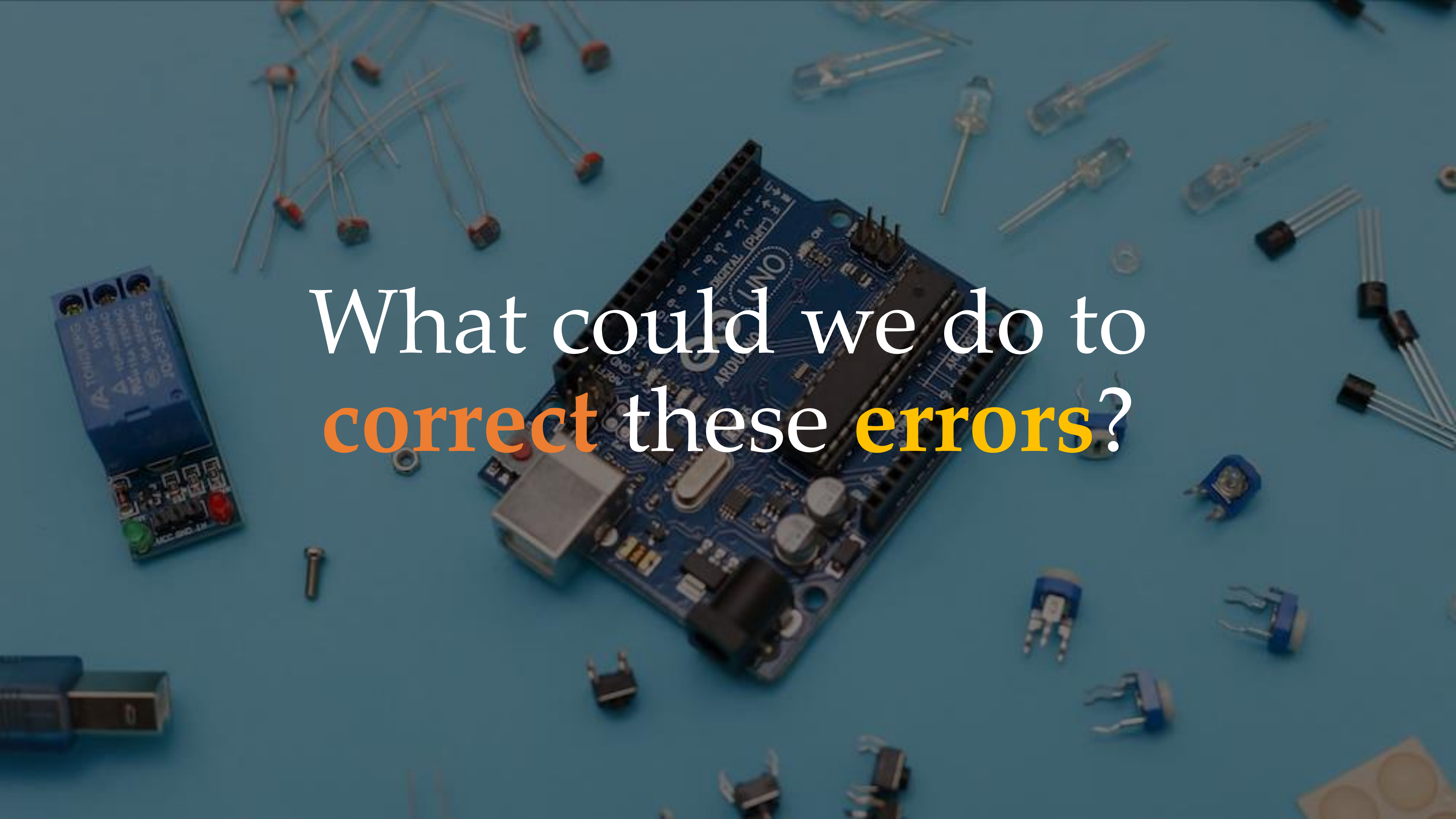
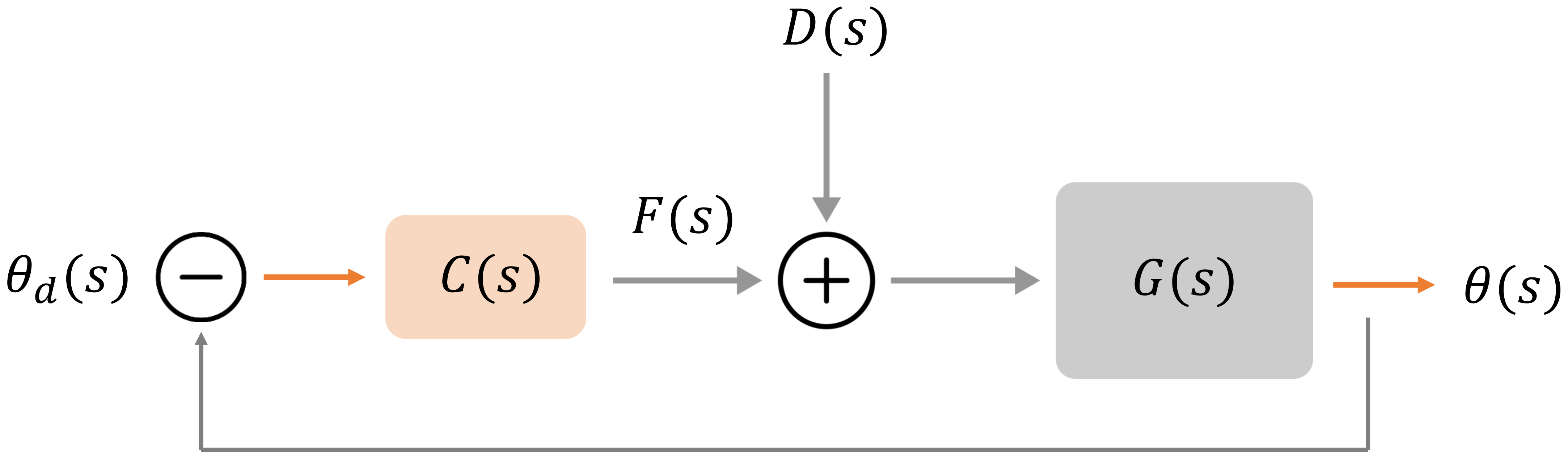


What could we do to **correct** these **errors**?

Closed-Loop Control



Measure the joint position θ, base control decisions on $(\theta_d - \theta)$
Need an accurate sensor here

Closed-Loop Control

$$\theta(s) = \frac{C(s)G(s)}{1 + C(s)G(s)}\theta_d(s) + \frac{G(s)}{1 + C(s)G(s)}D(s)$$

Ideally $\rightarrow 1$ *so that*
$\theta = \theta_d$

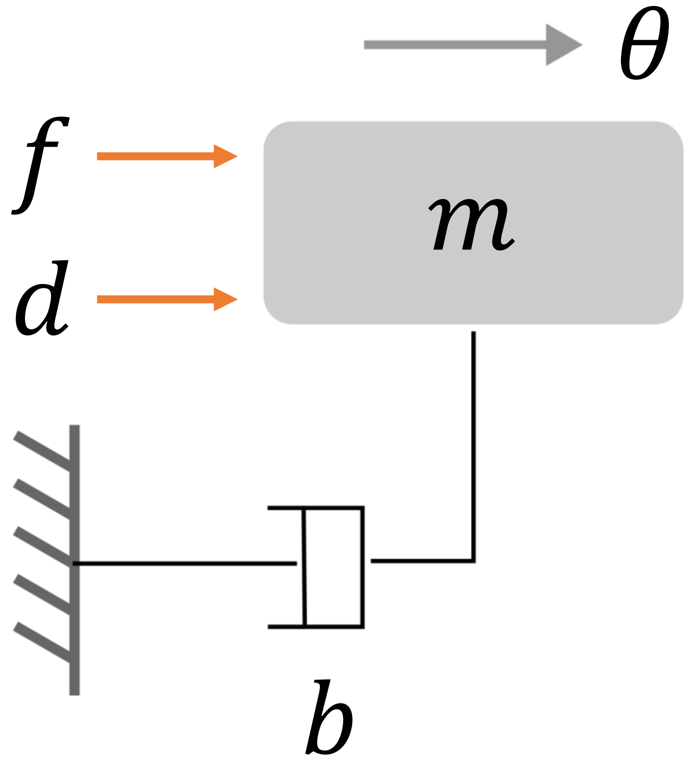
Ideally $\rightarrow 0$ *so that*
disturbances do not affect θ

Example

Find a controller that drives $\theta \to \theta_d$ while rejecting disturbances.

$$G(s) = \frac{1}{ms^2 + bs}$$

$$\theta(s) = \frac{C(s)G(s)}{1 + C(s)G(s)}\theta_d(s) + \frac{G(s)}{1 + C(s)G(s)}D(s)$$

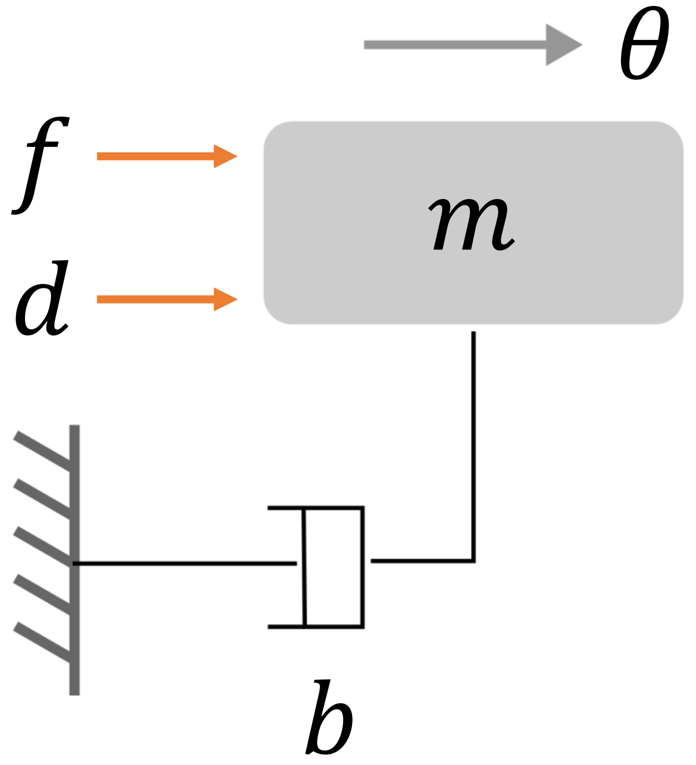


Example

Find a controller that drives $\theta \to \theta_d$ while rejecting disturbances.

$$G(s) = \frac{1}{ms^2 + bs}$$

$$\theta(s) = \frac{C(s)}{ms^2 + bs + C(s)}\theta_d(s) + \frac{1}{ms^2 + bs + C(s)}D(s)$$



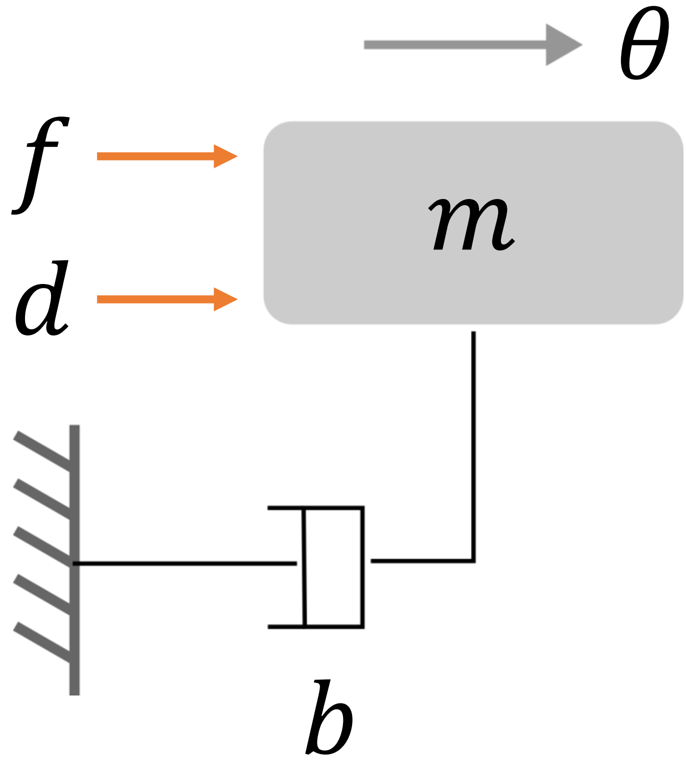
Example

Find a controller that drives $\theta \to \theta_d$ while rejecting disturbances.

$$\theta(s) = \frac{C(s)}{ms^2 + bs + C(s)}\theta_d(s) + \frac{1}{ms^2 + bs + C(s)}D(s)$$

Try $C(s) = k_p$ so that the actuator force is:

$$\boxed{f = k_p(\theta_d - \theta)}$$



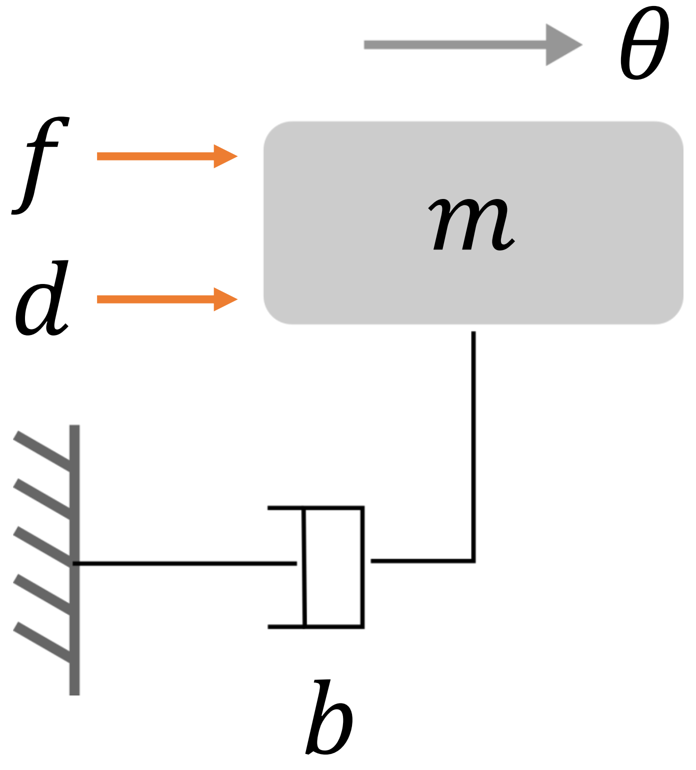
Example

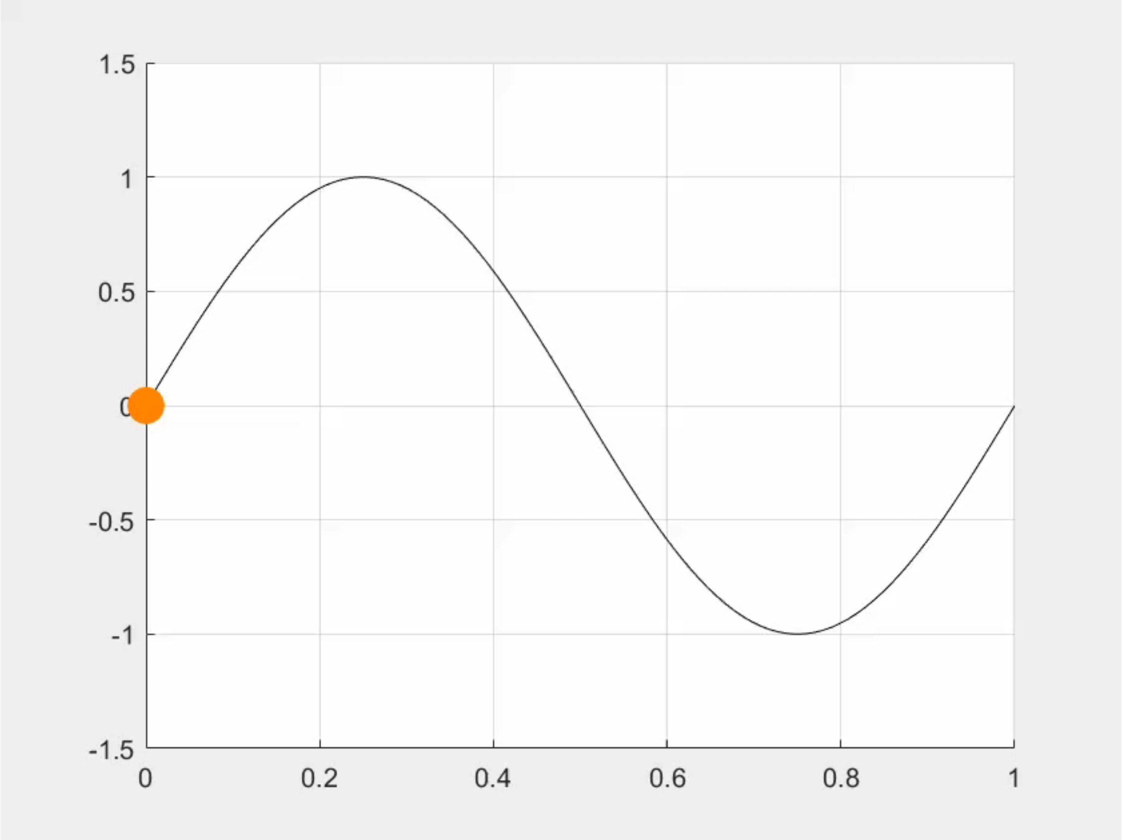
Find a controller that drives $\theta \rightarrow \theta_d$ while rejecting disturbances.

$$\theta(s) = \frac{\boldsymbol{k_p}}{ms^2 + bs + \boldsymbol{k_p}}\theta_d(s) + \frac{\mathbf{1}}{ms^2 + bs + \boldsymbol{k_p}}D(s)$$

Approaches $\frac{k_p}{k_p} = 1$ as the control gain increases

Approaches $\frac{1}{k_p} = 0$ as the control gain increases

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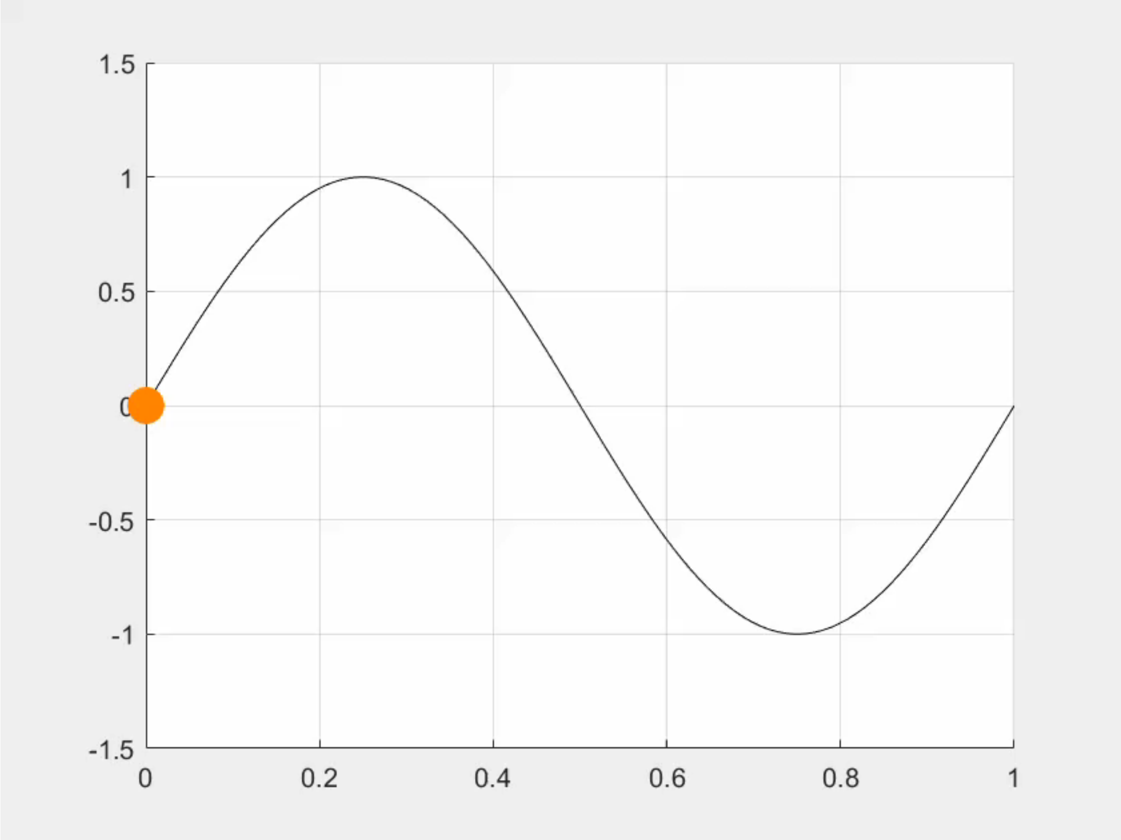
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What are some challenges for closed-loop control?

This Lecture

- Why use control?
- What are open-loop and closed-loop control?
- How do we start choosing a controller?

Next Lecture

- How do we know if a controller is stable?
- How do we extend this to multi-DoF robot arms?