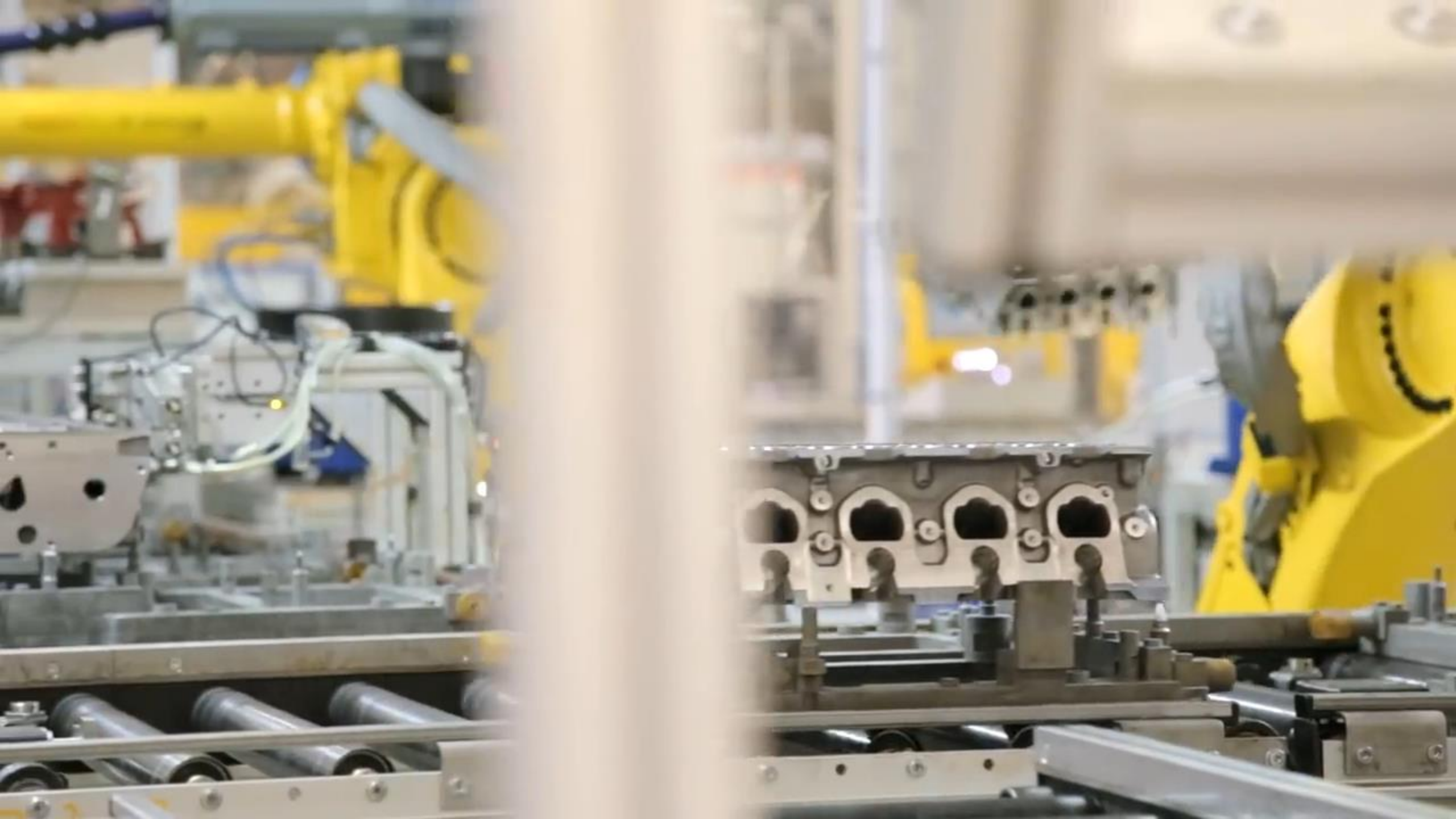


Control Review



Reading: Robot Modeling and Control 6.2, 6.3, 6.4

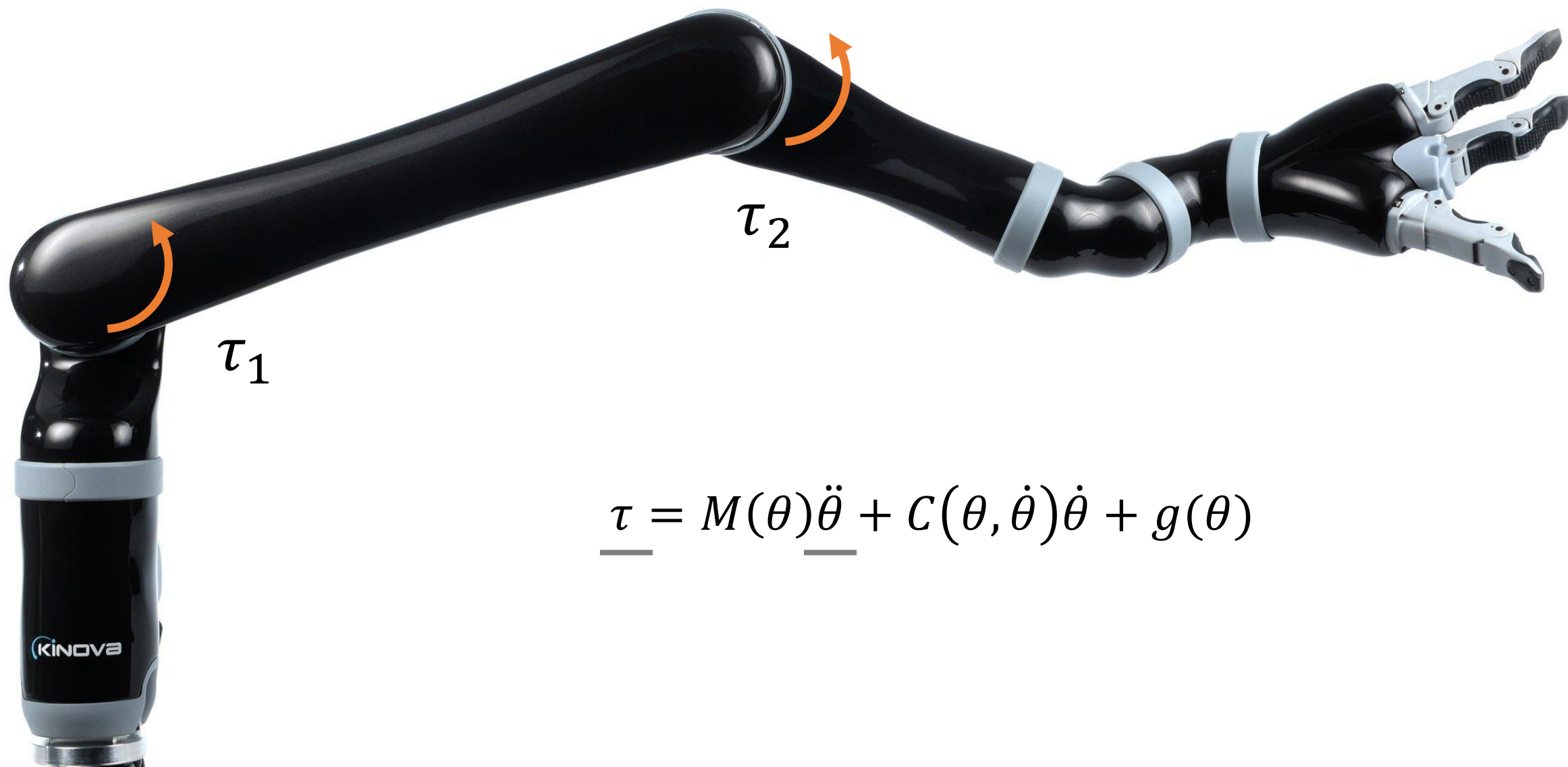


This Lecture

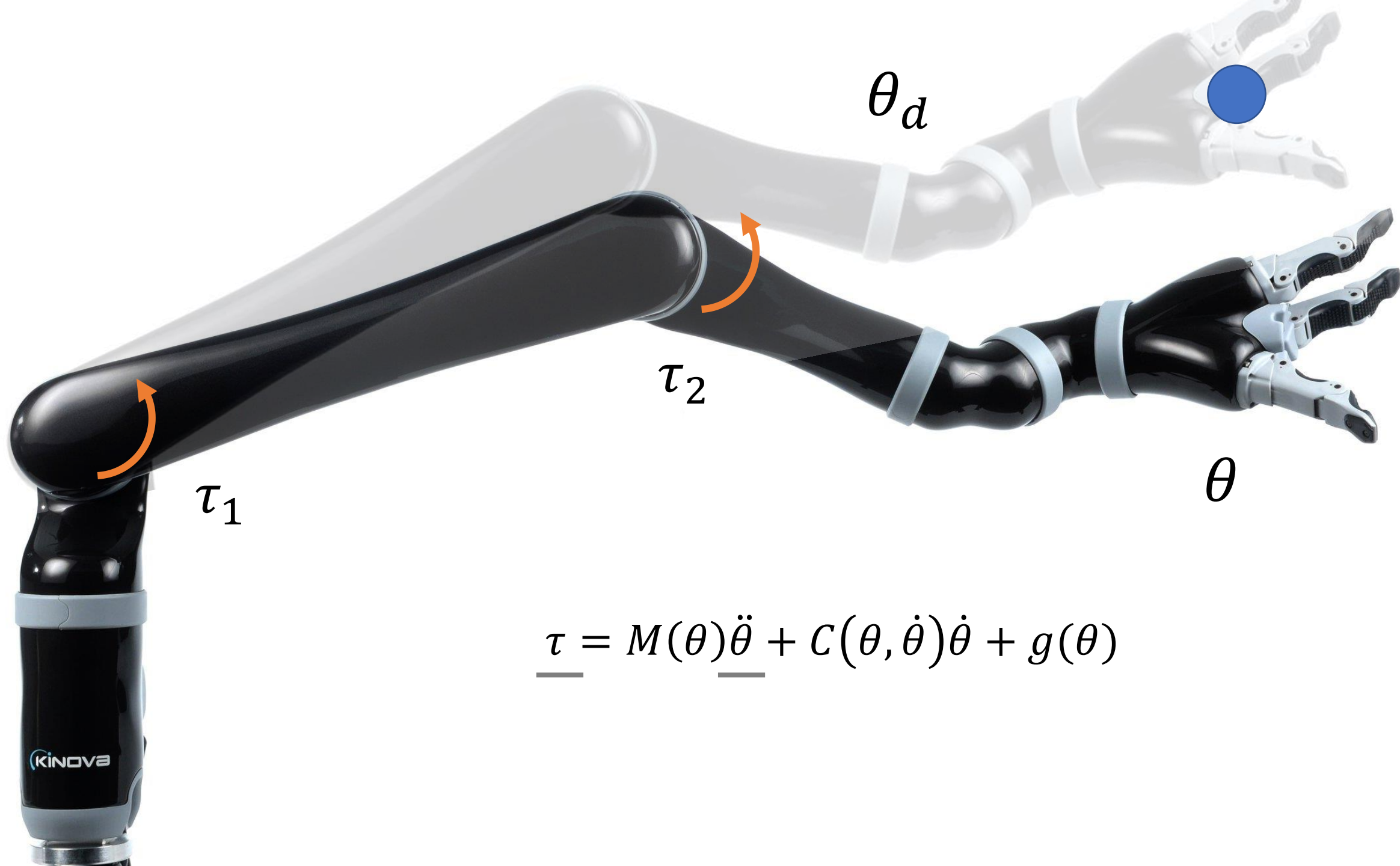


- Why use control?
- What are open-loop and closed-loop control?
- How do we start choosing a controller?

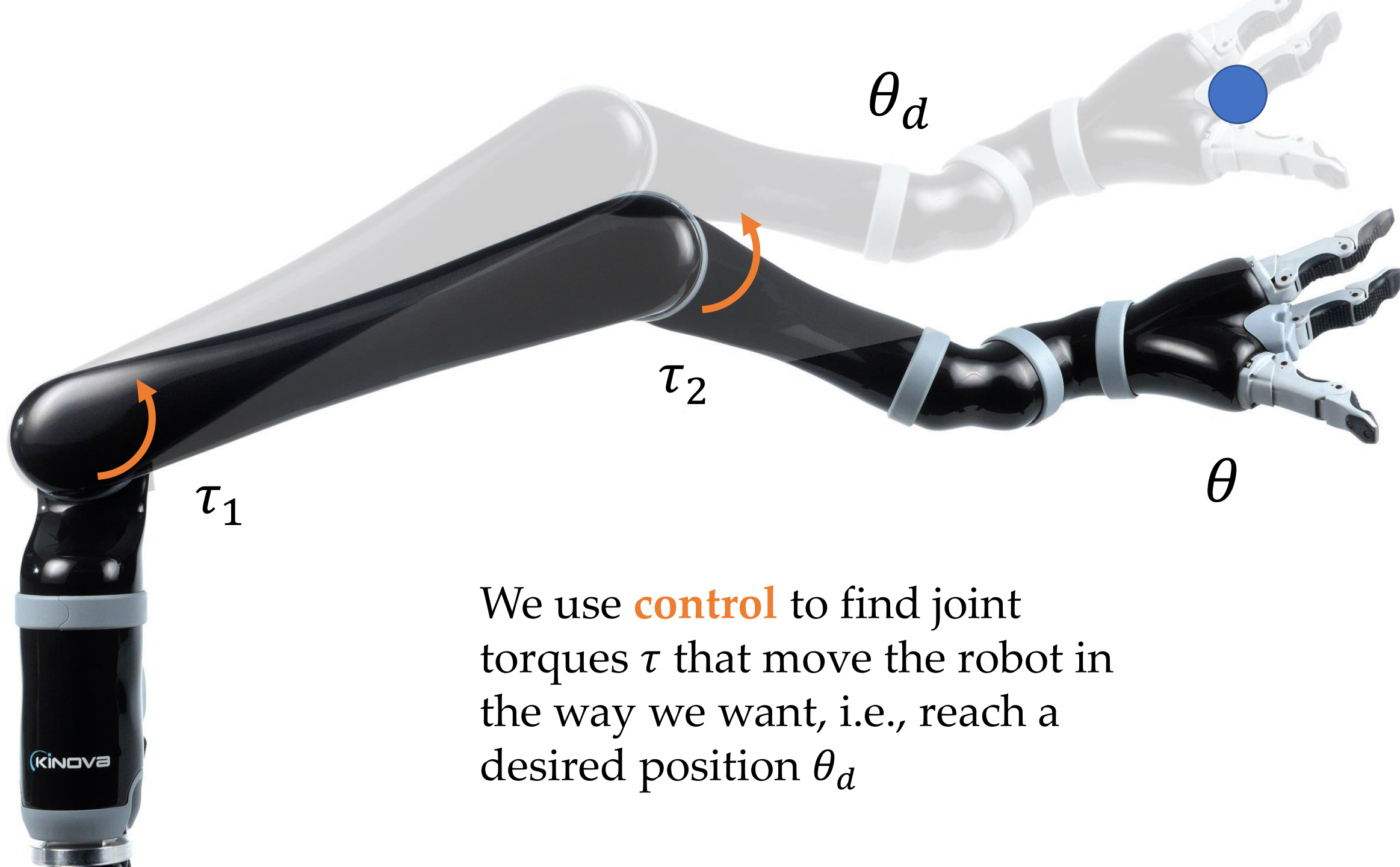




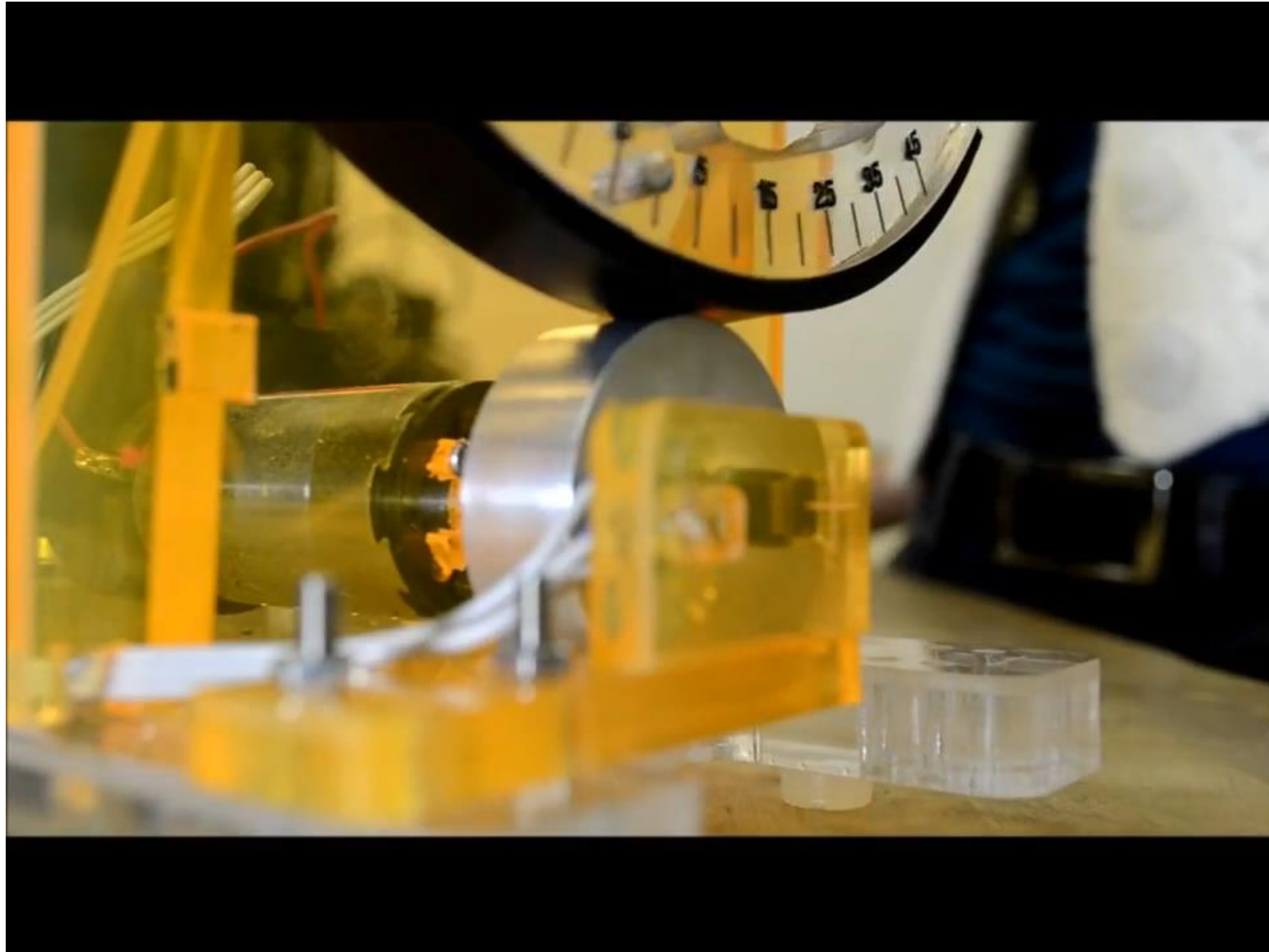
$$\underline{\tau} = M(\theta)\underline{\ddot{\theta}} + C(\theta, \dot{\theta})\dot{\theta} + g(\theta)$$



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



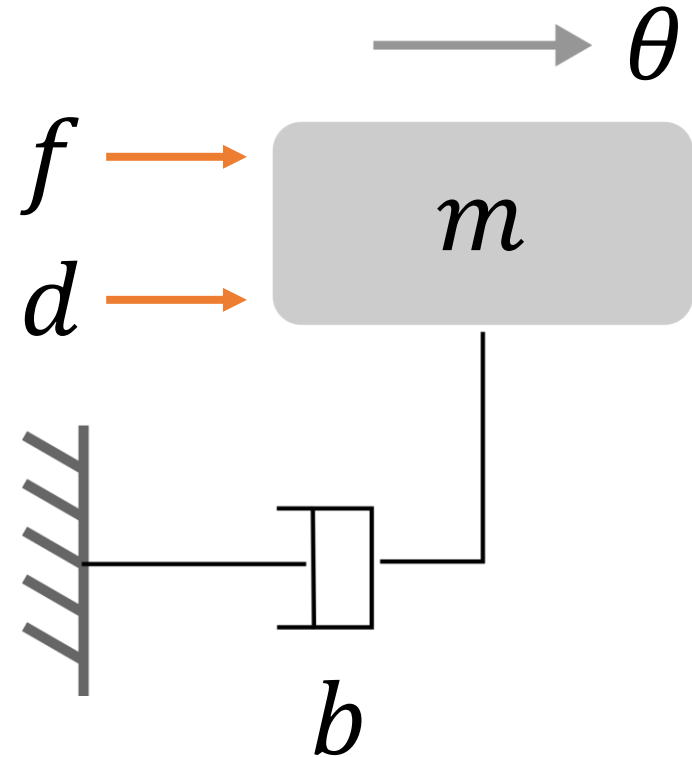
We use **control** to find joint torques τ that move the robot in the way we want, i.e., reach a desired position θ_d



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?

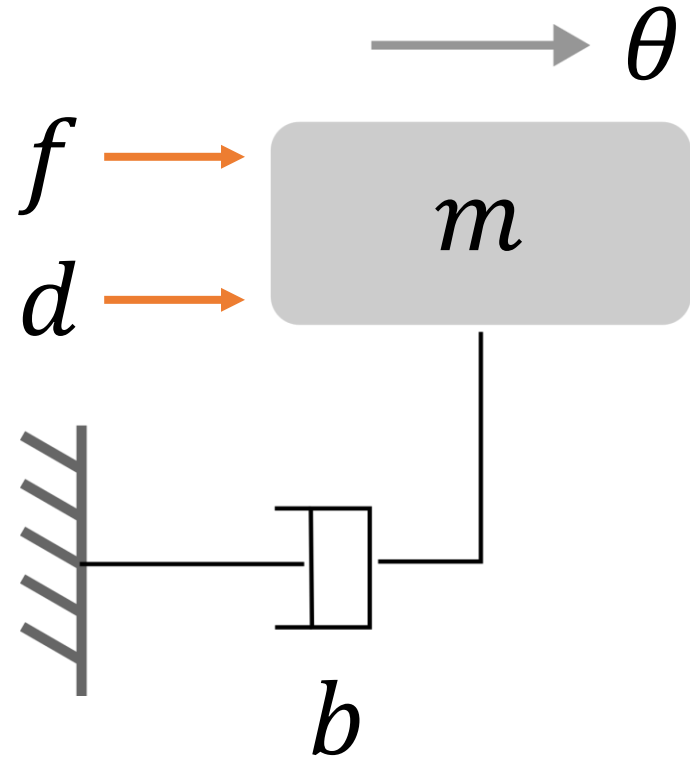


Example

- 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

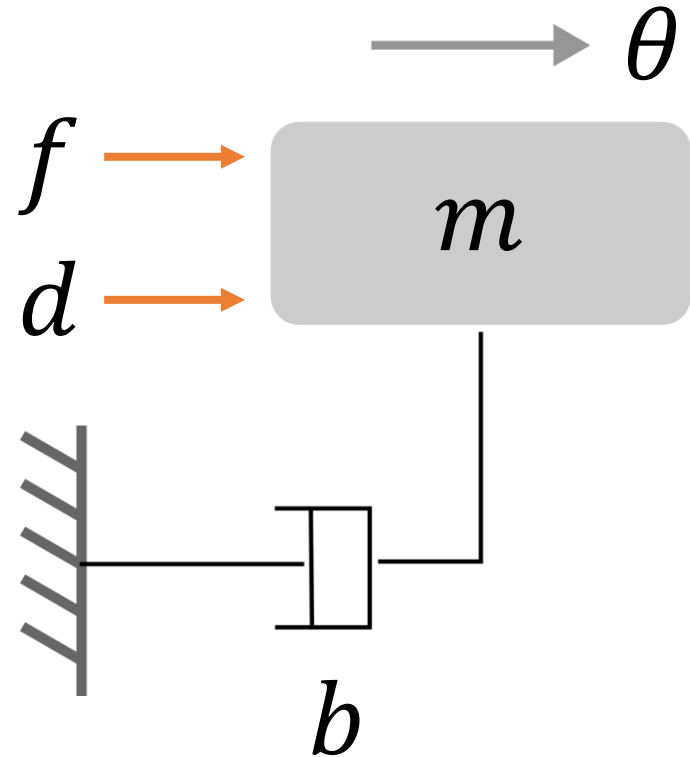


Example

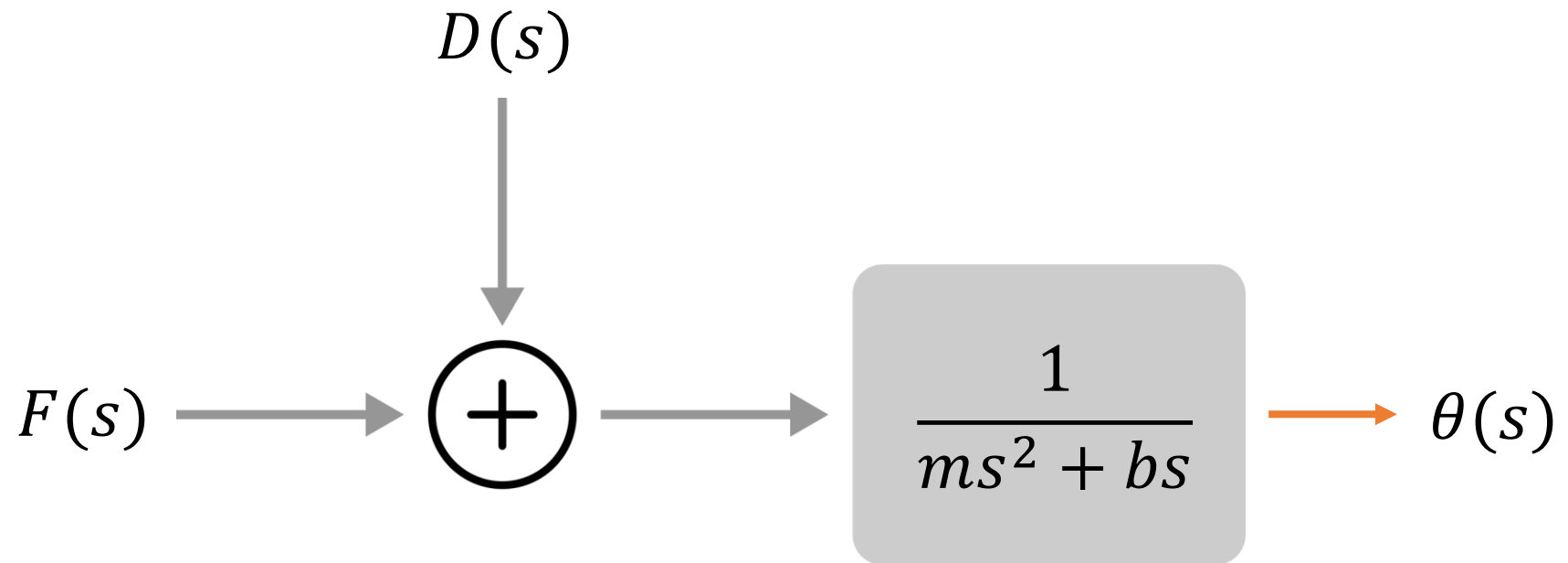
- 1-DoF Robot
- Model as a **mass-damper**
- f is the force applied by the actuator
- d is a disturbance force

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

Convert to block diagram



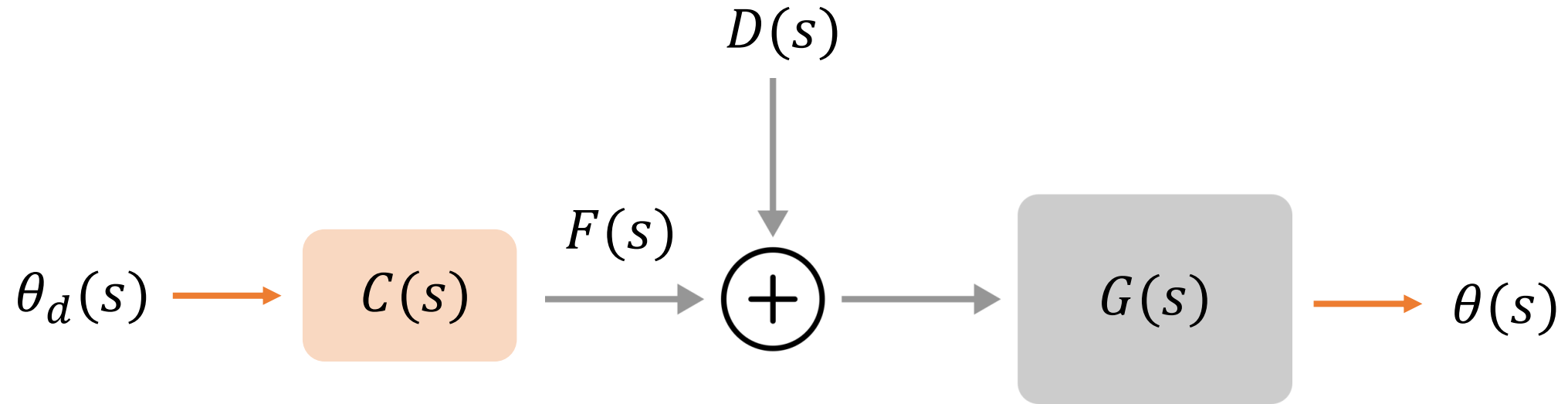
Example





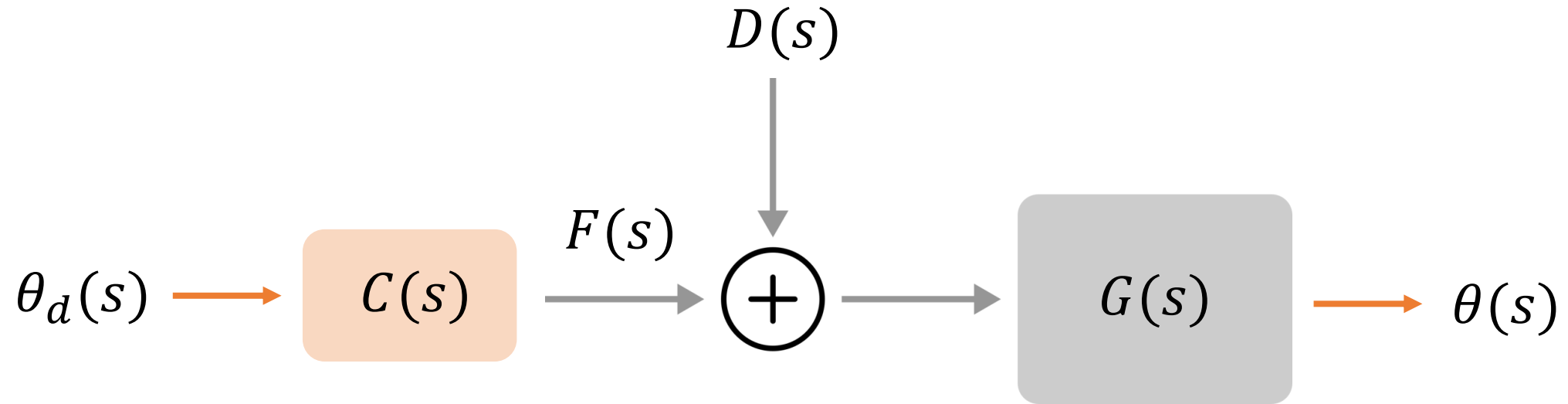
How could we **control**
this single joint?

Open-Loop Control



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

Open-Loop Control

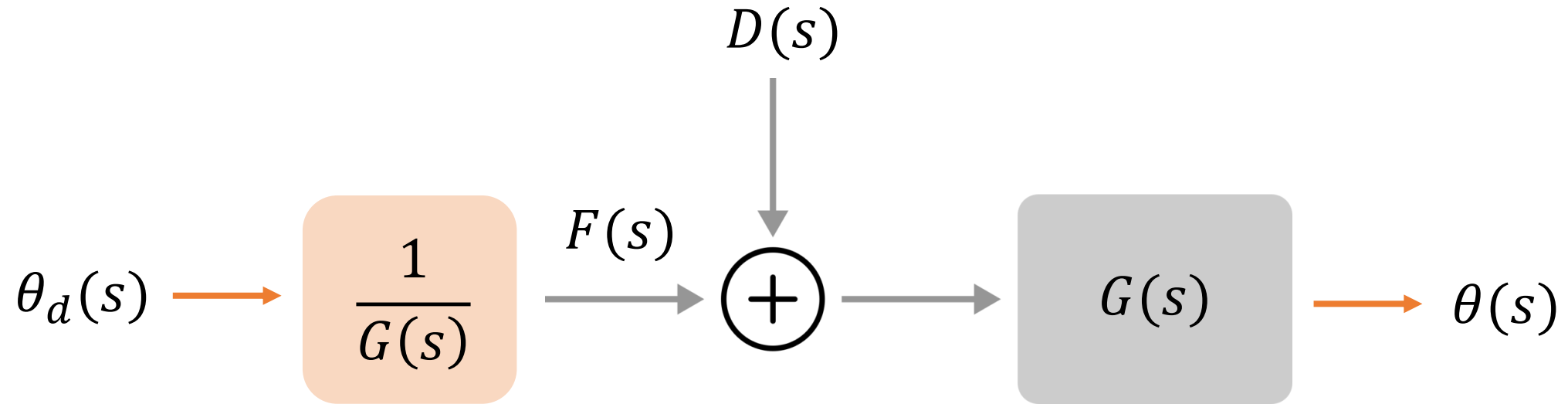


$$\theta_d(s)C(s)G(s) + D(s)G(s) = \theta(s)$$

Pick $C(s)$ so $\theta = \theta_d$

For the moment, assume $D = 0$

Open-Loop Control



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

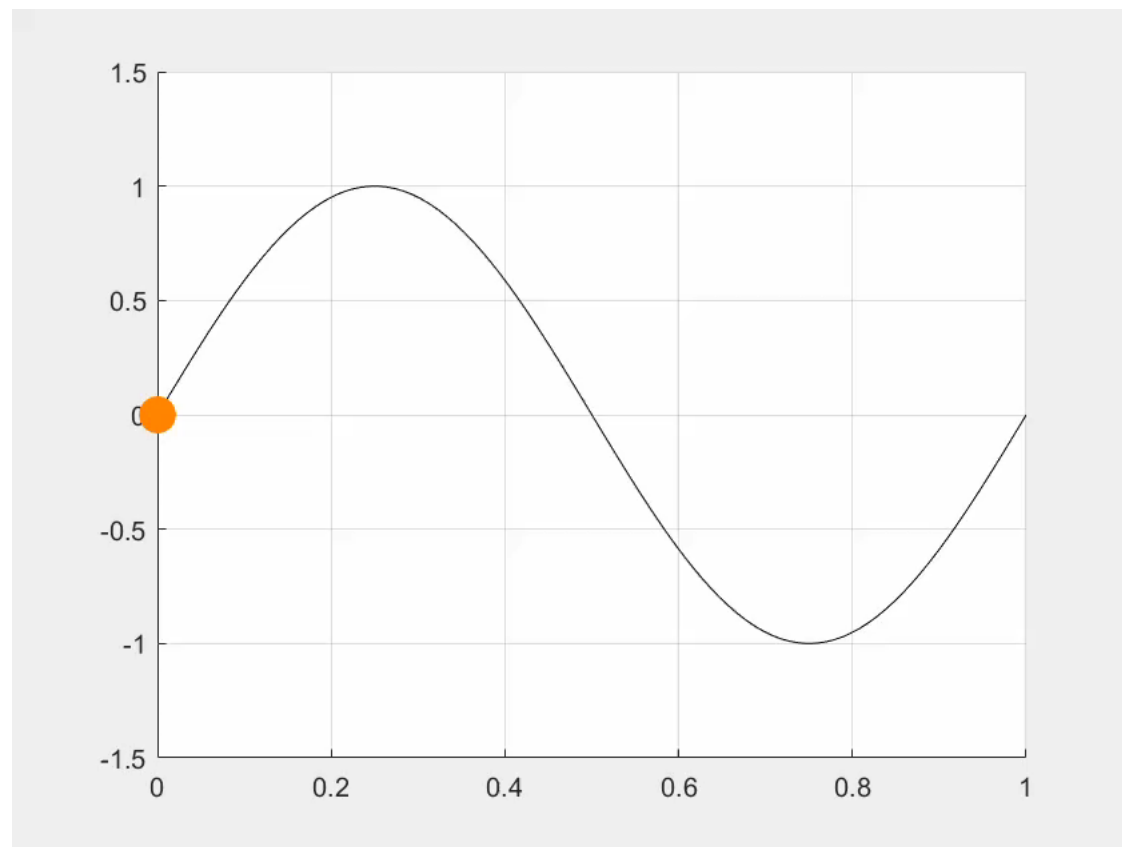
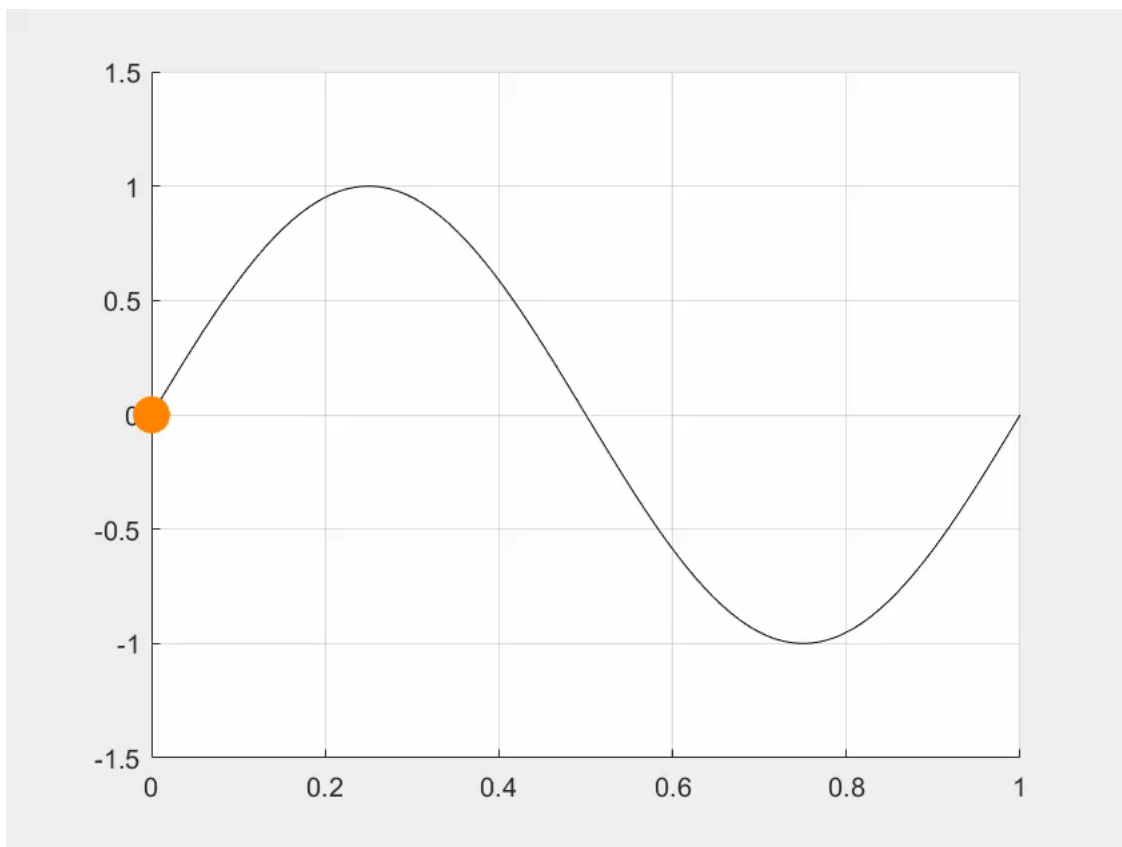
Pick $C(s) = \frac{1}{G(s)}$ to cancel dynamics

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.



Open-Loop Control

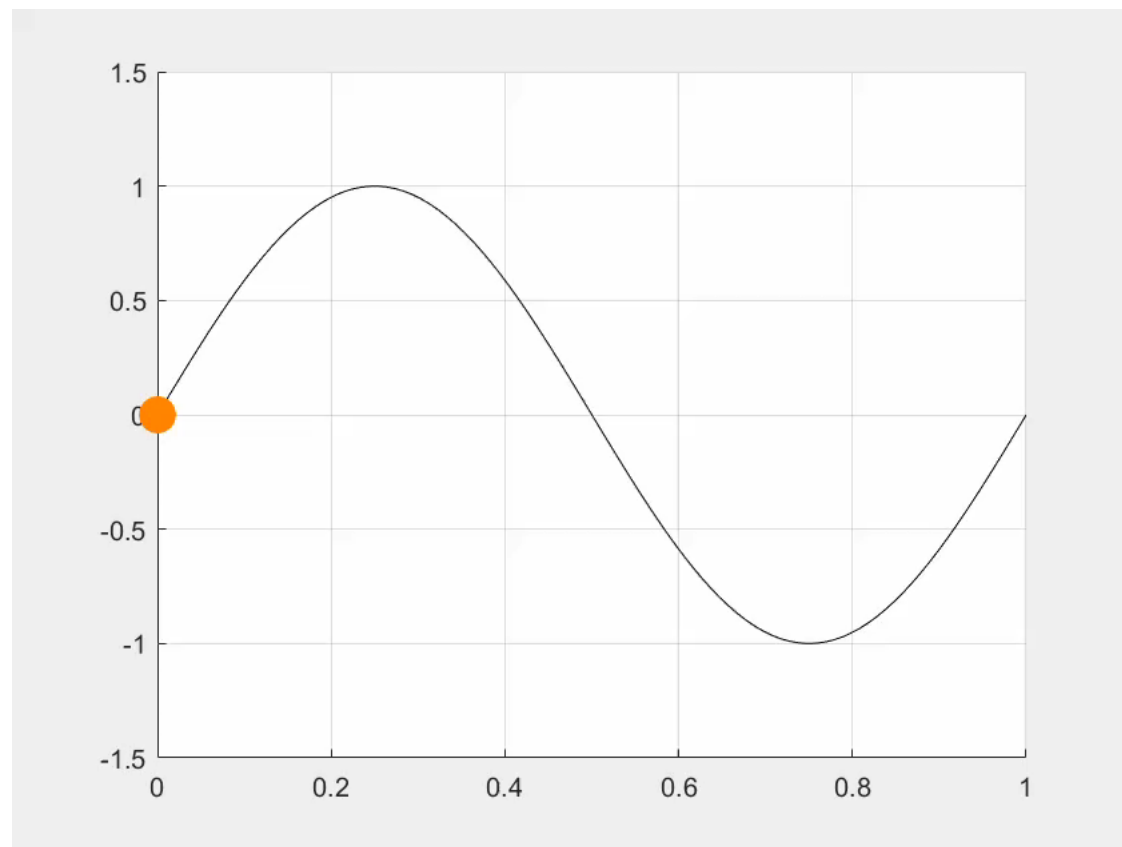
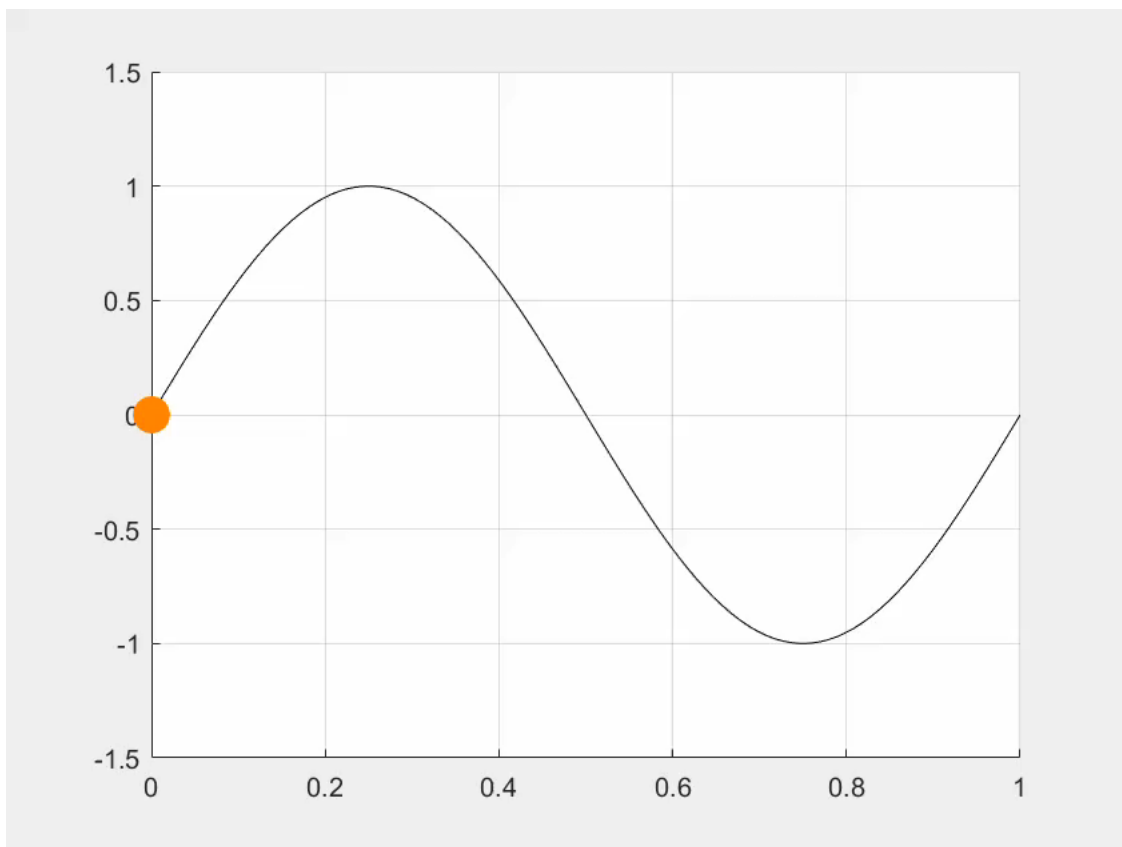
1. Need accurate **model** of system.

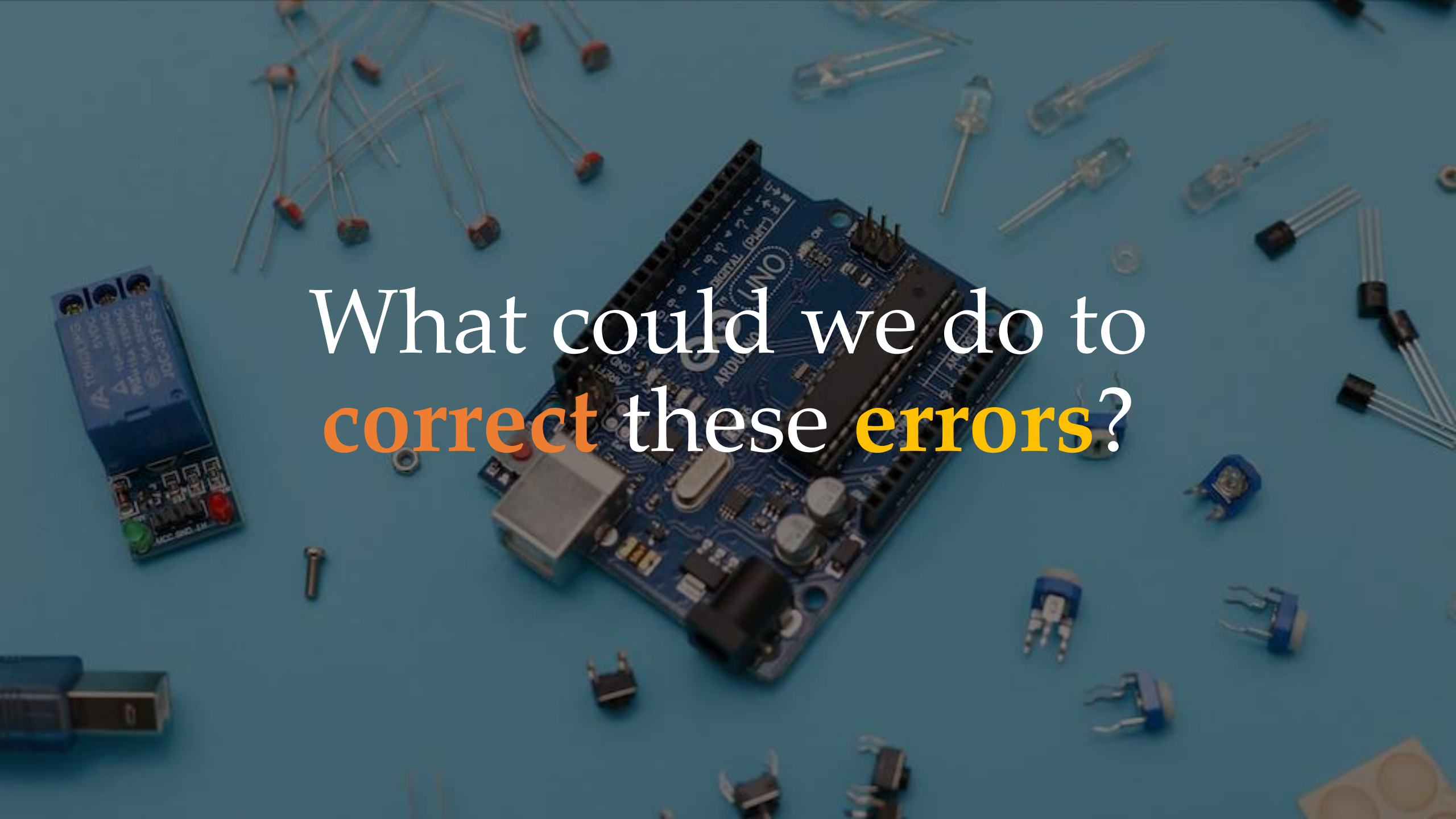
$$C(s) = \frac{1}{G(s)} = ms^2 + bs$$

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

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

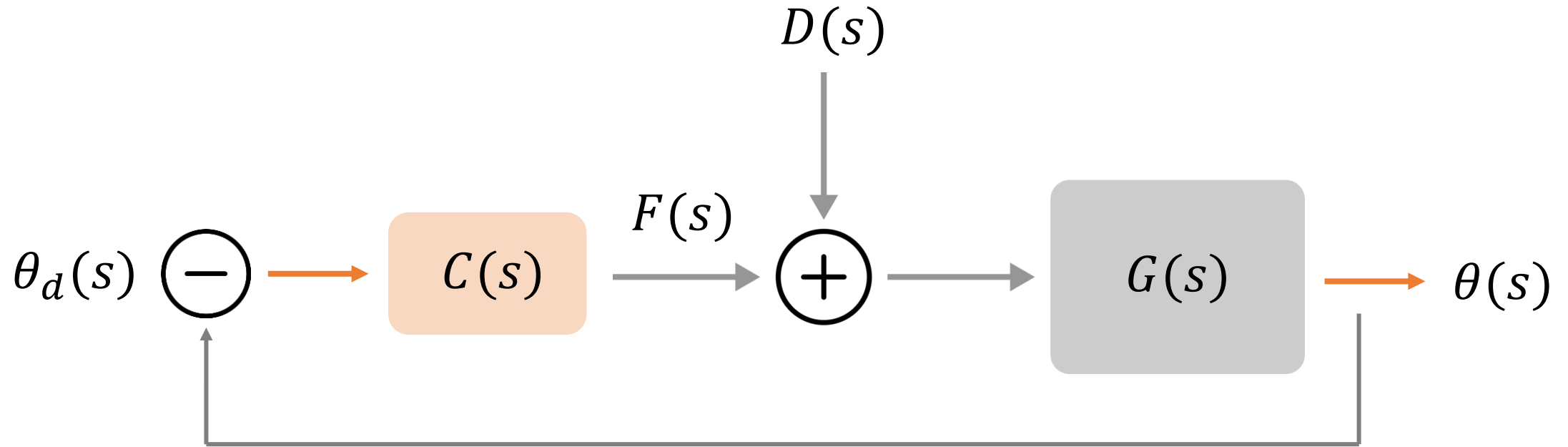
External force moves system
away from desired position



The background of the image is a solid blue surface. Scattered across this surface are various electronic components. In the upper left, there is a cluster of resistors with different colored bands. To the right of the resistors, several small, clear LEDs are visible. In the center, an Arduino Uno microcontroller board is prominently displayed, showing its various pins, a USB Type-B port, and a DC power jack. To the left of the Arduino, there is a blue USB Type-A to Type-B cable. In the lower right, there are several small, blue, three-pin components, possibly sensors or small modules. The text "What could we do to correct these errors?" is overlaid on the image, with "correct" in orange and "errors" in yellow, while the rest of the text is white. The text is centered horizontally and vertically.

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
 $\theta = \theta_d$*

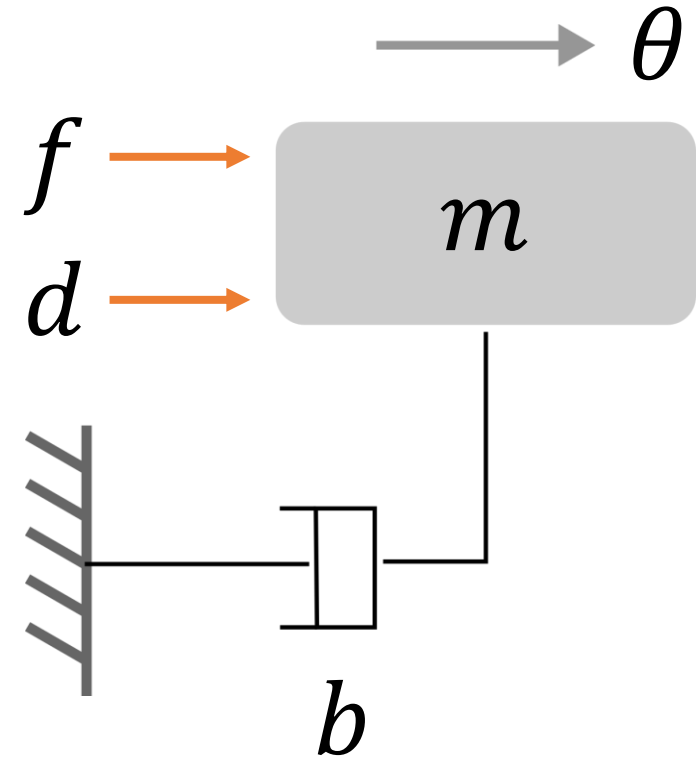
*Ideally $\rightarrow 0$ so that
disturbances do not affect θ*

Example

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

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

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

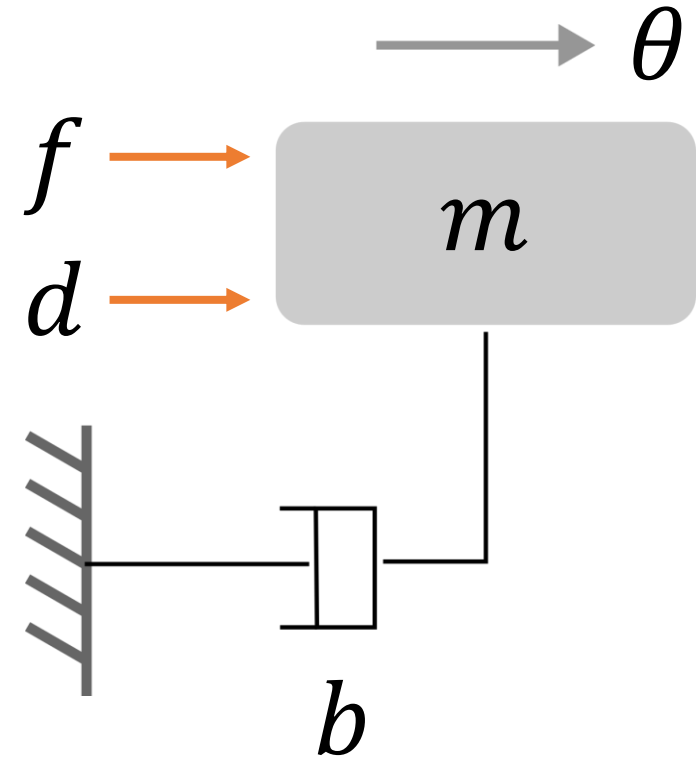


Example

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

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

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



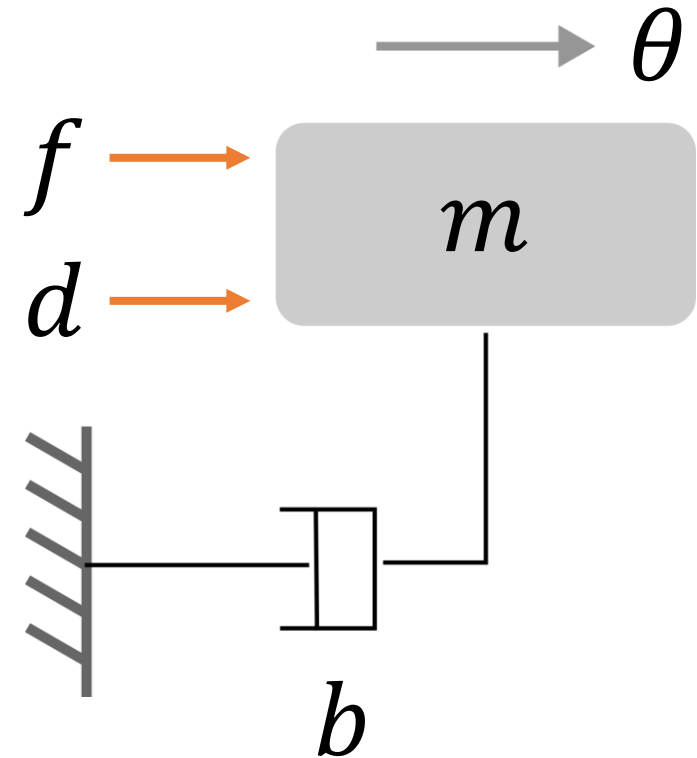
Example

Find a controller that drives $\theta \rightarrow \theta_d$ 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:

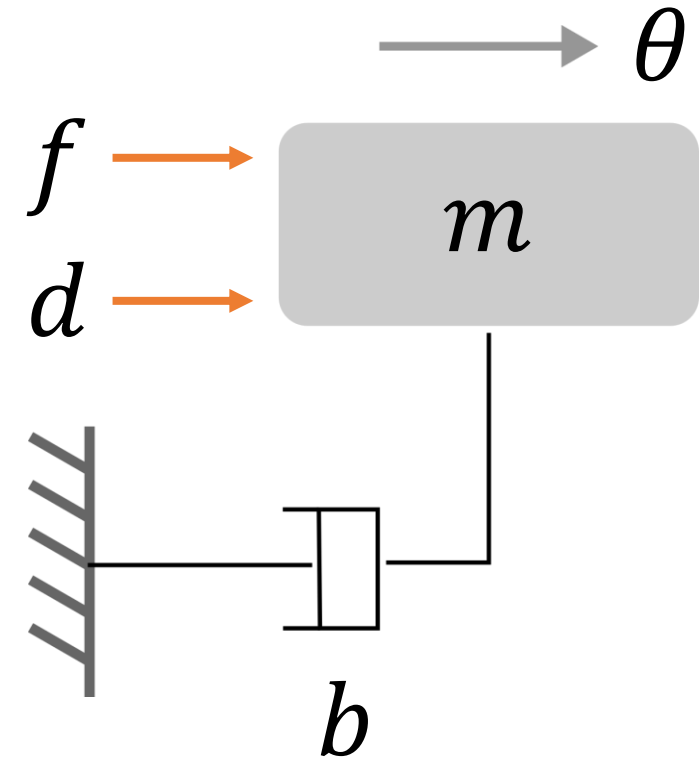
$$f = k_p(\theta_d - \theta)$$

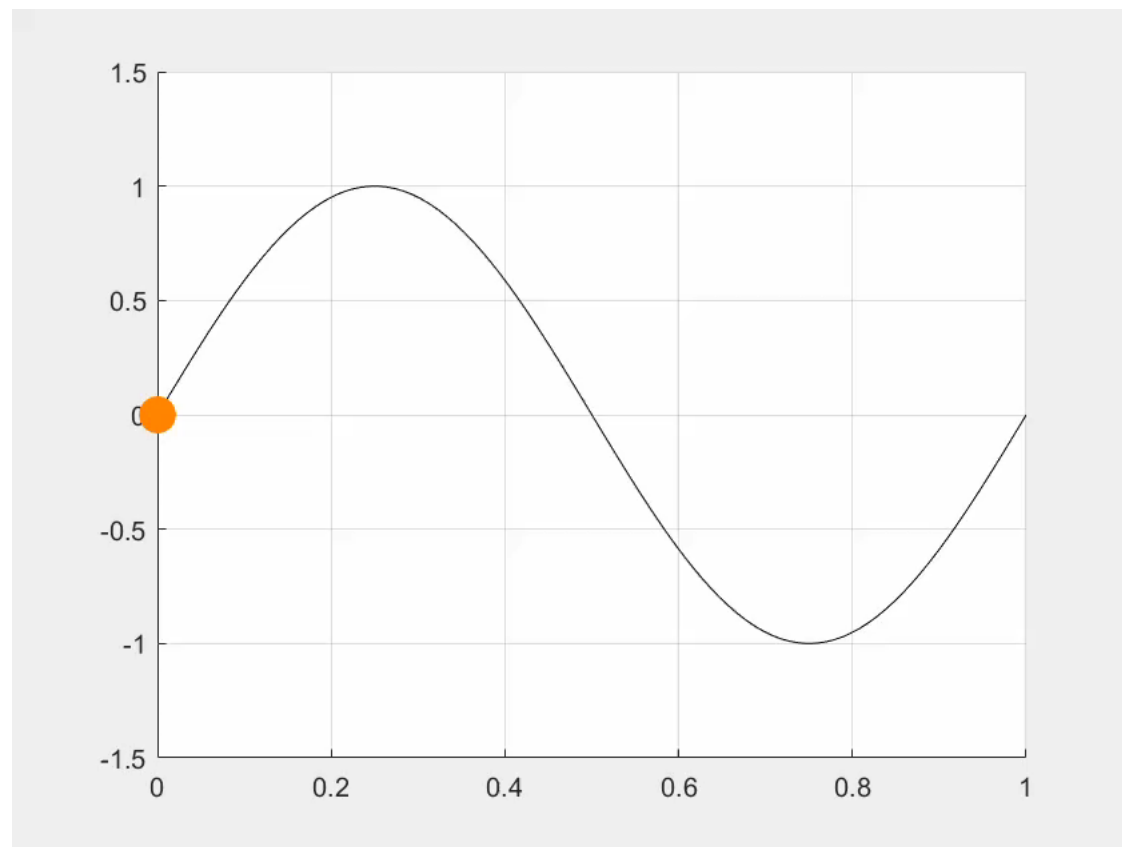
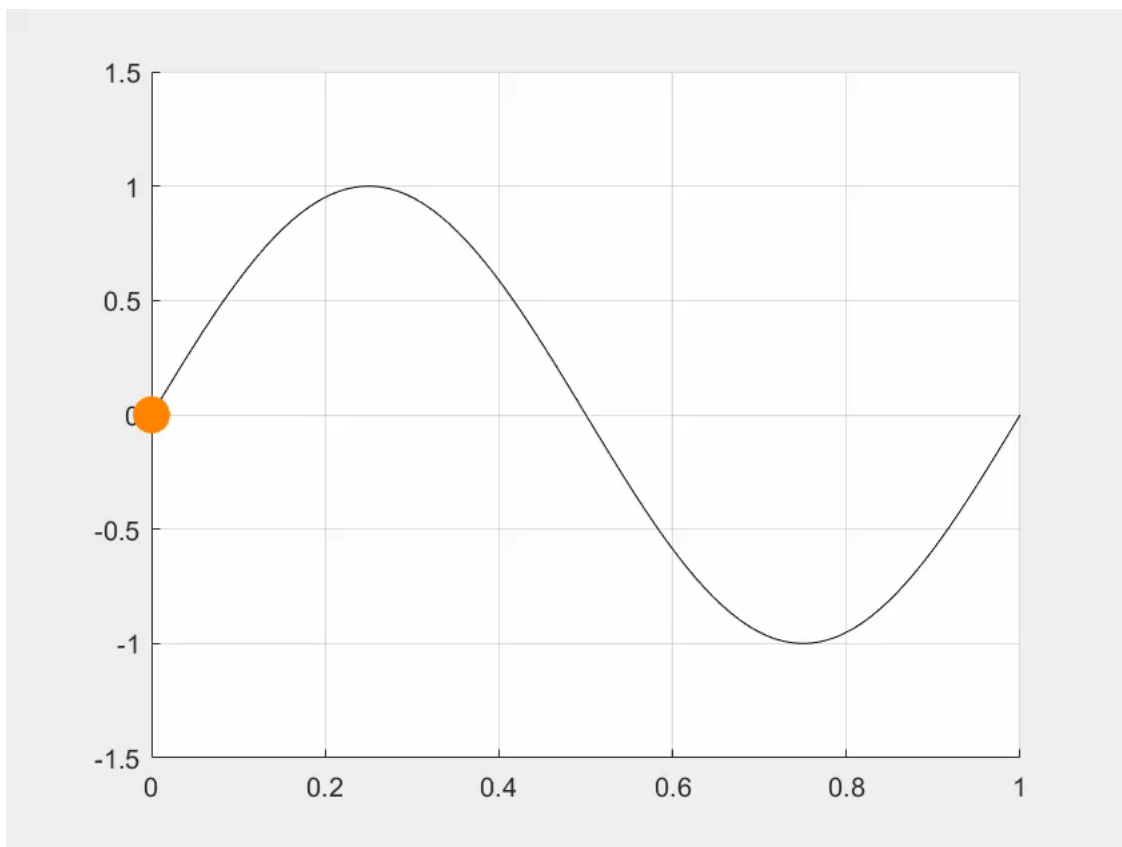



Example

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

$$\theta(s) = \underbrace{\frac{k_p}{ms^2 + bs + k_p}}_{\text{Approaches } \frac{k_p}{k_p} = 1 \text{ as the control gain increases}} \theta_d(s) + \underbrace{\frac{1}{ms^2 + bs + k_p}}_{\text{Approaches } \frac{1}{k_p} = 0 \text{ as the control gain increases}} D(s)$$







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?