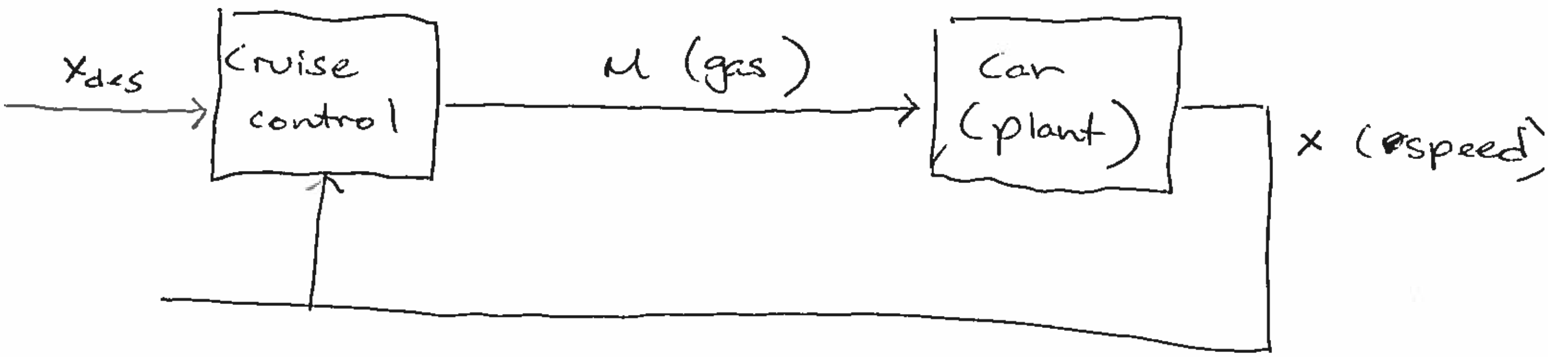
Feedback control



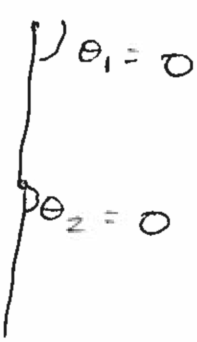
- x is state
  u is control

- This is a proportional controller: amount of gas proportional to error

$$u = K \cdot (x_{des} - x)$$

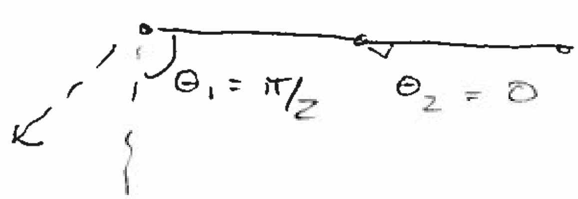
Problem with P-control:

- Rise time too long or too much overshoot (depending on size of K term)



Object of study: double pendulum

Desired set point:



State for pendulum: $\theta_1, \theta_2, \dot{\theta}_1, \dot{\theta}_2$

Notation: $\dot{\theta}_1 = d\theta/dt$ (θ is a function of time)

Control for pendulum: τ_1, τ_2

- We'll ignore actual dynamics of pendulum for now except to say that:

$$\{\ddot{\theta}_1, \ddot{\theta}_2\} = f(\theta_1, \theta_2, \dot{\theta}_1, \dot{\theta}_2, \tau_1, \tau_2)$$

Still complicated, but given large enough positive τ_1, τ_2 then $\ddot{\theta}_1, \ddot{\theta}_2$ will be positive

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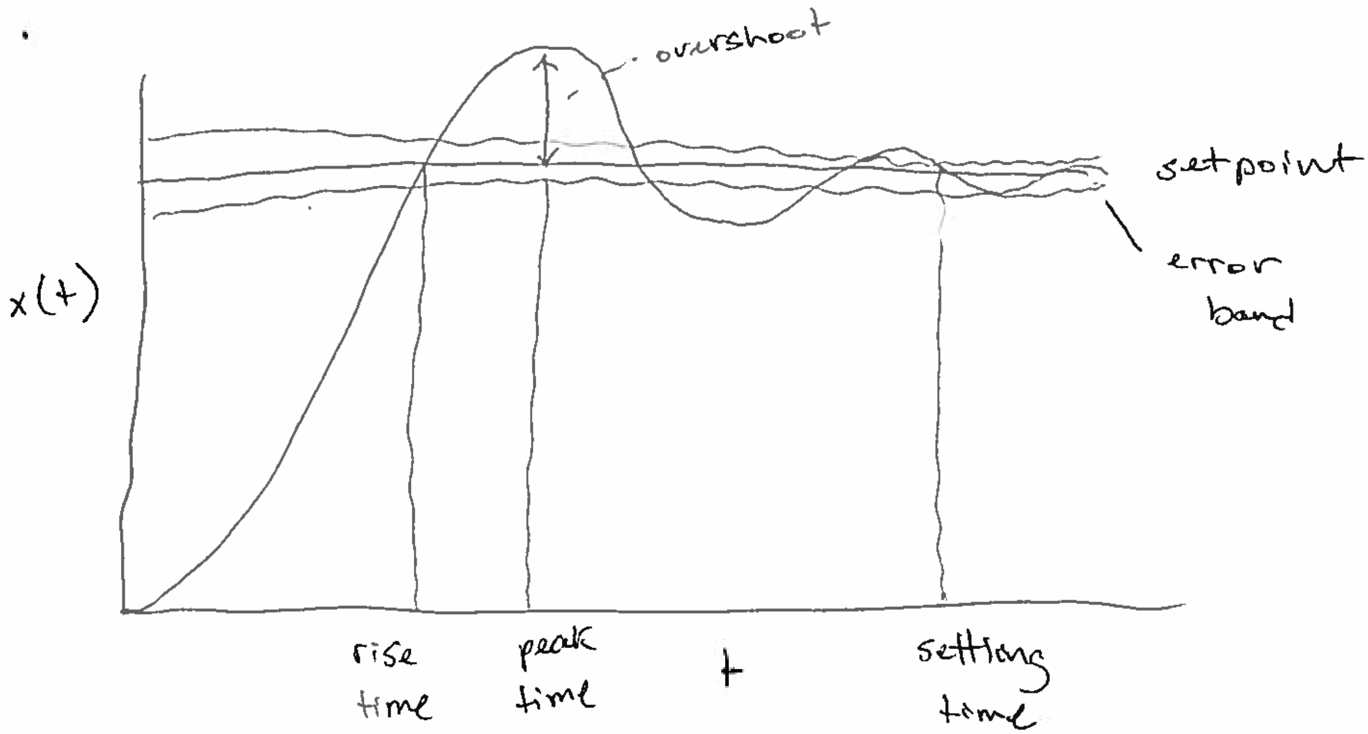
Proportional-derivative controller:

$$\tau_1 = K_p^1 \cdot (\theta_1^{des} - \theta_1) + K_d^1 \cdot (\dot{\theta}_1^{des} - \dot{\theta}_1)$$

$$\tau_2 = K_p^2 \cdot (\theta_2^{des} - \theta_2) + K_d^2 \cdot (\dot{\theta}_2^{des} - \dot{\theta}_2)$$

- How to pick K_p, K_d?
  - Rule of ~~t~~thumb K_d order of mag smaller than K_p
  - Ziegler-Nichols
  - Optimization

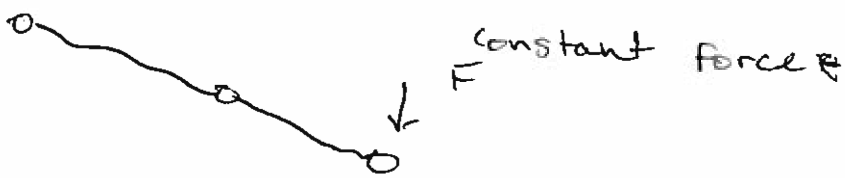


rise time: time to reach the set point from start

peak time: time at maximum overshoot

settling time: time at which system enters and remains within error band

Integral control:



Steady ~~state error will~~ applied force may make it difficult for robot to get to the set point

Add integral term: $K_i \int_0^t (\theta^{des}(t) - \theta(t))\, dt$

Can also have $PIDD^2$ controllers, integrals on velocity error, etc.

Exercise: write a PD controller (in class) function using this template:

```
double PD_controller(double theta_des,
    double dtheta_des, double theta,
    double dtheta)
{


}
```