Classical Control

Lecture 1

Outline

1. Introduction
2. Control Specifications

Prerequisites

- Block diagram for system modeling
- Modeling
  - Mechanical
  - Electrical

Outline

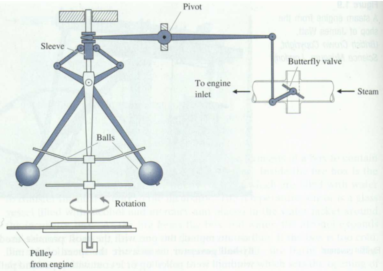
1. Introduction
   - Background
   - Basic Systems
   - Models/Transfers functions
2. Control Specifications
   - Closed Loop Stability
   - System Performance
   - Effect of Poles
   - Effect of Additional Poles/Zeros

Goal of Control Engineering

Graham C. Goodwin:

The fundamental goal of CE is to find technically, environmentally, and economically feasible ways of acting on systems to control their outputs to a desired level of performance in the face of uncertainty of the process and in the presence of uncontrollable external disturbances acting on the process.

The Fly-Ball Governor



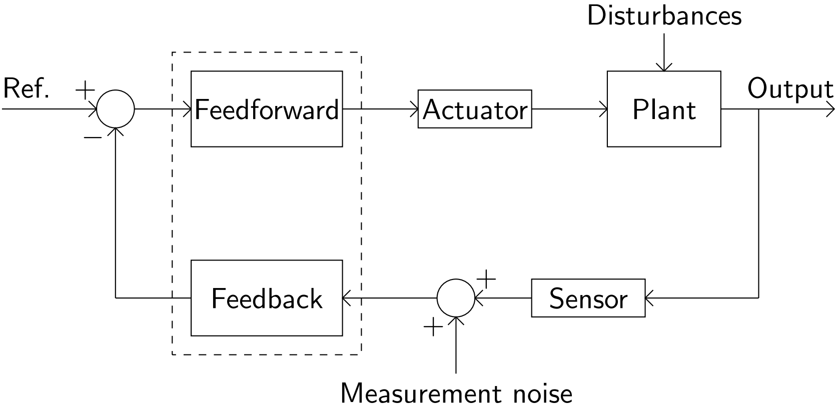
Historical Periods

- The Industrial Revolution (1860s)
- World War II (1940-1945)
- The Space Race (1960s,1970s)
- Economic Globalization (1980s)

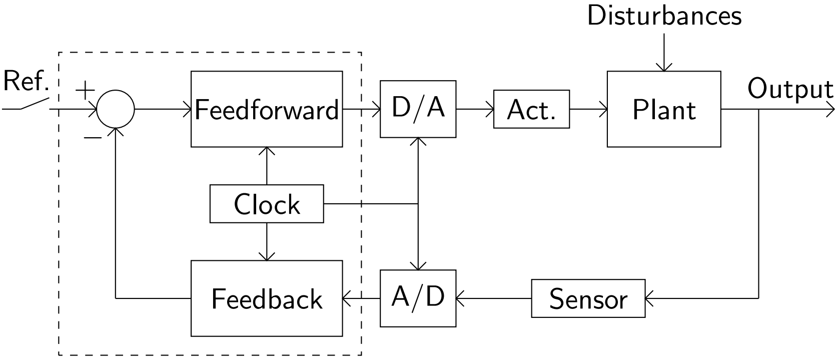
Evolution of Control

- 1940 Classical Control
  - Frequency Domain
  - Mainly useful for SISO systems
  - A fundamental tool for many practicing engineers
- 1960 Modern Control
  - State-space approach to linear control theory
  - Suitable for both SISO and MIMO systems
  - No explicit definition of performance and robustness
- 1970 Optimal Control
  - Minimize a given objective function (fuel, time)
  - Suitable for both open-loop and closed-loop control
- 1980 Robust Control
  - Generalization of classical control ideas into MIMO context
  - Based on operator theory which can be interpreted into frequency domain
- Nonlinear control, Adaptive Control, Hybrid Control

Basic Continuous Control System



Basic Digital Control System



Continuous System Models

Numerator and denominator

- General formula

$$G(s) = \frac{Y(s)}{U(s)} = \frac{b_0 s^m + b_1 s^{m-1} + \cdots + b_m}{a_0 s^n + a_1 s^{n-1} + \cdots + a_n}$$

- Second order system (special case)

$$G(s) = \frac{K}{s_2 + 2\zeta\omega_n s + \omega_n^2}$$

- MATLAB

```
sys=tf(num,den)
```

Continuous System Models

Zeros and poles

- General formula

$$G(s) = \frac{Y(s)}{U(s)} = K\frac{\prod_{k=1}^{m}(s - z_k)}{\prod_{i=1}^{n}(s - p_i)}$$

- Second order system (special case)

$$G(s) = \frac{K}{(s - p_1)(s - p_2)} \qquad p_{1,2} = -\zeta\omega_n \pm j\omega_n\sqrt{1 - \zeta^2}$$

- Matlab

```
sys=zpk(z,p,k)
```

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Bounded Input Bounded Output

- Impulse response
- Roots of characteristic equation
- Gain and phase margins
- Nyquist stability criterion

Stability - Impulse Response

Continuous systems

The system is BIBO stable if and only if the impulse response $h(t)$ is absolutely integrable

Discrete systems

The system is BIBO stable if and only if the impulse response $h[n]$ is absolutely summable

Stability - Characteristic Roots

Asymptotic internal stability

Continuous systems

All poles of the system are strictly in the LHP of the s-plane

Discrete systems

All poles of the system are strictly inside the unit circle of the z-plane

Analyzing System Performance

System types

- Continuous system
- Discrete system

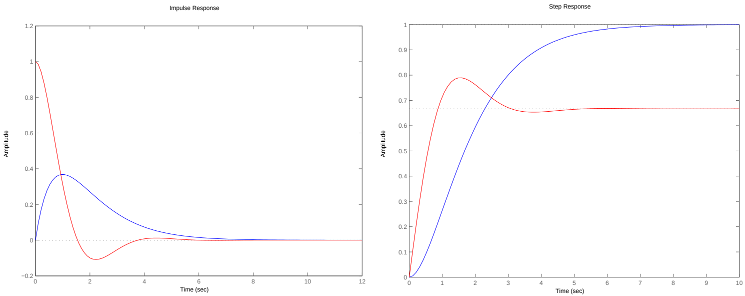
Analysis domain

- Time-domain specifications
- Frequency-domain specifications

Different periods

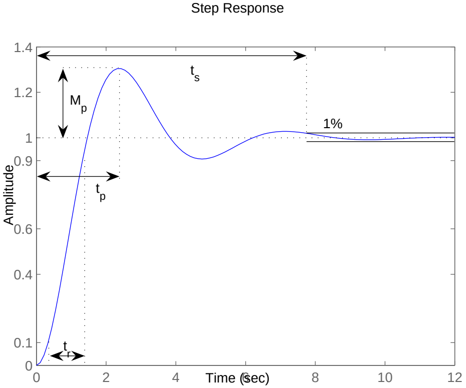
- Dynamic (transient) responses
- Steady-state responses

Continuous Time - Dynamic Response




```
num1=[1];
den1=[1 2 1];
num2=[1 2];
den2=[1 2 3];
impulse(tf(num1,den1),'b',tf(num2,den2),'r')
step(tf(num1,den1),'b',tf(num2,den2),'r')
```

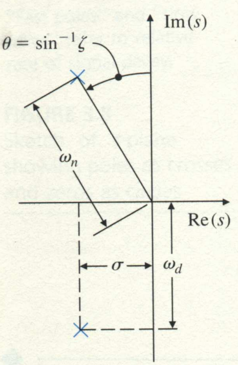
Continuous Time - Dynamic Response

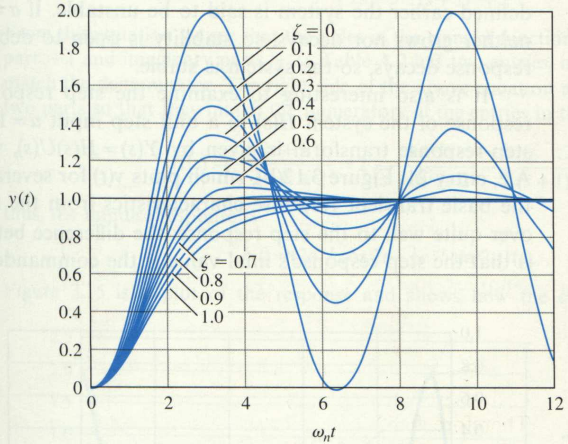


- Overshoot (M_p)
- Rise time (t_r)
- Settling time (t_s)
- Peak time (t_p)

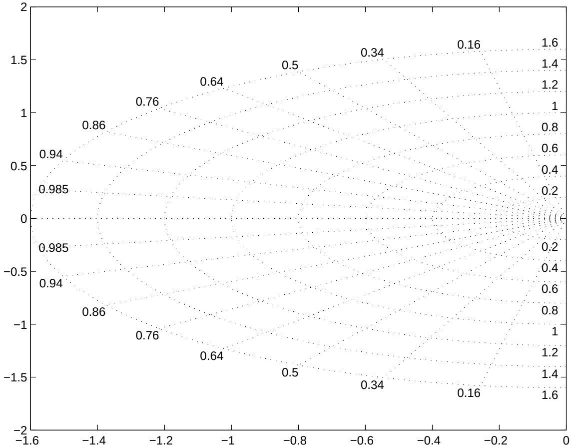
Natural Frequency and Damping

FIGURE 3.11
s-plane plot for a pair of complex poles

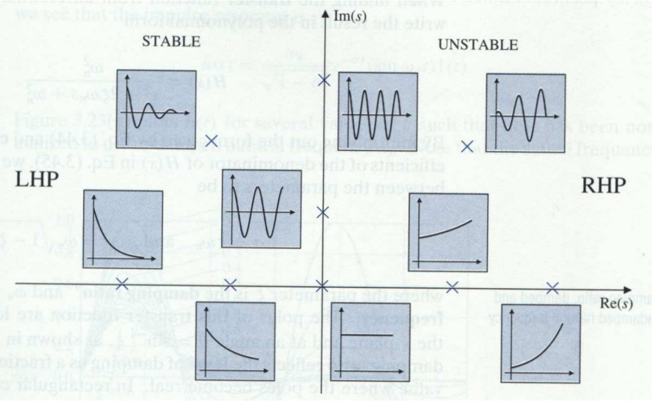




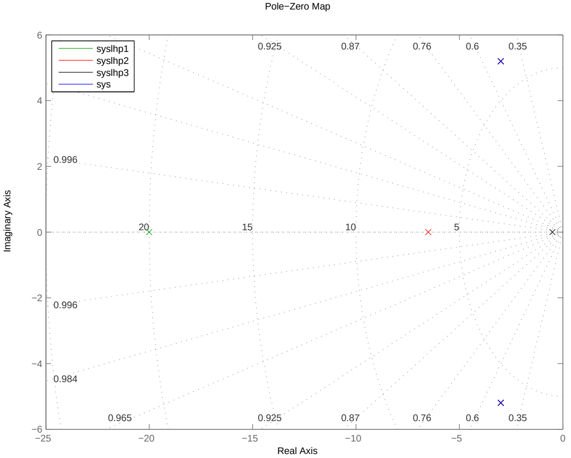
Poles in the Continuous s-plane



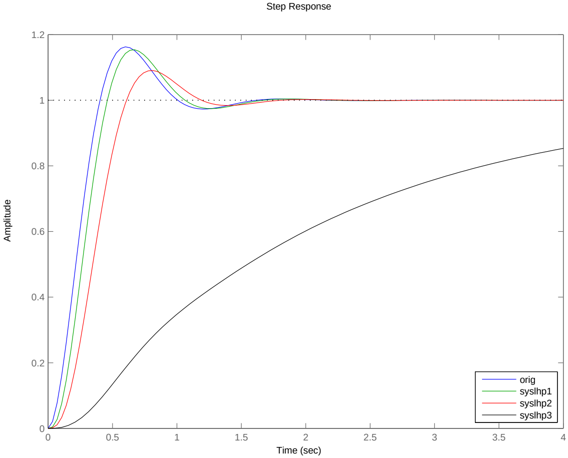
Poles in the Continuous s-plane



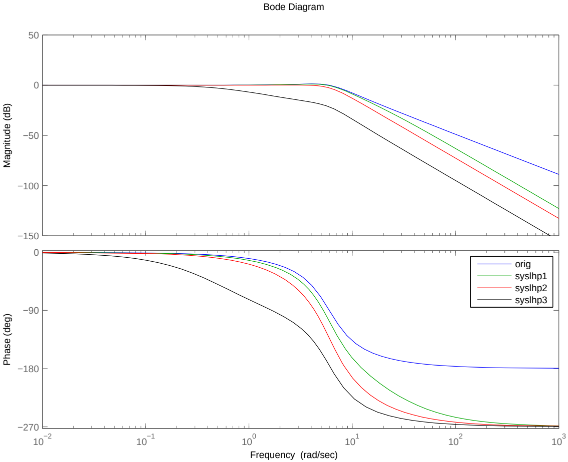
Systems with Different Poles



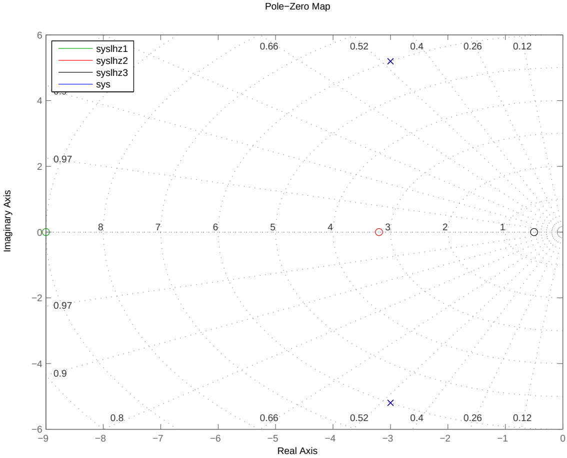
Step Response of Different Systems



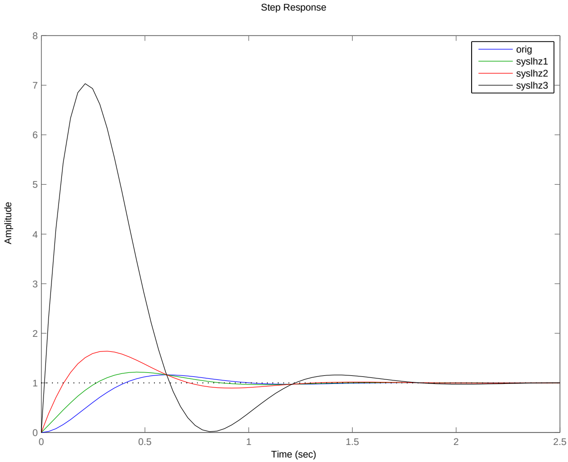
Bode Plot of Different Systems



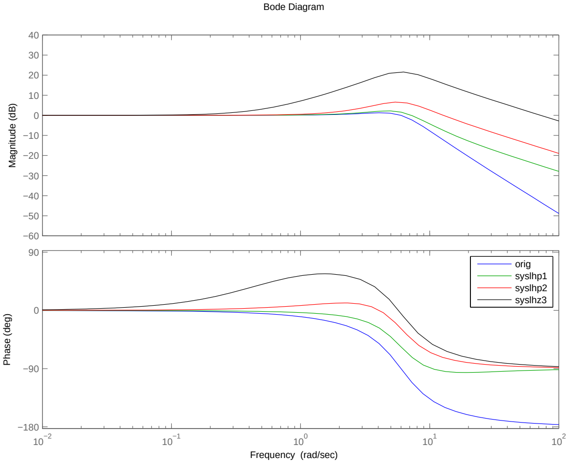
Systems with Different Zeros



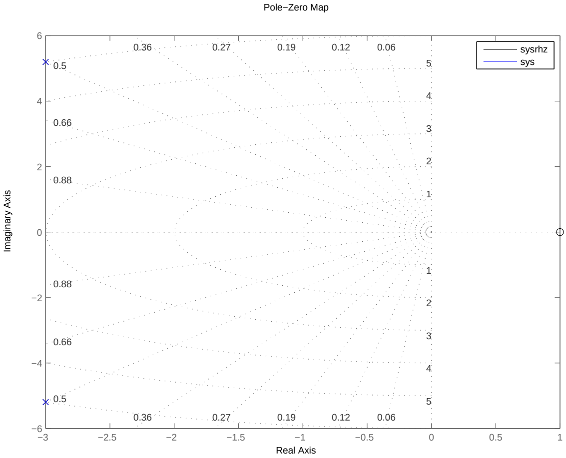
Step Response of Different Systems



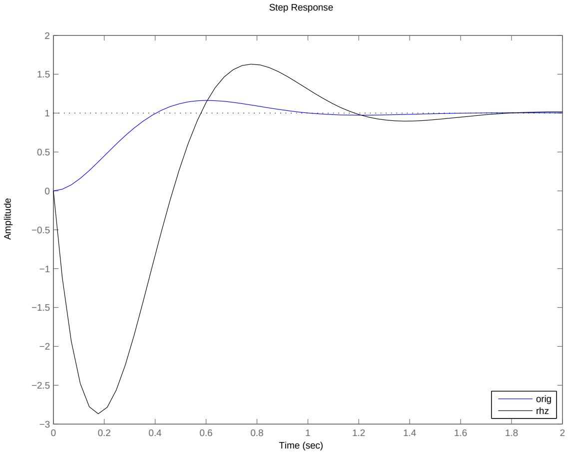
Bode Plot of Different Systems



System with Zero in RHP



Step Response



Bode Plot of System with RHP