Driver assistance system design A

Control of dynamic systems

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Outline

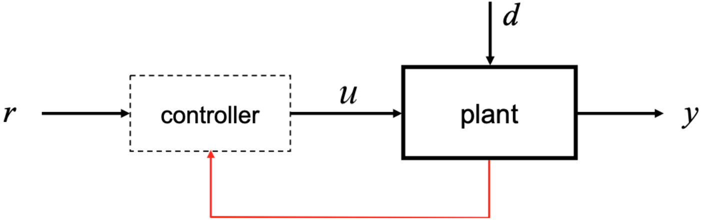
1. Basic concepts

2. Control system structures

3. Control objectives

What is control?

- Goal of control: obtain a desired behavior of a dynamic system.
- Controlling a dynamic system (plant): using a command u such that the corresponding output y tracks a desired reference r.
- The controlled system should be as little as possible sensitive to the disturbance d.



Control design problem: Find a system, called the controller, such that $y \cong r$ for a set of reference signals of interest. $\square$

Other examples

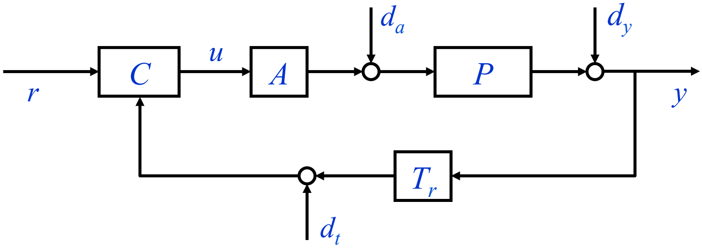
- Automotive control applications:
  - lateral control / lane keeping
  - longitudinal control / cruise control / adaptive cruise control
  - vehicle stability control (VSC) / electronic stability program (ESP)
  - vertical dynamics control / suspension control
  - active braking system (ABS)
  - engine control / emission control
  - heating system control
  - etc ...
- Other control applications:
  - aerospace
  - robotics
  - physics
  - biology
  - medicine
  - econometrics
  - etc ...

Control design methods

- Time-domain methods:
  - eigenvalue (pole) placement
  - proportional integrative derivative (PID)
  - optimal control (LQR)
  - model predictive control (MPC)
  - internal model control (IMC)
  - gain-scheduling
  - feedback linearization
  - sliding mode control
  - etc ...
- Frequency domain methods:
  - pole placement
  - proportional integrative derivative (PID)
  - root locus
  - lead-lag compensator
  - internal model control (IMC)
  - H_∞ control
  - etc ...

Control system structures

A general structure



Systems:

P : plant

C : controller

A : actuators

T_r : sensors (transducers)

Signals:

r : reference

y : output

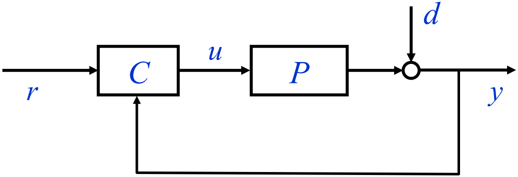
u : command input

$e = r - y$: tracking error

d_y, d_a, d_t : disturbances

Control system structures

A simplified structure



Systems:

A included in P

$T_r = 1$

Signals:

r : reference

y : output

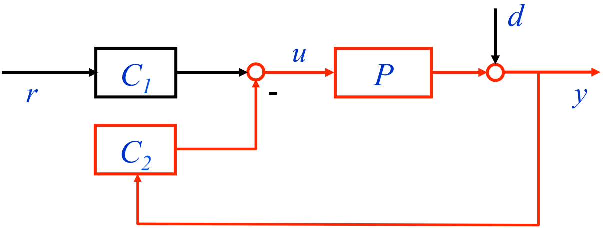
u : command input

$e = r - y$: tracking error

d : unique disturbance accounting for d_y, d_a, d_t

Control system structures

LTI systems: important transfer functions

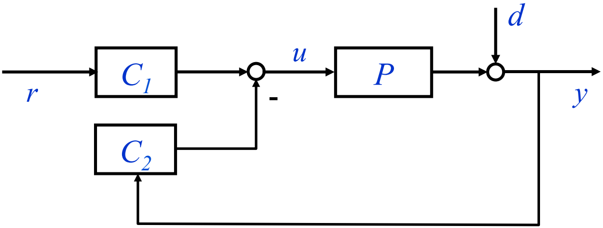


Loop function: product of all transfer functions appearing in the loop:

$$L(s) = P(s)C_2(s).$$

Control system structures

LTI systems: important transfer functions



Sensitivity:
transfer function $d \to y$

$$S(s) = \frac{y(s)}{d(s)} = \frac{1}{1+P(s)C_2(s)}.$$

Complementary sensitivity:
transfer function $r \to y$

$$T(s) = \frac{y(s)}{r(s)} = \frac{P(s)C_1(s)}{1+P(s)C_2(s)}.$$

For particular choices of C_1 and C_2: $\quad T(s) + S(s) = 1.$

Control objectives

- **Ideal control:**

$$
\begin{aligned}
T = 1 \quad &\Rightarrow \quad \text{exact reference tracking;}\\
S = 0 \quad &\Rightarrow \quad \text{complete disturbance rejection.}
\end{aligned}
$$

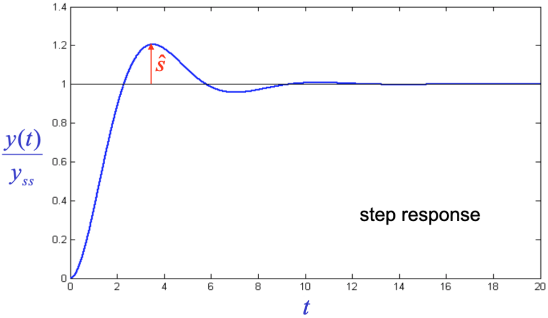
- **Real control:**
  - Stability:
    - ⋆ A closed-loop system is as. stable iff all its subsystems (from all inputs to all outputs) are as. stable.
  - Well-damped response.
  - Quick response.
  - Precision in steady-state.
  - Reduced influence of uncertainties (robustness).
  - Low command effort $\leftrightarrow$ low energy consumption.

Control objectives

- Consider the step response of a closed-loop system, i.e., its output when the reference is a step signal. Suppose that the following limit exists: $y_{ss} \doteq \lim_{t\to\infty} y(t)$.

- Well-damped response $\leftrightarrow$ "small" overshoot.

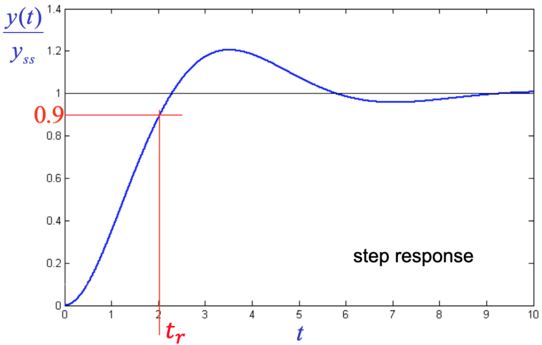
Definition. Maximum overshoot: $\hat{s} = \max_{t\in[0,\infty]}\left(\frac{y(t)}{y_{ss}}\right) - 1$



Control objectives

- Quick response $\leftrightarrow$ "short" rise time.

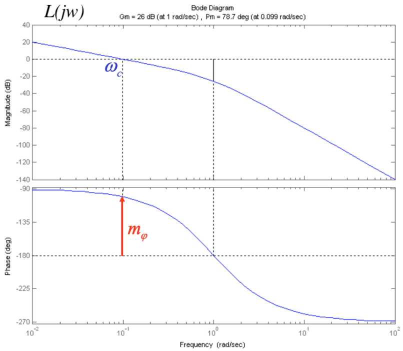
Definition. Rise time: $t_r : y(t_r)/y_{ss} = 0.9$



Control objectives

LTI systems

- In the case of LTI plant, overshoot and rise time are related to the loop function $L(s)$.



Definitions:

- Cross-over frequency:
  $\omega_c : |L(j\omega_c)| = 1.$
- Phase margin:
  $m_\phi = \angle L(j\omega_c) + 180^o.$

- The following relations hold:
  - Increase $\omega_c \rightarrow$ reduce t_r
  - Increase $m_\phi \rightarrow$ reduce $\hat{s}$, increase closed-loop robustness.
- Typical required values: $m_\phi \gtrsim 45^o$.

Control objectives

- In general: Precision in steady-state $\leftrightarrow e_{ss} \doteq \lim_{t \to \infty} e(t)$ "small".
- LTI systems: Precision in steady-state $\leftrightarrow$ high loop gain at low frequency or integrators in the loop (it can be proven, see the recap material).