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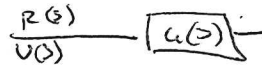
- systems are anything composed of components that can be described mathematically
  - ↳ input & output
  - ↳ processes signals
- we represent systems in several ways
  - ↳ differential equations
  - ↳ transfer functions
    - relationship between input and output (Laplace domain)
  - ↳ state space
    - time domain
  - ↳ block diagrams

- systems can be

open loop




$$\frac{Y(s)}{U(s)} = G(s)$$

closed loop


→ feedback

$$\frac{Y(s)}{U(s)} = \frac{G(s)}{1 + G(s)H(s)}$$

- we can design controllers to get system response to meet specific requirements
  - ↳ steady state error
    - how close to reference input
  - ↳ transient response
    - $M_p(\%)$, $t_s$, $t_r$, $t_p$ etc.
  - ↳ other optimization goals
    - robust to disturbances
    - minimal control effort
  - ↳ stability
    - all poles in LHP

- transient response characteristics
  - ↳ 2nd order system

$$\frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

$0 < \zeta < 1$ is underdamped
↳ oscillates but settles

$$M_p(\%) = 100\, e^{-\zeta\pi/\sqrt{1-\zeta^2}}$$

$$\zeta = \frac{-\ln(M_p(\%)/100)}{\sqrt{\pi^2 + \ln^2(M_p(\%)/100)}}$$

$$t_s = \frac{4}{\zeta\omega_n} \qquad t_p = \frac{\pi}{\omega_n\sqrt{1-\zeta^2}}$$

- ↳ what if system isn't 2nd order?
  - extra pole: $t_r \uparrow$ $M_p(\%) \downarrow$
  - extra zero: $t_r \downarrow$ $M_p(\%) \uparrow$
- ↳ effects of extra poles/zeros depend on "closeness" to $j\omega$ axis
  - if far in LHP, little effect.

Types of Control

1. proportional
   - ↳ steady state, root locus
2. PID
   - ↳ common! more on this in later lecture
3. Phase lead/lag
4. Bang, Bang control
5. state space (state feedback)
6. more advanced types like adaptive, robust, optimal.

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Control I rarely used in ENGR 4020:

1. Bang-Bang (On/off)
   - DEx: Motors full forwards or motors full stop
2. proportional
   - DEx: speed control
3. PID
   - is if you want

- In this class we will also look at more sophisticated "advanced" controls
  - will also make use of MATLAB & simulink

- for next lecture, make sure MATLAB/simulink student suite installed
  - don't forget add on package Robotics System tool box

- we will use these tools for control/ filtering/ computer vision parts of this course
  - even though this may not apply directly to your course project/ Robot, these tools are invaluable as you look for jobs in controls/ mechatronics.