Lecture 12 Servo Systems

Use electronic system to control a physical variable

Very general:

Position of a mass (using a motor)

Pressure in a tank (using a valve)

Current in a wire (using an amplifier)

Temperature in room (using heater)

etc

Same math applies to all

Set up: assume we have way to measure variable
& to change it

Suppose variable subject to environmental noise
Use control system to eliminate/reduce noise

Example: Driving a car

Variable: position in lane

Measurement: visual

Control: steering wheel

Noise: bumps & turns in road

Strategy: Watch road. If car starts to move from center of lane, adjust wheel to correct

Want to automate this process in a circuit

System called "servomechanism" or "servo"

Useful to describe with block diagram

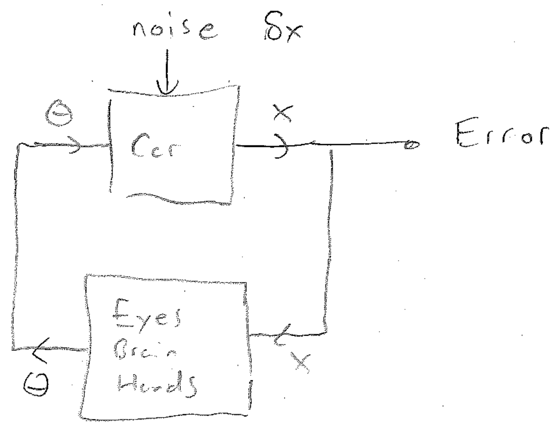
Each sub-system → block with transfer function

(assume Z_{in}'s large and Z_{out}'s small)

Car Example:

x = deviation from lane center

Θ = angle of steering wheel



Car described by G: $x(\omega) = G(\omega)\,\Theta(\omega) + \delta x(\omega)$

Driver described by H: $\Theta(\omega) = H(\omega)\,x(\omega)$

We want $x = 0$

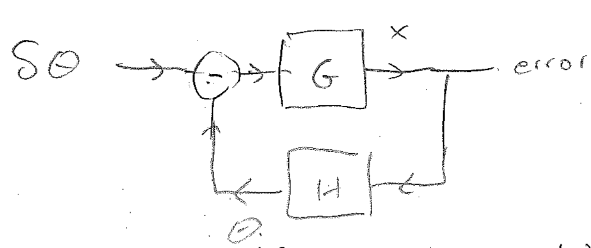
Define x = "error signal" = quantity we want to minimize

Note that co-dependence is essential

Neither car nor driver can respond to very fast inputs

Also, doesn't really matter where noise comes in

Could write:

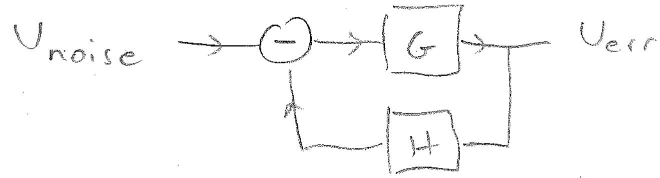


Use ⊖: subtract two inputs

$\Theta_{out} = \delta\Theta - \Theta_{in}$

Why subtract? Know we want negative feedback. If car drifts right, steer left

General diagram:



Analyze: $V_{err} = G(V_{noise} - H V_{err})$

$$V_{err}(1 + GH) = G V_{noise}$$

$$V_{err} = \frac{G V_{noise}}{1 + GH}$$

If $H = 0$ (no control), then $V_{err} = G V_{noise}$

Call this = "open loop" response V_o

Often write $G = G_o$ = open loop transfer function

With $H \neq 0$, call "closed loop" response V_c

So $V_c = \dfrac{V_o}{1 + G_o H}$

If $|1 + G_o H| \gg 1$, then $|V_c| \ll |V_o|$

control reduces noise ... good!

Typically G_o set by system

But H is ours to implement.

Just make H huge? $\rightarrow V_c \rightarrow 0$

No: problem with <u>phase</u>

Define <u>loop phase</u> ϕ = phase of $G_o H = \phi_G + \phi_H$

Any physical system: ϕ decreases as $\omega \rightarrow \infty$

finite response time

At some ω, $\phi \to -180°$

$\Rightarrow$ sign of feedback $\to$ positive!

Control increases noise, like microphone near speaker

Theorem (Nyquist stability criterion):

If $|G_0 H| \equiv$ loop gain is greater than 1 when $\phi \leq -180°$, then system is unstable

$$\frac{1}{1+GH} \to \infty \text{ at some } \omega$$

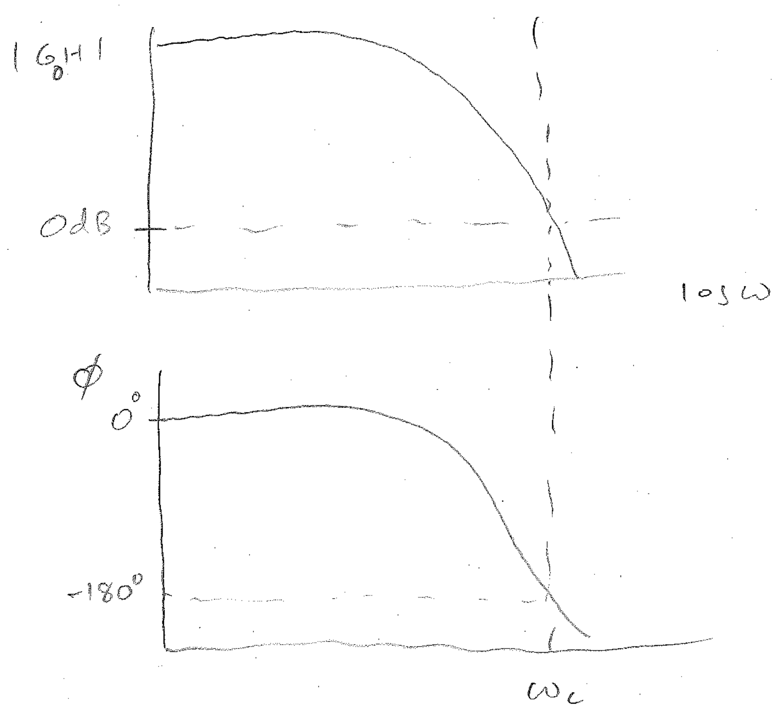
$\Rightarrow$ system freely oscillates at that ω

This would be bad, worse than no control!

Only fix: make sure $|G_0 H|$ drops below 1 before ϕ reaches $-180°$.

This limits gain at lower freqs too!

Example



Can't make H any larger without violating stability criterion.

Note: by convention, phase ϕ doesn't count
subtraction that makes feedback negative

Basically, assume $\phi \to 0°$ as $\omega \to 0$

We'll spend two labs exploring effects, optimizing performance

Use simple system: photodiode illuminated by LED

Noise = ambient lights

compensate for ambient changes by adjusting LED