

October 6, 2020

EE 1001
- Introduction to Control Systems -

Jiann-Shiou Yang

Professor

Department of Electrical Engineering

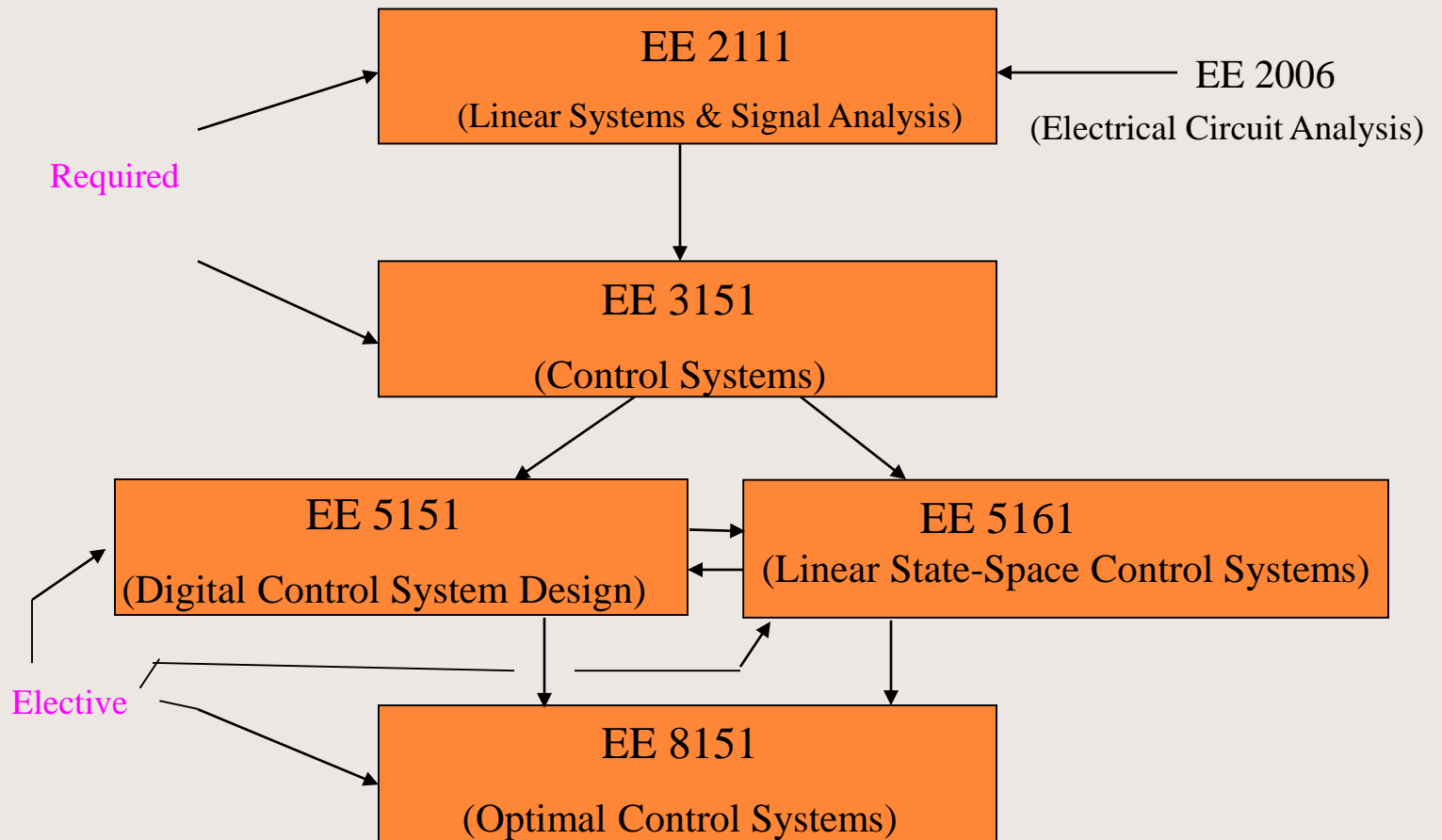
University of Minnesota

Duluth, MN 55812

Outline

- Systems & Control Courses
- Introduction to Control Systems
 - ▶ Examples of Control System Applications
 - ▶ What is a Control System?
 - ▶ Basic Control System Components
 - ▶ Open-Loop vs. Closed
- Software (Matlab, Simulink, Toolboxes)

Systems & Control Courses



“Why do you need a control system at all?”

- What good is an oven if you can't control the temperature? What good is an airplane if a pilot can't make it go where he wants it to go?
- The common denominator in these questions is that there is some physical quantity that must be somehow controlled in a desirable way.
- ➔ Need to think about how to control physical quantities, and to determine what can be done to implement the way we want.

Examples of Control Applications

Control is everywhere. Aircraft and spacecraft, process plants and factories, homes and buildings, automobiles and trains, cellular telephones and networks ... these and other complex systems are testament to the ubiquity of control technology.

- Aircraft autopilot
 - Disk drive read-write head positioning system
 - Robot arm control system
 - Automobile cruise control system
- etc.

The Impact of Control Technology – Overview, Success Stories, and Research Challenges, 2nd ed. - A special report published by the IEEE Control Systems Society at <http://www.ieeecss.org/impact-control-technology-2nd-edition>

What is a Control System?

A control system is an interconnection of components forming a system configuration to provide a desired system response.

Basic Control System Components

- Plant (or Process)

- The portion of the system to be controlled -

- Actuator

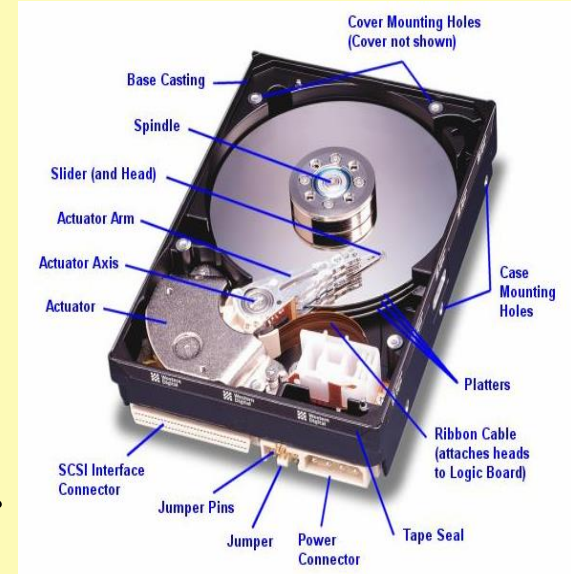
- An actuator is a device that provides the motive power to the process (i.e., a device that causes the process to provide the output).

■ Sensor

- A sensor most likely has an output, typically a voltage, that is proportional to the physical variable it measures.

■ Controller

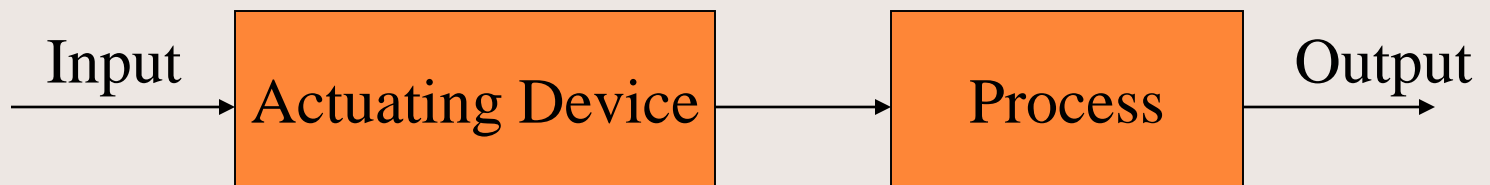
- A controller is a device, possibly in the form of a chip, analogue electronics, or computer, which monitors and physically alters the operating conditions of a given dynamical system.



Control engineering is fundamentally about the integration of many elements – plant, sensors, actuators, computing platform, algorithm

§ Open-Loop Control Systems

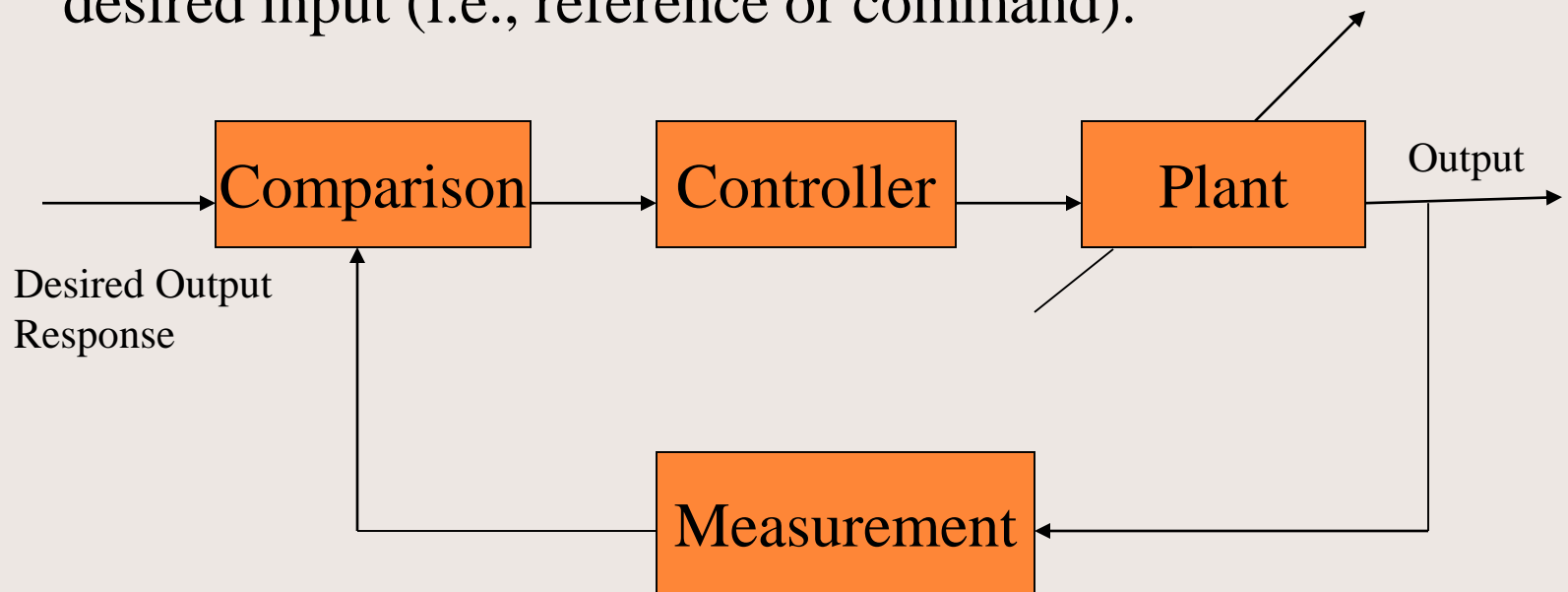
An open-loop control system utilizes an actuating device to control the process directly without using feedback.



The system outputs have no effect upon the signals entering the process. That is, the control inputs are not influenced by the process outputs.

§ Closed Loop (Feedback) Control Systems

A closed-loop control system uses a measurement of the output and feedback of this signal to compare it with the desired input (i.e., reference or command).



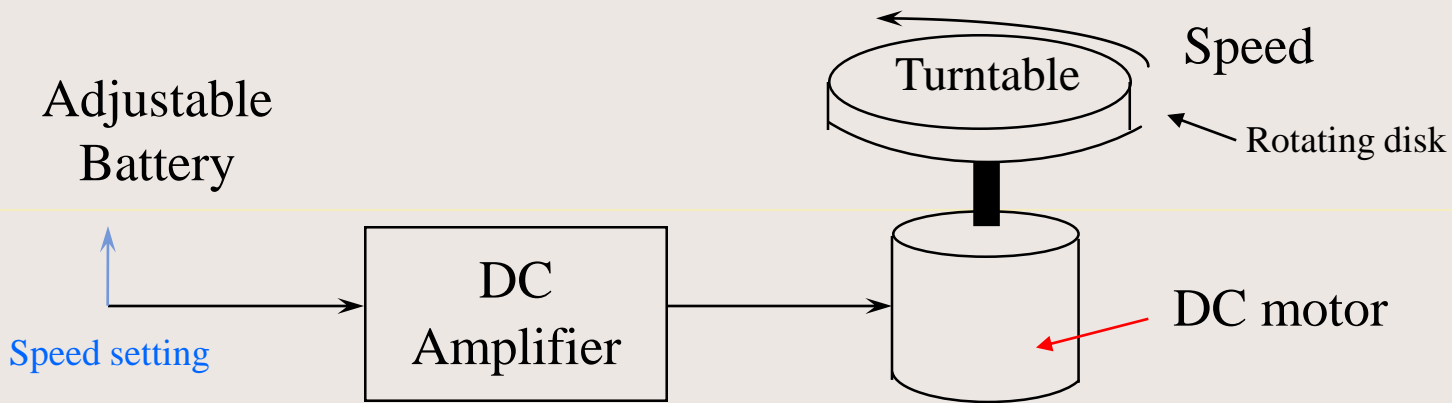
Closed-loop: General Form

Example (Ref: Dorf and Bishop, *Modern Control Systems*, 13/e, Prentice Hall, 2017)

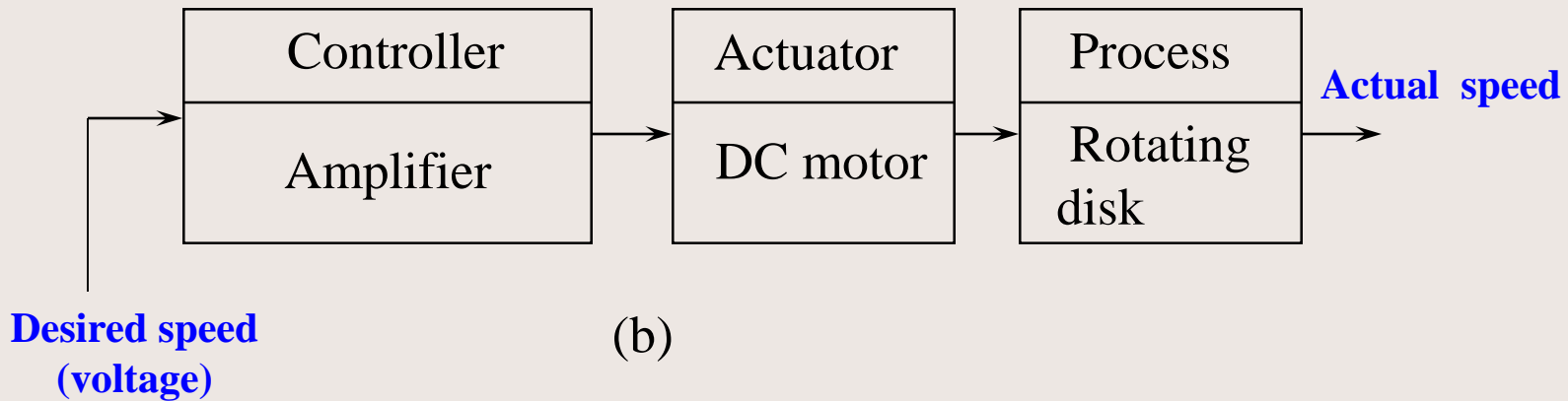
Rotating Disk Speed Control (Open-loop vs. Closed-loop)

■ Many modern devices use a rotating disk at a constant speed. For example, a computer disk drive and a CD player all require a constant speed of rotation in spite of motor wear and variation and other component changes.

■ For the rotating disk speed control, the goal is to design a controller that will ensure that the actual speed of rotation is within a specified percentage of the desired speed despite all possible uncertainties.



(a)



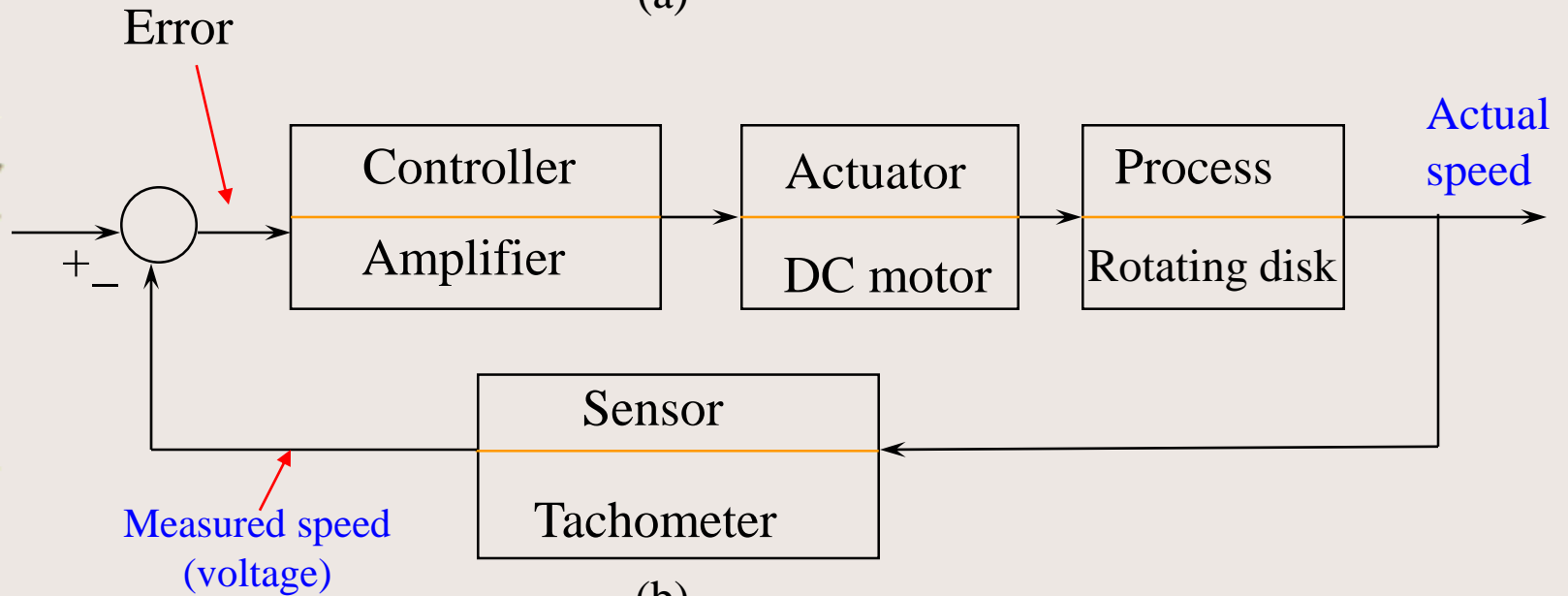
(b)

Rotating disk speed control: open-loop

Adjustable
battery



(a)

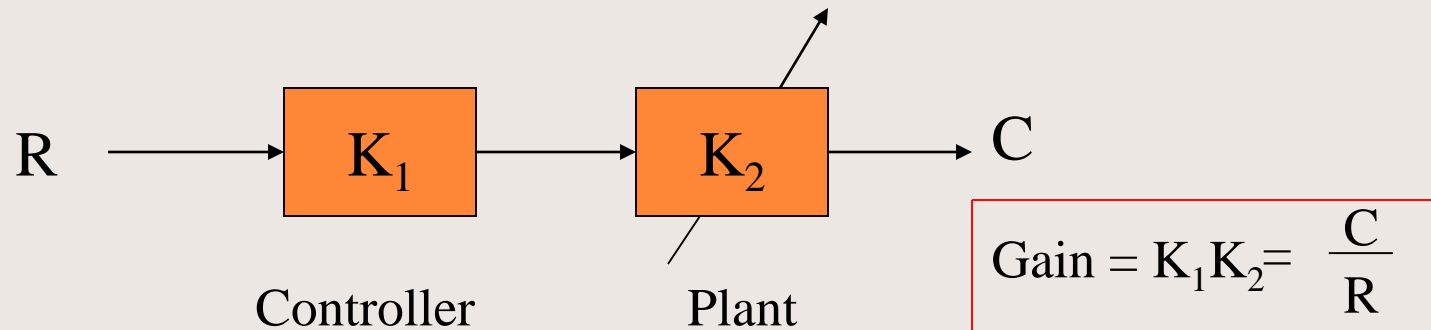


(b)

Rotating disk speed control: closed-loop

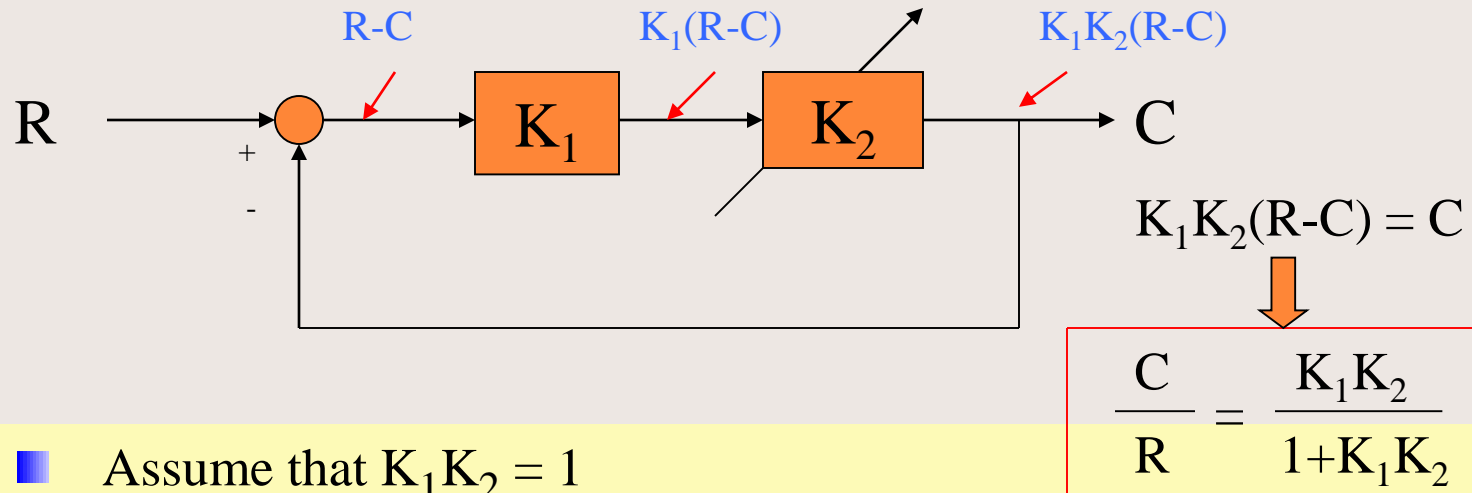
■ Effects of Feedback on Sensitivity

For the open-loop system shown below, if K_2 is halved, then the system gain is also halved (i.e., the overall system gain reduces to 50% of its original gain)



‡ Note that for simplicity, we assume that K_1 and K_2 are constant. In general, they are frequency dependent.

Consider the closed-loop system shown below:



- Assume that $K_1K_2 = 1$

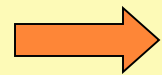
If K_2 is halved, then the overall system gain reduces to 67% of the original gain.

- Assume that $K_1K_2 = 9$

If K_2 is halved, then the overall system gain becomes 91% of the original gain.

■ Conclusion

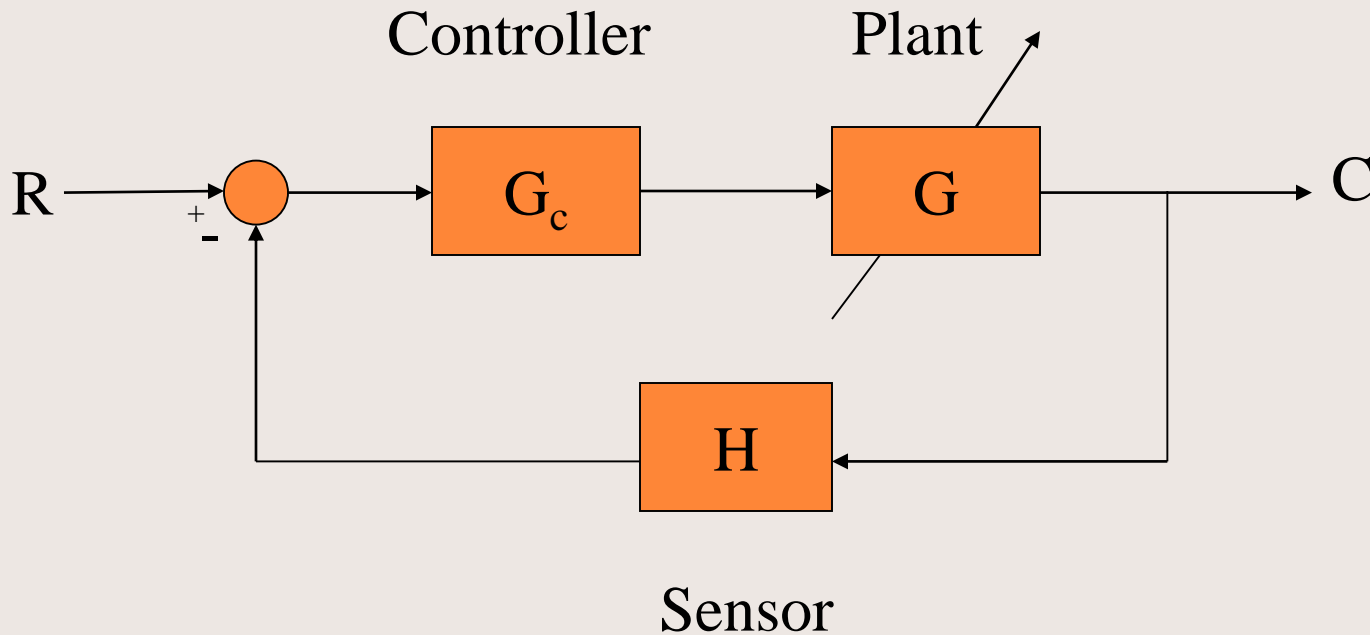
The sensitivity is reduced as the loop gain (i.e., K_1K_2) is increased.



Obvious advantage of using feedback

■ Effect of Feedback on Sensitivity (Cont'd)

-- Sensitivity to Plant Parameter Variations and Model Uncertainty --



Closed-loop transfer function:

$$T = \frac{C}{R} = \frac{G_c G}{1 + G_c G H}$$

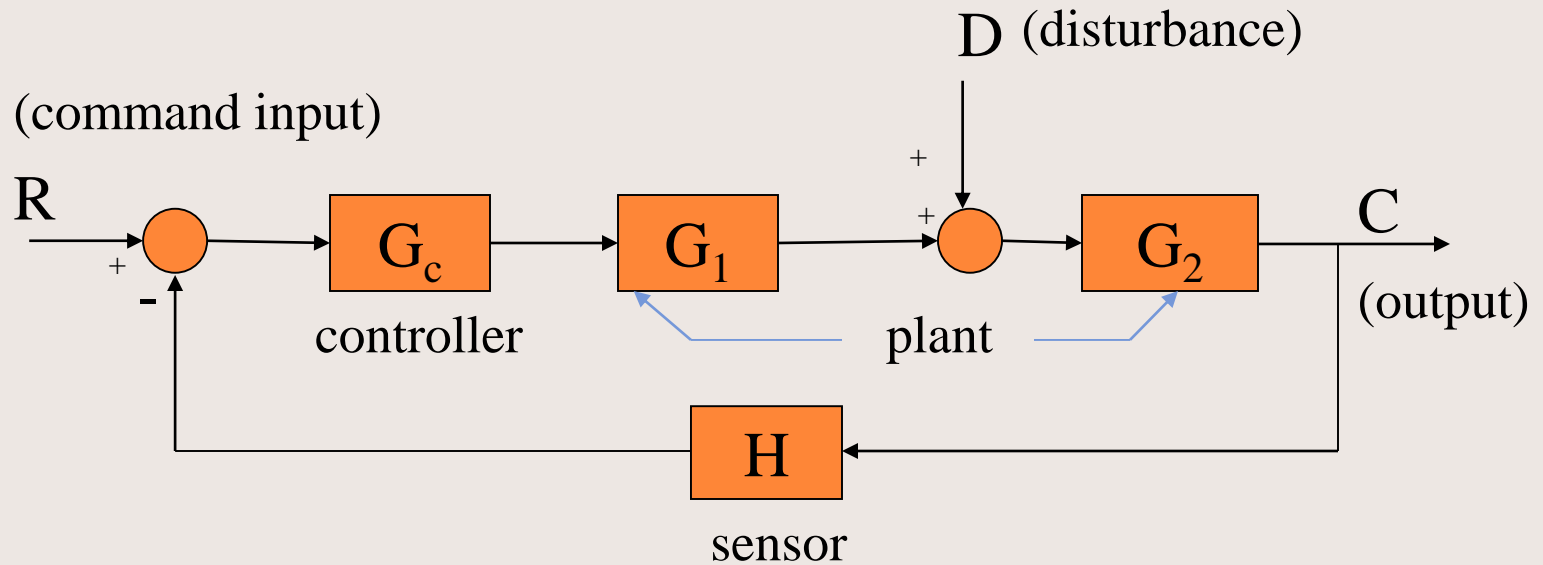
If $G_c G H \gg 1$

$$T = \frac{C}{R} \approx \frac{G_c G}{G_c G H} = \frac{1}{H}$$

■ Effect of Feedback on Sensitivity (Cont'd)

- If the loop gain $G_cGH \gg 1$, C/R depends almost entirely on the feedback H alone, and is virtually independent of the plant G and other elements in the forward path and of the variations of their parameters.
- The sensitivity of the system performance to the elements in the forward path reduces as the loop gain is increased.

■ Effect of Feedback on External Disturbance



$$\frac{C}{D} = \frac{G_2}{1 + G_c G_1 G_2 H}$$

$$\frac{C}{R} = \frac{G_c G_1 G_2}{1 + G_c G_1 G_2 H}$$

For loop gain $G_c G_1 G_2 \gg 1$,

$$\frac{C}{D} \approx \frac{1}{G_c G_1 H} \qquad \frac{C}{R} \approx \frac{1}{H}$$

- If the loop gain $G_c G_1 G_2 \gg 1$, then feedback reduces the effect of disturbance D on C if $G_c G_1 H \gg 1$ (i.e., the high gain is in the feedback path between C and D).
- To ensure a good response to input R as well, the location of the high gain should be further restricted to $G_c G_1$, between the points where R and D enter the loop.
- The sensitivity to disturbances reduces as this gain is increased.

Motivations for Feedback

The main reasons of using feedback are the following:

- Reducing the sensitivity of the performance to parameter variations of the plant and imperfections of the plant model used for design
- Reducing the effects of external disturbances and sensor noises

Feedback can also

- Improve transient response characteristics
- Reduce steady-state error

Simulink



Matlab

Matlab Programming Language

User-written Functions



Built-in Functions

Graphics
2-D Graphics
3-D Graphics
Color and Lighting
Animation

Computations
Linear Algebra
Data Analysis
Signal Processing
Polynomial Interpolation
Solution of ODEs

External Interface
Interface with C and
FORTRAN and other
Programs

Toolboxes
(Collections of Specialized Functions)
Signal Processing
Control Systems
Image Processing
Communications And many more

MATLAB (MATrix LABoratory)

- Matlab is a software package developed by Mathworks for high performance numerical computation and visualization. It has been widely adopted in the academic community.
- Many universities and colleges around the world use MathWorks products for teaching and research in a broad range of technical disciplines
- Matlab provides an interactive environment with hundreds of built-in functions for technical computation, graphics, and animation.
- Matlab also provides easy extensibility with its own high level programming language.

<http://www.mathworks.com/products/matlab.html>

Toolboxes

- Toolboxes are libraries of Matlab functions that customize Matlab for solving particular classes of problems.
- Toolboxes are open and extensible; you can view algorithms and add your own.
- Toolboxes: control systems, communications, signal processing, robust control, neural network, image processing, optimization, wavelet, system identification, etc.

SIMULINK

- Simulink is an extension to Matlab that allows engineers to rapidly and accurately build computer models of dynamical systems, using block diagram notation.
- Simulink is a software package for use with Matlab for modeling, simulating, and analyzing dynamical systems. Its graphical modeling environment uses familiar block diagrams, so systems illustrated in text can be easily implemented in Simulink.
- **The simulation is interactive, so you can change parameters and immediately see what happens.** It supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two.

<http://www.mathworks.com/products/Simulink.html>

Matlab and Control Systems Tutorials

- Matlab and Simulink Tutorials are available:

http://www.mathworks.com/academia/student_center/tutorials.html

- Interactive Control Systems Tutorial is available:

http://www.mathworks.com/academia/student_center/tutorials/controls-tutorial-launchpad.html