WHAT IS CONTROL?

*Control* is the process of altering, manually or automatically, the performance of a system to a desired one.

WHY CONTROL?

Because systems by themselves usually do not behave the way we would like them to.

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**Manual Control**

- process operator
- levers of power
- measured behaviour
- system to be controlled

**Automatic Control**

- automatic controller
- process supervisor
- measured behaviour
- system to be controlled
MAIN AIMS OF CONTROL SYSTEMS

- **Regulation** – regulate the output from some process to remain constant to a required value despite disturbances and/or noise

- **Tracking or Servo system** – make the process output follow a particular changing form

- **Sequential Control** – make events occur in a particular sequence, either time driven or event driven

THE THREE ELEMENTS FOR SUCCESSFUL CONTROL DESIGN

- a definition of desired behaviour

- an ability to generate and apply actions

- a means to select actions or to make modifications that when applied to the system will result in the desired behaviour being obtained
OPEN- versus CLOSED-LOOP CONTROL

- **Open-Loop Control** – the controller does *not* use a measure of the system output to be controlled in computing the control action to take.

- **Closed-Loop Control** – the controlled output *is* measured and fed back for use in the computation of the control action.

**OPEN-LOOP CONTROL**

- **Process** – of which a variable (output) is being controlled.
- **Controller** – determines the action to be taken as a result of the system input.
- **Actuator** – gives an output of some action designed to change the controlled variable.
OPEN-LOOP CONTROL: Some Comments

The controller is designed on the basis of previous experience as likely to give the output required. Therefore, the behaviour of the process must be known as accurately as possible. There is no changing of the control action to account for any disturbances which may change the output variable.

WE PLAY GOD
OR
WE RELY HEAVILY ON HIM

CLOSED-LOOP or FEEDBACK CONTROL

Main futures: Feedback and Comparison

- **Sensor** – measures the system output and feeds it back
- **Comparator** – computes the difference between the reference signal and the sensor output to give the controller a measure of the system error
CLOSED-LOOP or FEEDBACK CONTROL

Example: Automobile Cruise Control

THE EFFECTS OF FEEDBACK

- Reduce the error between the actual and the desired value
- Change the stability of the system
- Change the overall system gain
- Change the sensitivity of the system gain
- Change the bandwidth of the system
- Reduce the effect of external disturbances and noise
- Reduce the effect of variations of system parameters
THE DESIGN PROCESS
➢ Transform Requirements into a Physical System

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THE DESIGN PROCESS
➢ Draw a Functional Block Diagram

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THE DESIGN PROCESS

➢ Create a Schematic

➢ Develop a Mathematical Model (Block Diagram)
THE DESIGN PROCESS

- Reduce the Block Diagram
- Analyse and Design

MATHEMATICAL MODELING

WHAT IS A MODEL?

The term *model*, as it is used and understood by control engineers, primarily means a set of differential equations that describe the dynamic behaviour of a system.
MATHEMATICAL MODELING

HOW IS A MODEL OBTAINED?

- Using principles of underlying physics
- Testing a prototype, measuring the response to specific inputs, and using the data to construct an analytical model

Example: A Simple System; Cruise Control Model

physical system

free body diagram

Equations of motion:

\[ u - bx = mx \Rightarrow \ddot{x} + \frac{b}{m} \dot{x} = \frac{u}{m} \]

or \[(v = \dot{x})\]

\[ \dot{v} + \frac{b}{m} v = \frac{u}{m} \]
**Example: A Simple System; Cruise Control Model**

Apply Laplace transform to $\dot{v} + \frac{b}{m}v = \frac{u}{m}$ with zero initial conditions.

$$V(s) = \frac{1/m}{s + b/m} U(s) = G(s)U(s), \ s \in \mathbb{C}$$

**Transfer Function**

![Transfer Function Diagram](image)

$Y(s) = G(s)U(s)$ **INPUT/OUTPUT DESCRIPTION**

**FREQUENCY DOMAIN – (s=j\omega)** **FREQUENCY RESPONSE**

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**Example: A Simple System; Cruise Control Model**

Introduce two variables *(states)* $x_1 = x, \ x_2 = \dot{x}$

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & -b/m \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ -1/m \end{bmatrix} u$$

Then

$$y = v = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

![State Space Diagram](image)

$\dot{x} = Ax + Bu$

$y = Cx + Du$ **STATE – SPACE or INTERNAL DESCRIPTION**
BASIC PERFORMANCE CRITERIA

- Stability
- Time response shape
- Frequency response shape

BASIC PERFORMANCE CRITERIA

Input/Output Stability

> *Bounded-Input Bounded-Output (BIBO) Stability*

For every bounded input the output of the system is bounded as well

![Diagram](image-url)

- BIBO stable
- BIBO unstable
BASIC PERFORMANCE CRITERIA

Internal Stability

➢ Asymptotic Stability

All states tend to zero as time tends to infinity for every initial condition.

\[ \text{inputs } u(t) \rightarrow \text{outputs } y(t) \]

\[ \text{states } x(t) \]

Asymptotically stable

Asymptotically unstable

BASIC PERFORMANCE CRITERIA

Time Response Shape

input \( u(t) \) \rightarrow output \( c(t) \)

\[ \text{steady-state error} \]

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WHAT IS FREQUENCY RESPONSE?

\[ G(j\omega) = M(\omega)\angle\phi(\omega) \]

- \[ f(t) \]
- \[ x(t) \]

Input

Output

\[ M_0 = M_1 M \]

\[ \phi_0 = \phi_1 + \phi \]
BASIC PERFORMANCE CRITERIA
Frequency Response Shape

The Control Design Trade–Off

\[ Y = Y_r + Y_d + Y_n = \frac{G_1G_2}{1+G_1G_2}R + \frac{G_2}{1+G_1G_2}D - \frac{G_1G_2}{1+G_1G_2}N \]

- If \( G_1 \gg \gg \) \( \Rightarrow \{Y_r = R, Y_d = 0 \text{ and } Y_n = -N\} \Rightarrow Y = R - N \)
- If \( G_1 \ll \ll \) \( \Rightarrow \{Y_r = 0, Y_d = G_2D \text{ and } Y_n = 0\} \Rightarrow Y = G_2D \)
THE CONTROL DESIGN TRADE – OFF

If \( G \gg \gg \) \( \Rightarrow \{ Y_r = R, \ Y_d = 0 \ \text{and} \ Y_n = -N\} \ \Rightarrow \ Y = R - N \)

If \( G \ll \ll \) \( \Rightarrow \{ Y_r = 0, \ Y_d = G_2D \ \text{and} \ Y_n = 0\} \ \Rightarrow \ Y = G_2D \)

- Make the controller gain \( G \), large at “low” frequencies so that the closed – loop system follows its reference input and rejects the external disturbances.
- Make the controller gain \( G \), small at “high” frequencies so that the closed – loop system rejects the measurement noise.
- Ensure reasonable gain and phase margins at crossover frequency for stability purposes.

Example: “Primitive” Pitch Control of the RPV XRAE-1

Open Loop XRAE-1 (Flight Controller Off)

Elevator \( \rightarrow \) XRAE-1 \( \rightarrow \) Pitch Angle

Open loop response to a step in the elevator of XRAE-1

Pitch angle (rads)

Time (secs)
Example: “Primitive” Pitch Control of the RPV XRAE-1

Closed Loop XRAE-1 (Flight Controller On)

- pitch angle demand
- elevator
- Flight controller $K$
- XRAE-1
- actual pitch angle

Closed loop step response of XRAE-1
Closed loop step response of XRAE-1

PID: A Commonly Used Controller

\[ R(s) \rightarrow E(s) \rightarrow N(s) \rightarrow \text{Controller } G_1(s) \rightarrow D(s) \rightarrow \text{Process } G_2(s) \rightarrow Y(s) \]

Proportional action

Integral action

Derivative action

\[ K_p \]

\[ K_i \int \]

\[ K_d \frac{d}{dt} \]

error signal

control signal