Lecture 1: Overview and modelling issues

1.1 Definitions

In this subject, we are concerned with "automatic control systems". Some dictionary definitions:

Automatic: able to activate, move or regulate itself

Control: command, direct, rule, check, limit, restrain, regulate or operate

System: a group or combination of interrelated, interdependent, or interacting elements forming a collective entity or

A system is an arrangement of physical components connected or related in such a manner as to form and/or act as an entire unit.

A control system is an arrangement of physical components connected or related in such a manner as to command, direct, or regulate itself or another system.

Control engineering is concerned with modifying the behaviour of dynamical systems in order to achieve desired goals.

In the most abstract sense, it is possible to consider every physical object a control system

In engineering and science, we usually restrict the meaning of control systems to apply to those systems whose major function is to dynamically or actively command, direct, or regulate.

1.2 The basic idea

Generally, we have a dynamical process or ‘plant’, the ‘output’ of which is of interest to us.

We may wish the output to be maintained at a desired level (the *regulator* problem) or to closely follow some specified time history (the *servo* problem).

A ‘controller’ interprets the specified ‘command input’ (the desired value) and applies an appropriate ‘control input’ to the plant so as to drive its output to the desired value.

In the case of ‘feedback’ control (discussed later in this subject), the form of the control input is determined on the basis of a comparison between the desired and actual values of the output.

The **“input”** is the stimulus, excitation or command applied to a control system, typically from an external energy source, usually in order to produce a specified response from the control system.

The **“output** “is the actual response obtained from a control system. It may or may not be equal to the specified response implied by the input.

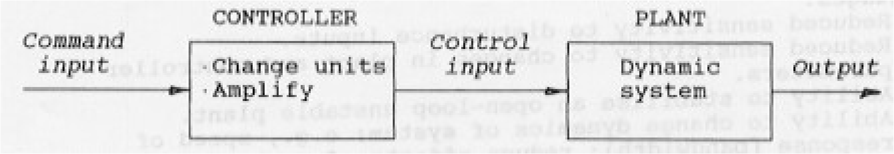
1.3 Historical examples

Class discussion

1.4 Open-loop and closed-loop systems

The distinction is determined by the control action, that quantity responsible for activating the system to produce the output.

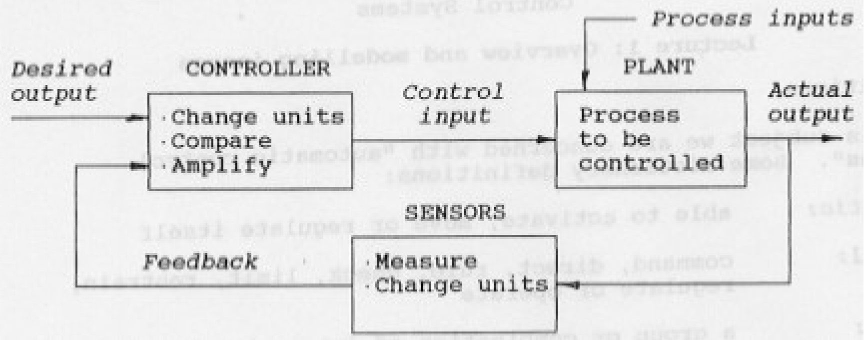
In an *open-loop* control system, the control input is independent of the plant output(s)



‘Block diagram’ of open-loop system

Examples: class discussion

In a *closed-loop* control system, the control input is somehow related to an output of the plant.



Block diagram of a closed-loop system

Examples: class discussion

1.5 Open-loop control

Is often used when:

1. Precise output control is not required.
2. Disturbances are not significant.
3. The input-output relationship of controlled system is *known* and *invariant*.

Advantages:

1. Stability is not a problem (if plant is stable).
2. Usually cheaper than closed-loop.
3. Can be used where the output cannot be (economically) measured.

Disadvantages:

1. Changes in calibration and disturbance inputs can result in uncontrolled errors.
2. Periodic calibration required--actually a form of closed-loop control!

Two outstanding features of open-loop control systems are:

1. Their ability to perform accurately is determined by their calibration. To calibrate means to establish or reestablish the input-output relation to obtain a desired system accuracy.

2. They are not usually troubled with problems of instability.

1.6 Closed-loop (feedback) control

Advantages:

1. Reduced sensitivity to disturbance inputs.
2. Reduced sensitivity to changes in plant and controller parameters.
3. Ability to stabilize an open-loop unstable plant.
4. Ability to change dynamics of system; e.g., speed of response (bandwidth); reduce effects of nonlinearities.

Disadvantages:

1. Increased complexity and cost.
2. Risk of instability.

Feedback is that property of a closed-loop system, which permits the output (or some other controlled variable) to be compared with the input to the system (or an input to some other internally situated component or subsystem) so that the appropriate control action may be formed as some function of the output and input.

Characteristics of Feedback

1. The presence of feedback typically imparts the following properties to a system.
2. Increased accuracy. For example, the ability to faithfully reproduce the input.
3. Tendency toward oscillation or instability.
4. Reduced sensitivity of the ratio of output to input to variations in system parameters and other characteristics.
5. Reduced effects of nonlinearities.
6. Reduced effects of external disturbances or noise.
7. Increased bandwidth. The bandwidth of a system is a frequency response measure of how well the system responds to (or filters) variations (or frequencies) in the input signal

1.7 Analog and Digital Control Systems

A signal dependent on a continuum of values of the independent variable t is called a continuous-time signal or, more generally, a continuous-data signal or (less frequently) an analog signal

A signal defined at, or of interest at, only discrete (distinct) instants of the independent variable t (upon which it depends) is called a discrete-time, a discrete data, a sampled-data, or a digital signal.

Continuous-time control systems, also called continuous-data control systems, or analog control systems, contain or process only continuous-time (analog) signals and components.
Discrete-time control systems, also called discrete-data control systems, or sampled data control systems, have discrete-time signals or components at one or more points in the system.

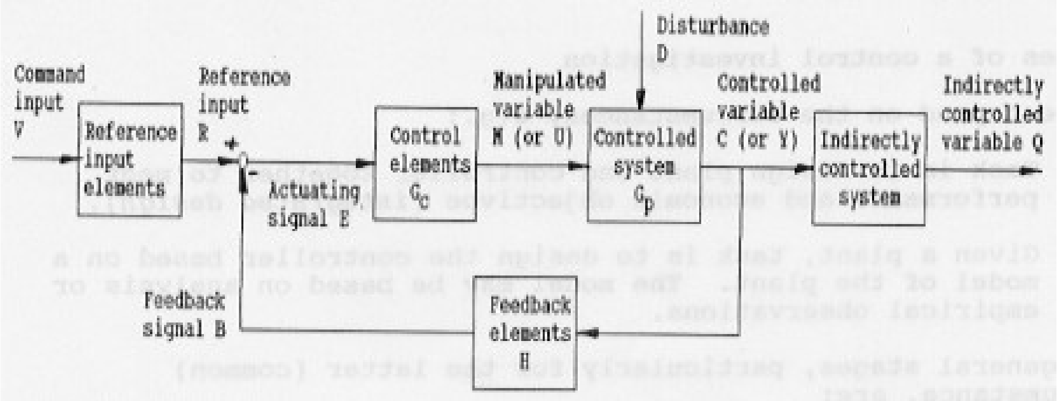
1.8 Control System Models or Representations

Three basic representations (models) of components and systems are used extensively in the study of control systems:

- Mathematical models, in the form of differential equations, difference equations, and/or other mathematical relations, for example, Laplace- and z-transforms
- Block diagrams
- Signal flow graphs

1.9 Standard notations

The following notations are commonly employed in texts on ‘classical control:



In ‘modern’ control theory, the control input is often denoted by *U*, and the plant output by *Y*. Some authors (e.g. Franklin and Powell) thus replace *M* by *U*, and *C* by *Y*.

1.10 Fields of control theory

‘Classical’ control

- Usually single-input, single-output (SISO) systems.
- Linear, time-invariant (LTI) systems.
- Design often involves a trial-and-error approach, using time and frequency domain analysis techniques (e.g. the Evans' root locus, Bode frequency response plots).
- Employs a *transfer function* representation of system.

‘Modern’ control

- Handles multiple-input, multiple-output (MIMO) systems naturally.
- Uses *state space* differential equation representation of systems.
- Explicit design procedures to get specified closed-loop characteristics (e.g. ‘pole placement’) or to satisfy performance criteria (e.g. ‘optimal’ control).

Other branches of control theory: (Fourth-year and beyond)

- Robust control
- Adaptive control
- Multivariable control
- Nonlinear control
- Stochastic control
- Distributed-parameter control
- Learning and self-organizing control
- Hierarchical control
- Intelligent control

Discrete-event control

1.11 Stages of a controller design problem

These depend on the circumstances; e.g.:

1. The task may be to design plant and controller together to meet performance and economic objectives (*integrated design*).
2. Given a plant, the task may be to design the controller based on a model of the plant. The model may be based on analysis or empirical observations.

In general, and particularly for the latter, more common instance, the stages of the design problem can be summarized as:

1. Define performance objectives: the required dynamic performance (precision, speed and stability of response to command and disturbance inputs).
2. Define constraints: technical, cost, etc.
3. Model the plant to be controlled.
4. Analyze the dynamic performance of model.
5. Design a control algorithm to modify the dynamics of the system so that the specified performance will be achieved.
6. Simulate the performance under operational conditions.
7. Evaluate the performance, cost, etc.
8. Accept the design or iterate through previous steps.

Trial-and-error is generally involved. Experience, judgement and some heuristics are available to guide the design process.

This subject is concerned with the modelling and analytical aspects of the above procedure. It provides the tools and (hopefully) the understanding of the system dynamics required for control design.