ECM2105

CONTROL ENGINEERING

Syllabus

Introduction

- How the Course Will Work
- Aims of the Module
- Control Applications
- Control System Design
- Open-Loop and Closed-Loop Control

Mathematical Foundation

- Complex Variable Concepts
- Laplace Transform -- Definition and Notation
- Properties and Theorems of Laplace Transform
- Inverse Laplace Transform and Partial Fraction Expansion
- Using Laplace Transforms to Solve Differential Equations

System Dynamics

- Mechanical Systems
- Electrical Systems
- Electrical and Mechanical Systems
- Linearisation of Nonlinear Systems

Transfer Functions and Block Diagrams

- Transfer Functions of Linear Systems
- Block Diagrams
- Multiple Inputs

System Response

- Response Analysis of First-Order Systems
- Second-Order Systems
- Sinusoidal Response of the System
- Polar (Nyquist) Plot
- Bode Diagrams

Feedback Control Systems

- Open and Closed-Loop Control Systems
- Sensitivity of Control Systems to Parameter Variation
- Disturbance Rejection
- Transient Response
- Steady-State Error
- Case Study -- Speed Control of a DC Motor
- The Stability of Linear Feedback Systems
- Three-Term PID Controller
- Control of First-Order Systems
- Proportional (P) Control of First-Order Systems
- Integral (I) Control of First-Order Systems
- PI Control of First-Order Systems
- Derivative (D) Control
- PD Control of Second-Order Systems
- PID Control

INTRODUCTION

1. How the Course Will Work

- Lectures + tutorials + computer labs + reading + course work + examination.
- Covering approximately two major parts: modelling and control.
- If you have problems, help will be available in the tutorials and computer lab sessions.
- The course will be mainly you working on the indicated exercises and course work within the guiding framework of the lectures.
- I need feedback – tell me if you haven't got a clue what I am taking about:
  M.M.Aziz@ex.ac.uk, Harrison 310

- Module web site (contains lecture handouts, assignments, tutorial sheets, and past exam papers):
  www.people.ex.ac.uk/mmaziz/ecm2105/ecm2105.html

1.1. Assessments

- 70% examination: 2hr end of module, section A/B style paper, closed book/note examination conditions.
- 30% coursework:
  - 5% tutorial attendance
  - 5% MATLAB worksheets
  - 20% Assignment – given out: Thursday 18th Feb 2010; hand-in: Tuesday 9th Mar 2010.

1.2. References

- Dorf and Bishop, "**Modern Control Systems**".
- Ogata, "**Modern Control Engineering**".
- Gene F. Franklin, "**Feedback Control of Dynamic Systems**".
- Norman S. Nise, "**Control System Engineering**".

2. Aims of the Module

You may ask the following questions before you start to learn this module:

- ➢ What is a control system?
- ➢ Why is control system design important?
- ➢ What are the basic components of a control system?
- ➢ What are the applications?
- ➢ Why is feedback incorporated into most control systems?

Aims of this module are:

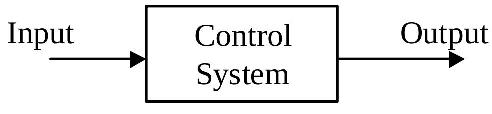
- Answer the above questions
- Understand why automatic control is useful for an engineering student
- Understand the essential dynamic concepts for typical engineering systems
- Recognise the value of integrated control and system design
- Understand key ideas and concepts: dynamics and feedback
- Know relevant mathematical theory
- Be able to solve simple control problems
- Recognise difficult problems
- Be aware of computational tools (e.g. MATLAB), and
- Appreciate the need for control in almost all branches of engineering systems design and operation.

3. Control Systems

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.

Each control system has ***input*** and ***output***:

> The ***input*** is the stimulus or excitation applied to a control system 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.

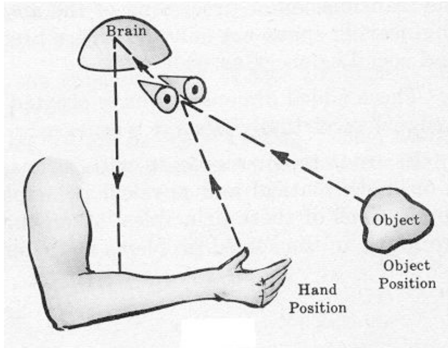


4. Control Applications

Control engineering is concerned with analysis and design of goal-oriented systems. The control of an industrial process (manufacturing, production, and so on) by automatic rather than manual means is called automation. Control systems play an increasingly important role in the development and advancement of modern civilisation and technology. Practically every aspect of our day-to-day activities is affected by some type of control systems, including the following areas: generation of energy, transmission of energy, communication, transportation (cars, trains, ships, aircrafts, space crafts), industrial processes, power systems, instrumentation, MicroElectroMechanical Systems (MEMS), robotics, consumer electronics, economy, biology, medicine, etc.

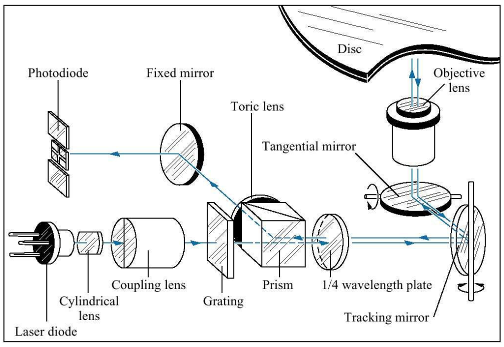
Typical examples are:

4.1. Biological system: reaching for an object



This control system consists of the brain, arm and hand and eyes. The brain sends the required nervous system signal to the arm and hand to reach the object. This signal is amplified in the muscles of the arm, which serve as actuators for the system. The eyes are employed as a sensing device, continuously "feeding back" the position of the hand to the brain.

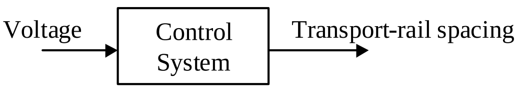
4.2. Tracking in a CD/DVD drive



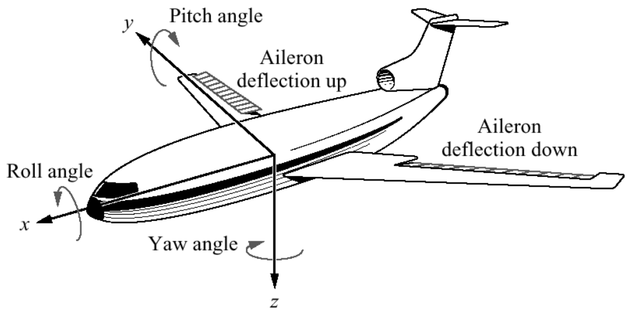
The reflected laser beam is used in a feedback control system to position and maintain the laser pickup assembly on the correct disk track.

4.3. Magnetic levitation transport

Transportation systems that use magnetic levitation can reach very high speeds, since contact friction at rails is eliminated. A control system is used to maintain a constant magnetic gap between the transport and the rail.



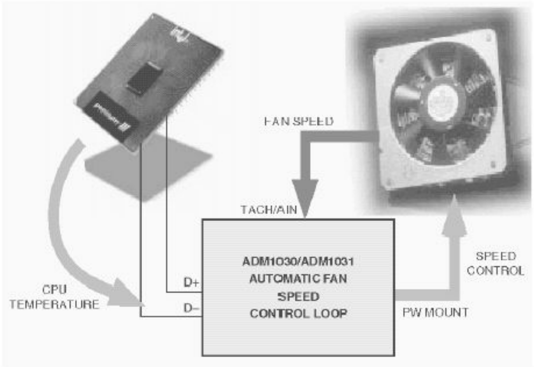
4.4. Aircraft autopilot



It consists of electrical, mechanical, and hydraulic devices that move the flaps, elevators, fuel-flow controllers, and other components that cause the aircraft to vary its flight. An *autopilot* mechanism maintain a specified airplane heading, despite atmospheric changes by measuring the actual airplane heading, and automatically adjusting the airplane control surfaces (rudder, flaps, etc.) so as to bring the actual airplane heading into correspondence with the specified heading.

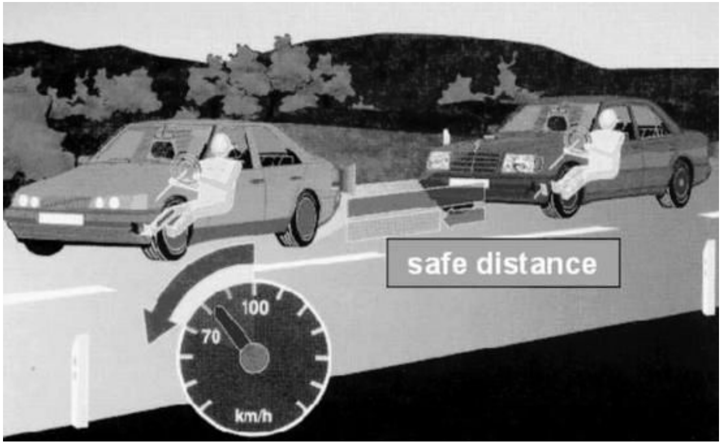
4.5. Hard-Disk Drive

Very high precision servo control system is used to position the read/write head (attached at the end of the arm) to the desired data track (~0.5μm wide) within 8ms while the disk is spinning at speeds over 5000rpm. The servo system must also cope with disturbances such as shock and movement.



4.6. Control of CPU temperature

The temperature of the microprocessor is constantly monitored and regulated by controlling the speed of the microprocessor fan.



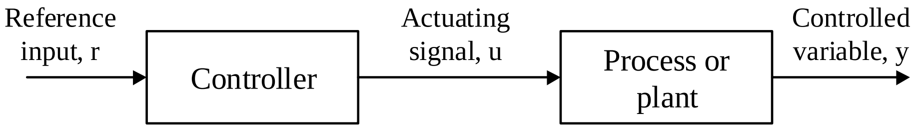
4.7. Adaptive cruise control

In addition to the standard cruise control system in cars that maintains constant acceleration irrespective of the road conditions, the adaptive cruise control systems uses radar or laser sensors to measure the distance to neighbouring cars and subsequently adjusts the speed to maintain a safe distance between the cars.

5. Open-Loop and Closed-Loop Control

5.1. Open-loop control systems

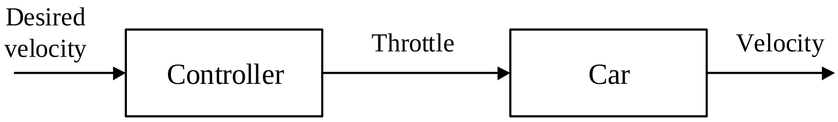
An ***open-loop*** control system utilises an actuating device to control the process directly, independent of the output. The elements of an open-loop control system can usually be divided into two parts: the *controller* and the *controlled process* or *plant* as shown in the block diagram.



An input signal or command r is applied to the controller (e.g. amplifier or mechanical linkage), whose output acts as the actuating signal u; the actuating signal then controls the process so that the controlled output y will perform according to some prescribed manner.

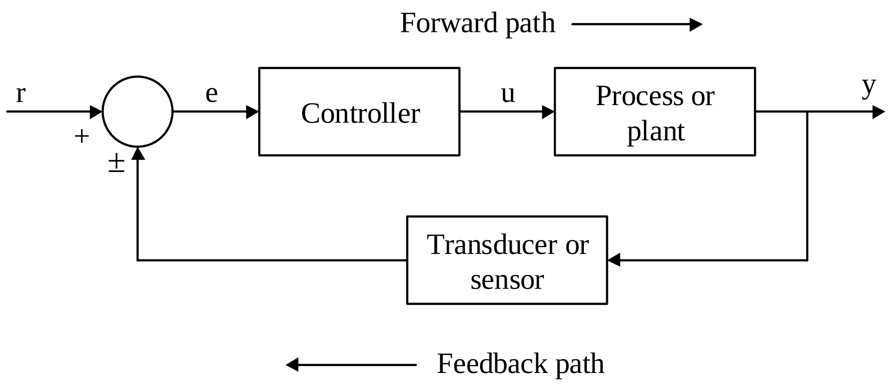
Examples:

Car speed control:



5.2. Closed-loop (feedback) control systems

A ***closed-loop*** control system is one in which the control action is somehow dependent on the output. The output y is fed-back and compared with the reference input r, and an error signal e is then generated and sent through the system to correct the error.



Plant: also called the **controlled system**, is the body, process, or machine, of which a particular quantity or condition is to be controlled.

Controller: or **control elements** are the components required to generate the appropriate control signal u applied to the plant.

***Reference input,* r**: is an external signal applied to a control system in order to command a specified action of the plant. It often represents ideal plant output behaviour.

***Controlled output,* y**: is that quantity or condition of the plant which is controlled.

***Error signal,* e**: or **control action** is the algebraic sum consisting of the reference input r plus or minus (usually minus) the feedback signal.

***Actuating signal,* u**: or **manipulated variable** is that quantity or condition which the controller apply to the plant.

Forward path: is the transmission path from the error signal e to the controlled output y.

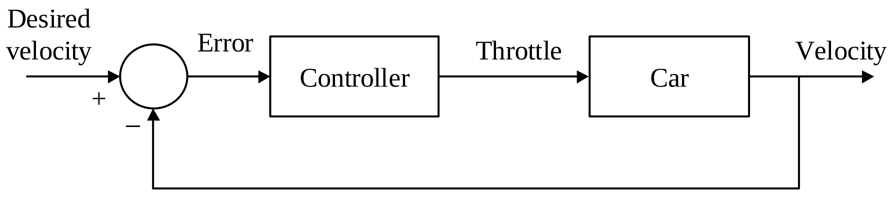
Feedback path: is the transmission path from the controlled output y to the summing point.

5.3. The idea of feedback

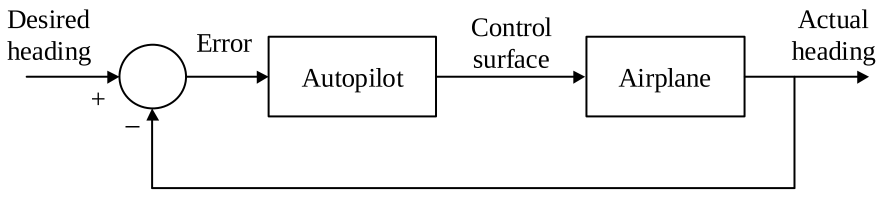
- Compare the actual result with the desired result.
- Take actions based on the difference.
- This seemingly simple idea is tremendously powerful.
- Feedback is a key idea in the discipline of control.

Examples:

Cruise control:



Autopilot:



6. Control System Design

The goal of control engineering design is to obtain the configuration, specification, and identification of the key parameters of a proposed system to meet the actual need.

- **Establishing system goals –** e.g. to control the velocity of a motor accurately
- **Identify the variables to control –** e.g. the speed of the motor
- **Establishing the system configuration and identifying the actuators and sensors –** e.g. the system structure electrical motor/hydraulic actuator/pneumatic actuator, tachometer/potentiometer/force sensor etc.
- **Obtaining a model of the process, the actuator, and the sensor –** e.g. $G(s) = k/(Ts + 1)$
- **Designing a controller –** e.g. PID controller
- **Simulation or experimental test –** e.g. MATLAB/Simulink, laboratory tests.

Example:
An innovation for a standard intermittent windshield wiper is the concept of a smart wiper that automatically adjusts its wiping cycle according to the intensity of rain. Sketch a block diagram of the wiper control system, identifying the function of each block, input variable, output variable and measured variable.

Example:
Many luxury automobiles have thermostatically controlled air-conditioning system for the comfort of the passengers. Sketch a block diagram of an air-conditioning system where the driver sets the desired interior temperature on a dashboard panel. Identify the function of each element of the thermostatically controlled cooling system and the desired input variable, output variable, and measured variable.

7. Summary

- Control engineering is a well-developed discipline with strong concepts, rich theory and effective design methods.
- Methodology for control system design
  - Modelling
  - Analysis and simulation
  - Design
  - Implementation
  - Commissioning and operation
- Control systems are everywhere.
- Control systems are increasingly mission critical.
- Use of feedback has often been revolutionary.