NAME 6503: Control Theory in Marine System Design

Chapter 1: Introduction to Control Systems

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INTRODUCTION TO CONTROL SYSTEM

Philosophical Viewpoints

- Engineering is concerned with understanding and controlling the materials and forces of the nature for the benefit of mankind.
- The present challenge to control engineers is the modeling and control of modern, complex, interrelated systems.

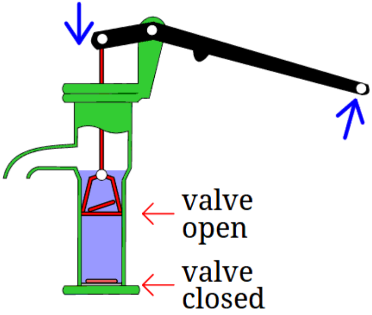
What is Control System?

At first, let us define:

- What is System?
- What is Control?

A System

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.



Examples: Hand Pump System

Control

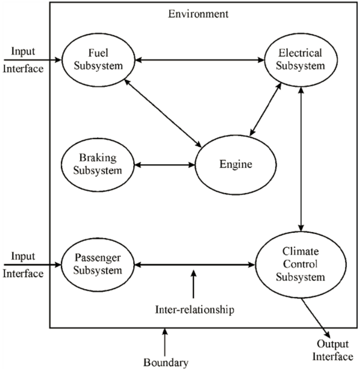
The word control is usually taken to mean regulate, direct or command.

Definition by DiStefano et al. (1995)

- 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.

Definition by Nise (2011)

- A control system consists of subsystems and processes (or plants) assembled for the purpose of obtaining a desired output with desired performance, given a specified input.



A car system and subsystems.

Definition by Dorf and Bishop (2011)

- A control system is an interconnection of components forming a system configuration that will provide a desired system response.
- The basis for analysis of a system is the foundation provided by linear cause-effect relationship for the components of a system.

What do we control?

- We control a component or a process or a plant.
- A component or process to be controlled can be represented by a block.
- The input-output relationship represents the cause-effect relationship of the process, which in turn represents processing of an input signal to provide an output signal.

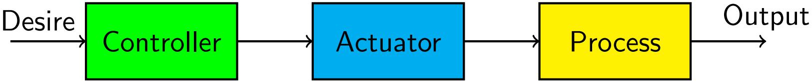
Types of Control Systems

Basically there are two types of control systems:

- Open-loop control system
- Closed-loop control systems

Open-loop control system

Dorf and Bishop (2011): An open-loop control system uses a controller and an actuator to obtain the desired response. An open-loop system is a system without feedback.



Example

An example of an open-loop control system is a toaster.

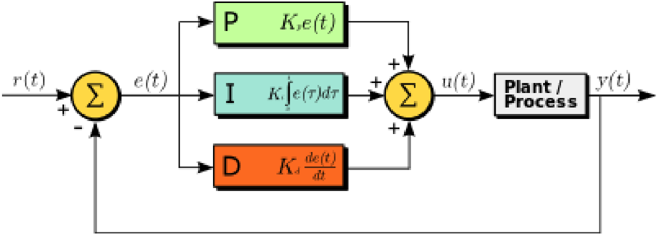
What is a controller?

In control theory, a controller is a device, historically using mechanical, hydraulic, pneumatic or electronic techniques often in combination, but more recently in the form of a microprocessor or computer, which monitors and physically alters the operating conditions of a given dynamical system. Typical applications of controllers are to hold settings for temperature, pressure, flow or speed.

Types of controller

There are various kinds of controllers:

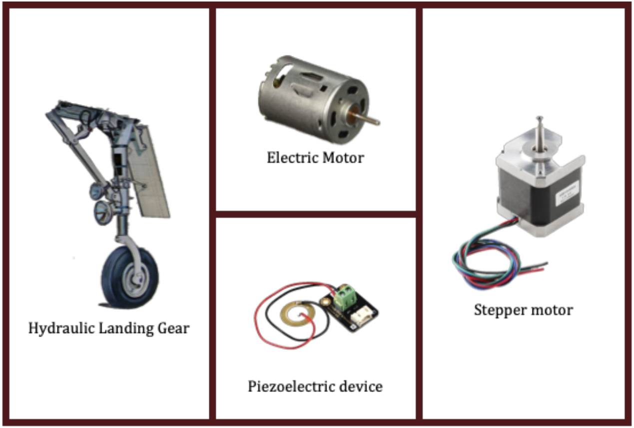
- Proportional, Integral and/or Derivative
- ANN based, Fuzzy logic based, Etc.
- Many others



What is an actuator?

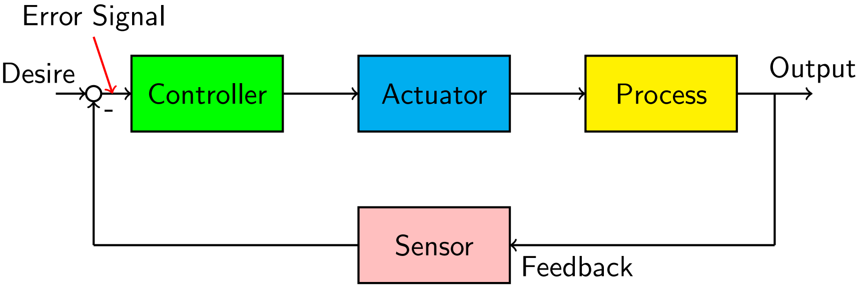
- An actuator is a device that provides the motive power to the process (Dorf and Bishop, 2011).
- An actuator is a power device that produces the input to the plant according to the control signal so that the output signal will approach the reference input signal (Ogata, 2010).
- Actuators are basically the muscle behind a mechatronics system that accepts a control command (mostly in the form of an electrical signal) and produces a change in the physical system by generating force, motion, heat, flow, etc. Normally, the actuators are used in conjunction with power supply and a coupling mechanism.

Example of actuators



Closed-loop control system

Dorf and Bishop (2011): A closed-loop control system uses a measurement of the output and feedback of this signal to compare it with the desired output (reference or command).



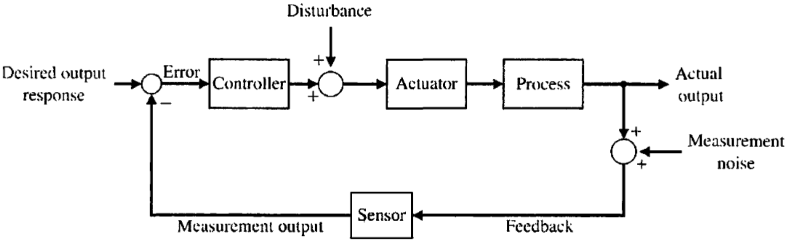
Example

An example of an closed-loop (feedback) control system is a toaster.

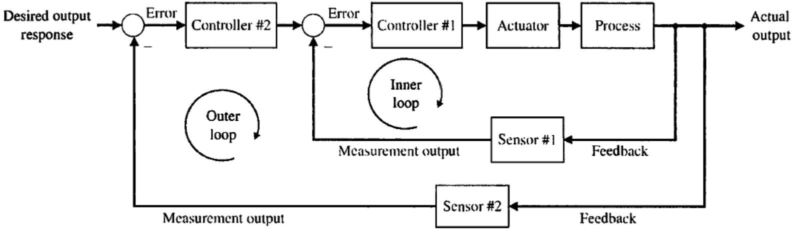
Let us exercise

1. Open-loop Control System
2. Closed-loop (Feedback) Control System

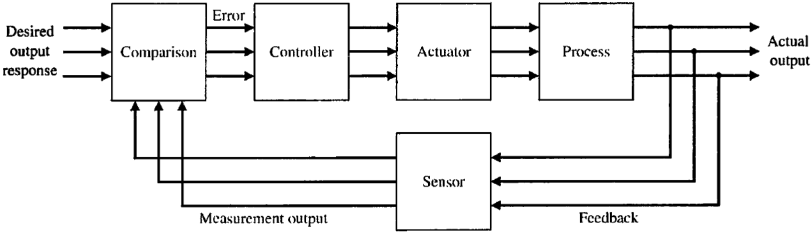
Closed-loop control system with disturbance and noise



Closed-loop control system with multiple loop



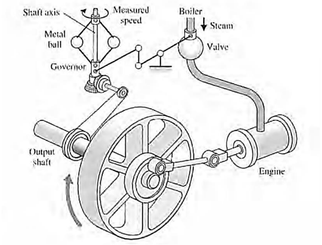
Closed-loop control system with multivariable

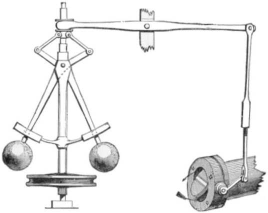


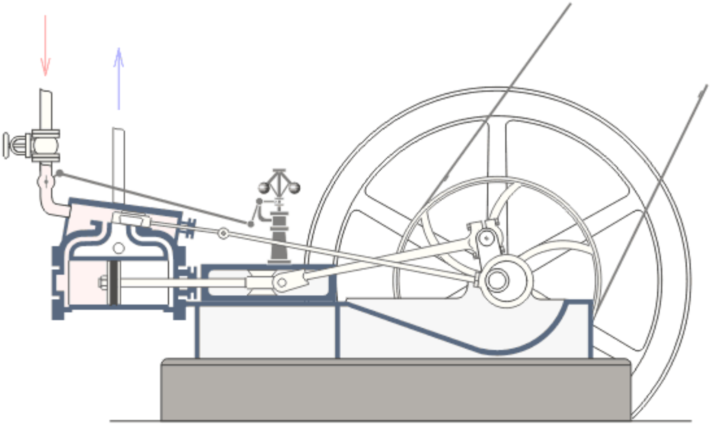
HISTORY OF AUTOMATIC CONTROL

James Watt's Flyball Governor

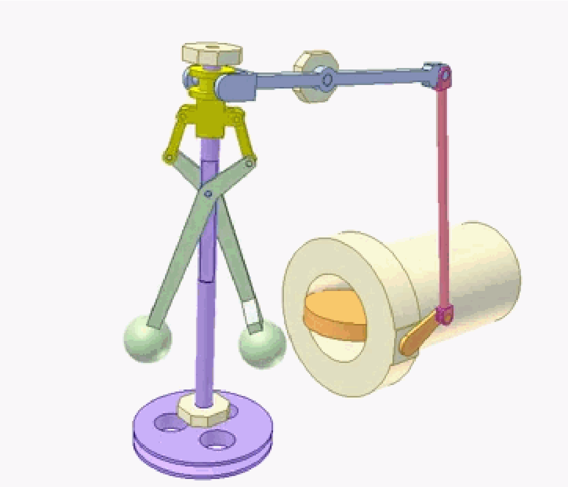
The first automatic feedback controller used in an industrial process is generally agreed to be James Watt's Flyball Governor, developed in 1769 for controlling the speed of a steam engine.







Steam Engine



Fly Ball Governor

Some Examples of Control Systems

Remember

In a closed-loop (feedback) control system the following items can exist:

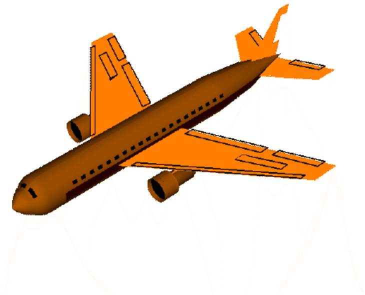
1. Plant
2. Desired output
3. Actual output
4. Controller
5. Actuator
6. Sensor
7. Disturbance
8. Noise

Example 1

Trapshooting

1. What is the desired output?
2. What is the actual output?
3. What is the controller?
4. What is the actuator?
5. What is the plant?
6. What is the sensor?
7. What is the disturbance?
8. What is the noise?

Example 2



1. What is the desired output?
2. What is the actual output?
3. What is the controller?
4. What is the actuator?
5. What is the plant?
6. What is the sensor?
7. What is the disturbance?
8. What is the noise?

Example 3

1. What is the desired output?
2. What is the actual output?
3. What is the controller?
4. What is the actuator?
5. What is the plant?
6. What is the sensor?
7. What is the disturbance?
8. What is the noise?

Example 4

1. What is the desired output?
2. What is the actual output?
3. What is the actuator?
4. What is the controller?
5. What is the plant?
6. What is the sensor?
7. What is the disturbance?
8. What is the noise?

Mechatronic Systems

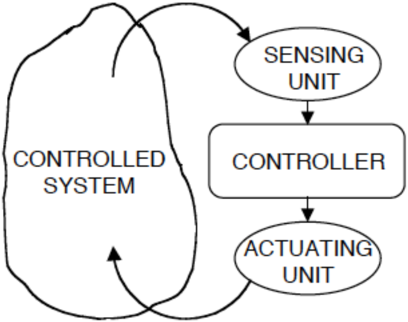
The term mechatronics was coined in Japan in the 1970s. Mechatronics is the synergistic integration of mechanical, electrical, and computer systems and has evolved over the past 30 years, leading to a new breed of intelligent products. Feedback control is an integral aspect of modern mechatronic systems. An example of mechatronic system is: Hybrid fuel vehicle.

Mechatronic Systems

The key elements of mechatronic systems are:

1. Physical systems modeling
2. Sensors and actuators
3. Signals and systems
4. Computers and logic systems
5. Software and data acquisition

Typical mechatronic system



Sensors

- Linear and Rotational: Contact, Infrared, Optical Encoders, Resistive, Tilt (Gravity), Capacitive, AC Inductive (LVDT, Resolver), DC Inductive (Hall Effect Switches, Analogue Hall Sensors, Tape Based Sensors), Ultrasonic, Magnetostrictive Time-of-flight, Laser Interferometry, Etc. types.
- Acceleration Sensors: Halit Eren,

See Chapter 16: Introduction to Sensors and Actuators - Bishop, R.H., 2002. The Mechatronics Handbook, CRC press.

Actuators

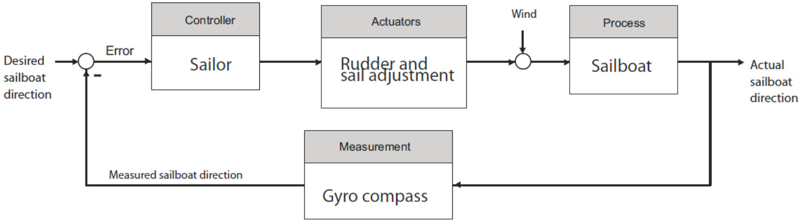
See Chapter 16: Introduction to Sensors and Actuators - Bishop, R.H., 2002. The Mechatronics Handbook, CRC press.

EXERCISES

Study the terms and concepts given at the end of the chapter.

E1.7: A sailboat cannot sail directly into the wind and travel straight downwind is usually slow. The shortest sailing distance is rarely a straight line. Thus using the sail and the rudder a sailboat tack upwind - a familiar zigzag course - and jibe downwind. A tactician's decision of when to tack when to jibe in addition to where to go can determine the outcome of a race in presence of random wind direction.
Sketch the whole process as a closed-loop feedback control system.

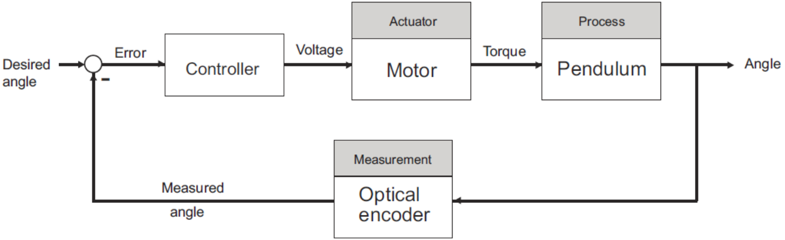
Solution


Desired sailboat direction
Error
-
Controller
Sailor
Actuators
Rudder and sail adjustment
Wind
Process
Sailboat
Actual sailboat direction
Measurement
Gyro compass
Measured sailboat direction

E1.9: Draw a block diagram of a closed-loop feedback control system for speed control of a motor cycle with a human driver. Consider wind effects on the motorcycle and speed breakers as individual disturbances in the system.

E1.13: Consider an inverted pendulum as shown in the Figure below. The objective is to keep the pendulum in the upright position, that is to keep $\theta_{desired} = 0$, in the presence of disturbances (wind and manual push). Sketch the block diagram of a feedback control system using the figure. Identify all important parts of the block diagram.

Solution:


Desired angle
Error
Controller
Voltage
Actuator
Motor
Torque
Process
Pendulum
Angle
Measurement
Optical encoder
Measured angle
–

P1.21: Consider a twin lift operation system above the Atlantic ocean using two helicopters as shown in the figure. The system shown in the figure is a typical "two-point pendent" twin lift configuration in the horizontal and vertical direction. The rotor speed enable the helicopters change altitude while the tilting the rotor axis enable the helicopters to change position in the horizontal direction. Develop a closed-loop feedback control system block diagram for the given problem.

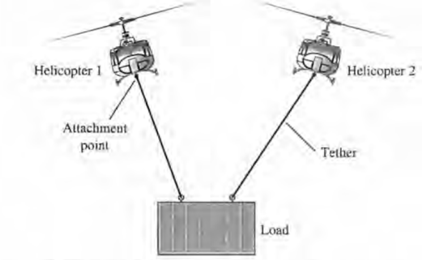
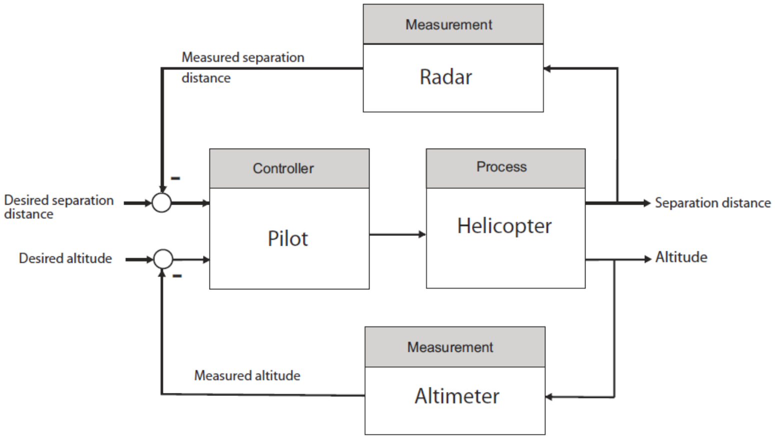


FIGURE P1.21 Two helicopters used to lift and move a large load.

A popular application!

The United States government dropped all of the defeated Decepticons into the Laurentian Abyss. It was hoped that the extreme pressure and temperature of the Abyss would destroy bodies of the Decepticons. The deployment of Megatron was done using a similar system.

Solution:


Measurement
Radar
Measured separation distance
Controller
Pilot
Process
Helicopter
Desired separation distance
Desired altitude
-
-
Separation distance
Altitude
Measurement
Altimeter
Measured altitude

Examples of Control Systems

Let's watch a video!

These are the top 10 coolest robots:

1. Robot fish
2. Robot bird
3. Robot spider
4. Robot octopus
5. Robot squid
6. Robot shark
7. LS3 (Legged Squad Support System)
8. The Cheetah
9. Robot snake
10. Salamander Robot