Unit 7: Control systems

(6 lessons allotted)

1. Introducing control systems

Control systems is about software interacting with and controlling hardware. The software and hardware operating together can be referred to as a system.

One might instinctively think of robotics, but control systems encompasses a much wider, diverse range of technologies. Many we use every day. Consider the following:

- Elevators
- Octopus gates
- Vending machines
- McDonalds food ordering
- Airport HKID gates
- Microwaves, kitchen appliances
- Washing machine
- Home security systems
- Air Conditioning systems
- Pacemakers (heart monitors), automated wearable insulin monitors (diabetes patients)
- Automated sensor doors
- Cruise control and power steering in a car

Why use automated control systems?

- Computers can respond very quickly to any change of state
- Computers can run 24/7 without needing a rest
- Computers can operate in hazardous environments
- Computers are consistent

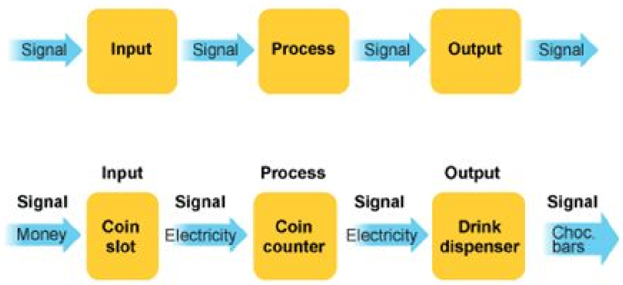
On the other hand…

- Computers require electricity
- Computers can only respond to anticipated events as per their programming

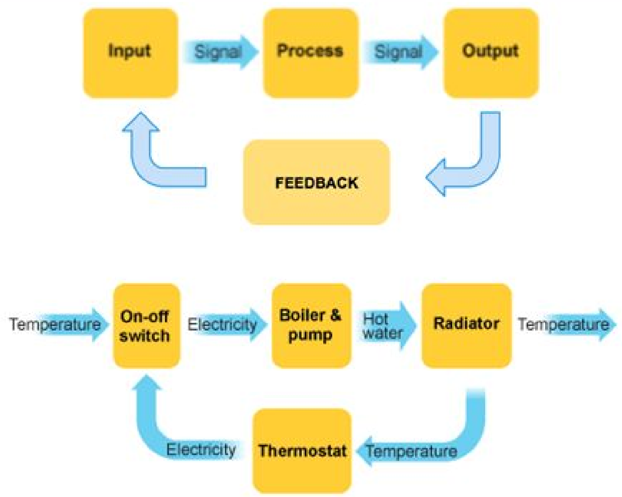
1.2 Open and closed loop systems

There is commonly a cyclic relationship between a sensor, the processor and an output transducer. This can be either an open-loop or a closed-loop depending on the circumstance. The difference between the two is the role that feedback plays within the system. If the output has a direct bearing on future inputs, then it is said to be a closed loop system.

OPEN LOOP SYSTEM



CLOSED LOOP SYSTEM



What other examples could we illustrate with?

2. Components in a control system

Microcontrollers & microprocessors

Microprocessor	Microcontroller
Flexible processor used for intensive computing such as in laptops, mobile phones etc.	It is used where the task is fixed and predefined, generally embedded systems.
Consists of just a CPU	Consists of a CPU, RAM and I/O interface all integrated into the one chip
Uses external bus to interface with RAM, ROM and peripherals	Uses an internal bus to interface with it's own RAM and ROM

An example of each that we may use:

The **Raspberry Pi** is a fully capable computer reduced to the size of a credit card. To function, it requires you provide it with a disk storage device containing an operating system to boot. It will boot as a fully interactive computer with keyboard, mouse and monitor functionality. You can open and close programs just like a normal computer. The Raspberry Pi 4 uses a Broadcom BCM2711 chip which is a 64 bit 1.4 GHz quad-core ARM processor. It has between 2GB to 8GB of RAM (depending on your model), and whatever quantity of non-volatile storage you choose to attach via the SD card slot.	The **Arduino Uno** is a microcontroller based board. Rather than booting into an operating system you can interact with, you write your software on a separate computer and upload it to the chip of the Arduino. When powered on, the Arduino will execute that one program you uploaded and that's all that will happen until you upload a new program. The Arduino Uno contains an ATmega328P chip which is an 8 bit 16MHz single core processor. It has 2 KB of operating SRAM and 32 KB of non-volatile flash memory to store the program and data when powered off.

Sensors, transducers & actuators

Definitions:

- Sensor: a device which detects or measures a physical property and records, indicates, or otherwise responds to it.
- Transducer: a device that converts variations in a physical quantity, such as pressure or brightness, into an electrical signal, or vice versa.
- Actuator: A device that moves or controls some mechanism. An actuator turns a control signal into mechanical action such as an electric motor.

Active & passive sensors

Sensors can be broadly categorised into two types: active and passive.

- Active sensors require an external power supply to operate, called an excitation signal which is used by the sensor to produce the output signal. Active sensors can also produce signal amplification.
- A passive sensor does not need any additional power source or excitation voltage. Instead a passive sensor generates an output signal in response to some external stimulus.

The ultrasonic sensor is active as it requires power to be supplied to it in order to function.

The light dependant resistor is passive as no power supply is required, its resistance is changing continually based on the light shining on it whether you are using it in a circuit, or it is just sitting in a drawer somewhere.

Analogue & digital sensors

Sensors can also be categorised into analogue or digital.

- Analogue sensors produce a voltage or signal output response which is proportional to the change in the quantity that they are measuring (the stimulus).
  - Eg: accelerometers, pressure sensors, light sensors, sound sensors, temperature sensors

- Digital Sensors produce a discrete output. Typically representing a binary number such as a logic level "0" or a logic level "1" (more on this later).
  - Eg: proximity sensor, IR sensor, PIR sensor

Common sensors

There are a lot of common sensors easily available to hobbyists through stores like adafruit.com.

Spend a little time exploring the types of sensors available and complete the following table:

Category	Example sensor found	Active or passive?	Analog or digital?
Light			
Temperature			
Force/pressure			
Sound			
Location			
Proximity			
Orientation			

More on Digital and analogue I/O

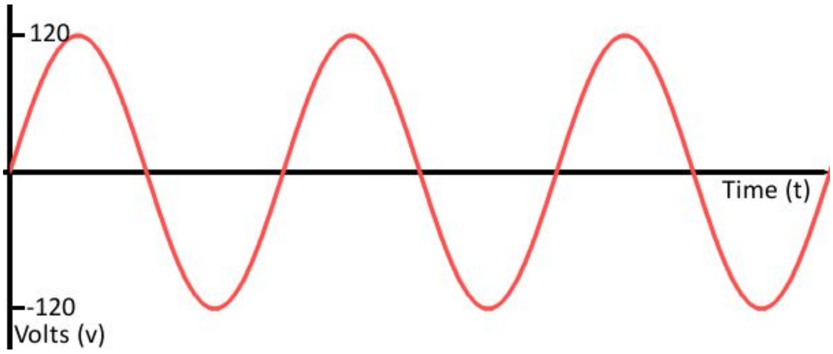
We live in an analog world. There are an infinite amount of colors to paint an object (even if the difference is indiscernible to our eye), there are an infinite number of tones we can hear, and there are an infinite number of smells we can smell. The common theme among all of these analog signals is their infinite possibilities.

Digital signals and objects deal in the realm of the discrete or finite, meaning there is a limited set of values possible. That could mean just two total possible values, 255 values (8 bit), or even 4,294,967,296 (32 bit), or anything else as long as it's not ∞ (infinity).

Working with electronics means dealing with both analog and digital signals, inputs and outputs. Our projects have to interact with the real, analog world in some way, but most of our microprocessors, computers, and logic units are purely digital components.

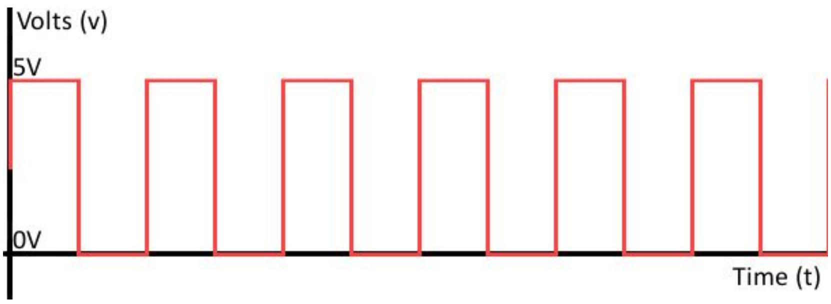
These signals are best thought of as time-varying "quantities" which convey some sort of information. In electrical engineering the quantity that's time-varying is usually voltage (if not that, then usually current). So when we talk about signals, just think of them as a voltage that's changing over time.

Signals are passed between devices in order to send and receive information, which might be video, audio, or some sort of encoded data. Usually the signals are transmitted through wires,

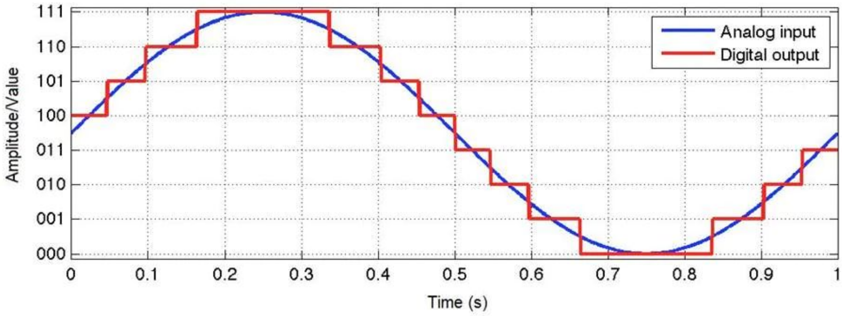


While these signals may be limited to a range of maximum and minimum values, there are still an infinite number of possible values within that range. For example, the analog voltage coming out of your wall socket might be clamped between -120V and +120V, but, as you increase the resolution more and more, you discover an infinite number of values that the signal can actually be (like 64.4V, 64.42V, 64.424V, and infinite, increasingly precise values).

Digital signals must have a finite set of possible values. The number of values in the set can be anywhere between two and a-very-large-number-that's-not-infinity. Most commonly digital signals will be one of two values -- like either 0V or 5V. Timing graphs of these signals look like square waves.



A digital signal can be a discrete representation of an analog waveform. Viewed from afar, the wave function below may seem smooth and analog, but when you look closely there are tiny discrete steps as the signal tries to approximate values:



That's the big difference between analog and digital waves. Analog waves are smooth and continuous, digital waves are stepping, square, and discrete.

Discussion questions

- When would it be more appropriate to use a digital v analogue input device?
- How can an analogue input be read by our digital computer systems (suggest: use an analogue input with a Raspberry Pi or Arduino to figure this out)

What input devices would be best suited for...?

- Measure traffic at intersections?
- Detect fire, smoke or a toxic gas?
- The size of a load in a washing machine?
- An elevator detecting when it has reached (and is exactly level with) a particular floor?
- Detect altitude and orientation of an airliner?
- Detect wind speed and direction?
- Maintain the temperature in a climate control system?

Brainstorm other familiar situations where there could be a computer with an input device. What input devices would be best suited for that situation?

Sources
https://learn.sparkfun.com/tutorials/analog-vs-digital
https://www.arrow.com/en/research-and-events/articles/engineering-resource-basics-of-analog-to-digital-converters
https://www.allaboutcircuits.com/projects/using-the-arduinos-analog-io/

3. Centralised vs distributed control

(Hong Kong's MTR control room)

Control systems deployed in industry may be either centrally controlled or use a distributed system of control.

Distributed control system (DCS) usually has many control loops, in which autonomous controllers are distributed throughout the system, but there is no central operator supervisory control. Control is more localized.

Centralized controllers use either discrete controllers located at a central control room or within a central computer. In a centrally controlled system, all sensors and transducers run cabling (or wireless signal) over a network back to a central control system.

Each method comes with it's own advantages and disadvantages.

- Pro: Cost, performance, scalability, reliability
- Con: Bandwidth, Security, Complexity

Processes where a DCS might be used include:

- Chemical plants
- Petrochemical (oil) and refineries
- Pulp and paper mills (see also: quality control system QCS)
- Boiler controls and power plant systems
- Nuclear power plants
- Environmental control systems
- Water and sewage treatment plants
- Sewage treatment plants

Increasingly, and ironically, DCS are becoming centralised at plant level, with the ability to log into the remote equipment. This enables operators to control both at enterprise level (macro) and at the equipment level (micro), both within and outside the plant, because the importance of the physical location drops due to interconnectivity primarily thanks to wireless and remote access.

Whether DCS will lead to the Industrial Internet of Things (IIOT) remains to be seen.

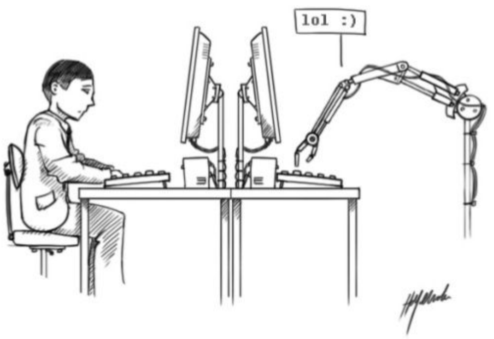
Many vendors provide the option of a mobile HMI (human-machine-interface), ready for both Android and iOS. With these interfaces, the threat of security breaches and possible damage to plant and process are now very real.

src

4. Autonomous systems

An autonomous agent is an intelligent agent operating on an owner's behalf but without any interference of that ownership entity. (Wikipedia, 2017)

What is an Autonomous Agent? The old answer...



The defining metaphor of an autonomous agent is the thinking machine.

They are (usually) designed in interact with their environment:

- Their behaviour is action-driven.
- Their physical implementation is important - at least their ability to manipulate symbols
- They do things in the physical world
- They go where humans do not (can not) go - eg: planetary rovers

It has been suggested agenthood of a computer system is restricted to the following (Woolridge et al 1995):

- Autonomy: being in control of its own actions
- Reactivity: reacts to events in its environment
- Proactivity: the ability to act of its own initiative
- Sociality: the ability to interact with other agents

From [Federico Gobbo, 2013]

Example: Self driving cars. When not everything is within the systems control.

5. Ethical considerations

Control systems, commonly also referred to as embedded systems, come with a range of social and ethical issues.

Some examples:

- Employee Monitoring: How Far is Too Far?
  http://www.innovativeemployeesolutions.com/articles/employeemonitoringhowfaristoofar/
- Should school children have tracking chips?
  http://blogs.discovery.com/inscider/2013/04/shouldchildrenhavetrackingchips.html
- U.S. Confirms That It Gathers Online Data Overseas
  http://www.nytimes.com/2013/06/07/us/nsaverizoncalls.html
- Satellite tracking for criminals
  http://news.bbc.co.uk/2/hi/uk_news/3620024.stm
- After Boston: The pros and cons of surveillance
  http://www.cnn.com/2013/04/26/tech/innovation/securitycamerasbostonbombings/
- Automating jobs traditionally performed by people
- Automated safety systems
- Driverless trains (South Island MTR in HK, some lines of Singapore MTR, Lausanne Metro)
- Driverless buses, here is one I took a ride on in Sion.

6. Practical task

I have a range of microcontroller and microprocessor boards available for you to experiment with.

Your task:

- Select one of the boards, either:
    - Raspberry Pi
    - Arduino Uno
    - Circuit Python

- Select a sensor or actuator from the list available, typically:
    - Ultrasonic
    - LEDs
    - 9g Servo
    - Neopixel LED ribbon
    - Momentary push button
    - IR LED

- Research into how to use your component with your selected board.

- Produce an instructions document you will submit to Google Classroom and share with your classmates, detailing:

1. Overview of sensor/actuator
    - What is it measuring / controlling?
    - Is it digital or analog?
    - Is it active or passive?
    - What do the signals represent?
    - What is the valid range of voltages in/out?

2. How to wire the sensor/actuator to your microcontroller/processor? (ie: hardware instructions)

    Include photos of your successful wiring with annotations of key details.

3. How to program your microcontroller/processor to interact with the sensor/actuator? (ie: software instructions).

    Include example source code you were successful with.