

Electronic Circuits

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Sensors and actuators

- Introduction
- Describing sensor performance
- Sensors
- Actuators
- Laboratory measuring equipment.

Introduction

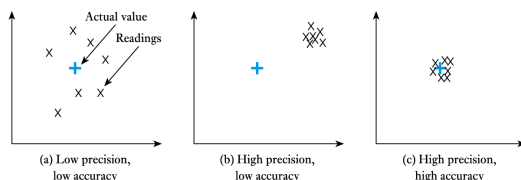
- To be useful, systems must interact with their environment. To do this they use sensors and actuators.
- Sensors and actuators are examples of **transducers**.
A transducer is a device that converts one physical quantity into another.
 - examples include:
 - a mercury-in-glass thermometer (converts temperature into displacement of a column of mercury)
 - a microphone (converts sound into an electrical signal).
- We will look at both **sensors** and **actuators** in this lecture.

Describing sensor performance

- **Range**
 - maximum and minimum values that can be measured.
- **Resolution or discrimination**
 - smallest discernible change in the measured value.
- **Error**
 - difference between the measured and actual values.
 - random errors
 - systematic errors
- **Accuracy, inaccuracy, uncertainty**
 - accuracy is a measure of the maximum expected error.

Describing sensor performance (contd.)

- **Precision**
 - a measure of the lack of random errors (scatter)



Error, Accuracy, and Precision

Experimental uncertainty is part of all measurements. **Error** is the difference between the true or best accepted value and the measured value. **Accuracy** is an indication of the range of error in a measurement.

Precision is a measure of repeatability.



Describing sensor performance (contd.)

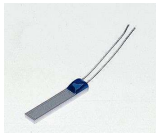
- **Linearity**
 - maximum deviation from a 'straight-line' response
 - normally expressed as a percentage of the full-scale value
- **Sensitivity**
 - a measure of the change produced at the output for a given change in the quantity being measured.

Sensors

- Almost any physical property of a material that changes in response to some excitation can be used to produce a sensor.
 - Widely used sensors include those that are:
 - resistive
 - inductive
 - capacitive
 - piezoelectric
 - photoresistive
 - elastic
 - thermal.
 - In this lecture we will look at several examples.

Temperature sensors

- **Resistive thermometers**
 - typical devices use platinum wire (such a device is called a **platinum resistance thermometers** or PRT)
 - *linear* but has poor *sensitivity*.



A typical PRT element



A sheathed PRT

Temperature sensors (contd.)

- **Thermistors**
 - use materials with a high thermal coefficient of resistance
 - *sensitive* but highly *non-linear*.



A typical disc thermistor



A threaded thermistor

Temperature sensors (contd.)

- **pn junctions**
 - a semiconductor device with the properties of a diode (we will consider semiconductors and diodes later)
 - *inexpensive, linear* and *easy to use*
 - *limited temperature range* (perhaps -50°C to 150°C) due to nature of semiconductor material.



pn-junction sensor

Light sensors

- **Photovoltaic**
 - light falling on a *pn-junction* can be used to generate electricity from light energy (as in a **solar cell**).
 - small devices used as sensors are called **photodiodes**.
 - fast acting, but the voltage produced is *not* linearly related to light intensity.

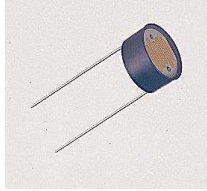


A typical photodiode

Light sensors (contd.)

• Photoconductive

- such devices do not produce electricity, but simply change their resistance.
- photodiodes (as described earlier) can be used in this way to produce linear devices.
- phototransistors act like photodiodes but with greater sensitivity.
- light-dependent resistors (LDRs) are slow, but respond like the human eye.

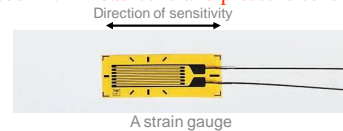


A light-dependent resistor (LDR)

Force sensors

• Strain gauge

- stretching in one direction increases the resistance of the device, while stretching perpendicular to this has little effect
- can be bonded to a surface to measure strain
- used within load cells and pressure sensors.



Displacement sensors

• Potentiometers

- resistive potentiometers are one of the most widely used forms of position sensor.
- can be angular or linear.
- consists of a length of resistive material with a sliding contact onto the resistive track.
- when used as a position transducer a potential is placed across the two end terminals, the voltage on the sliding contact is then proportional to its position.
- an inexpensive and easy to use sensor.

Displacement sensors (contd.)

• Inductive proximity sensors

- coil inductance is greatly affected by the presence of ferromagnetic materials.
- here the proximity of a ferromagnetic plate is determined by measuring the inductance of a coil.

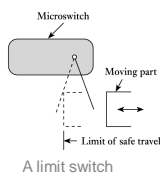


Inductive proximity sensors

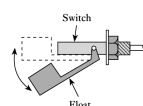
Displacement sensors (contd.)

• Switches

- simplest form of *digital* displacement sensor
- many forms: lever or push-rod operated microswitches, float switches, pressure switches, etc.



A limit switch

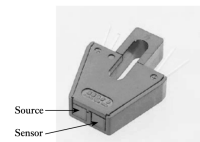


A float switch

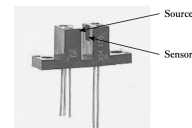
Displacement sensors (contd.)

• Opto-switches

- consist of a light source and a light sensor within a single unit.
- 2 common forms are the reflective and slotted types.



A reflective opto-switch

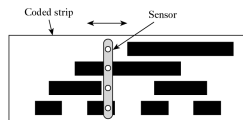


A slotted opto-switch

Displacement sensors (contd.)

- **Absolute position encoders**

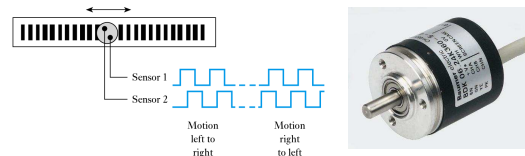
- A pattern of light and dark strips is printed on to a strip and is detected by a sensor that moves along it.
 - The pattern takes the form of a series of lines as shown below.
 - It is arranged so that the combination is unique at each point.
 - Sensor is an array of photodiodes.



Displacement sensors (contd.)

- **Incremental position encoder**

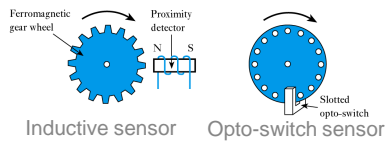
- uses a single line that alternates black/white
 - two slightly offset sensors produce outputs as shown below
 - detects motion in either direction, pulses are counted to determine absolute position (which must be initially reset).



Displacement sensors (contd.)

- **Other counting techniques**

- several methods use counting to determine position
 - two examples are given below.



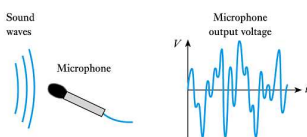
Motion sensors

- Motion sensors measure quantities such as velocity and acceleration.
 - Can be obtained by differentiating displacement
 - Differentiation tends to amplify high-frequency noise.
- Alternatively can be measured directly
 - some sensors give velocity directly
 - e.g. measuring frequency of pulses in the counting techniques described earlier gives speed rather than position.
 - some sensors give acceleration directly
 - e.g. accelerometers usually measure the force on a mass.

Sound sensors

- **Microphones**

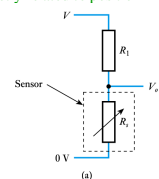
- a number of forms are available
 - e.g. carbon (resistive), capacitive, piezoelectric and moving-coil microphones
 - moving-coil devices use a magnet and a coil attached to a diaphragm.



Sensor interfacing

- **Resistive devices**

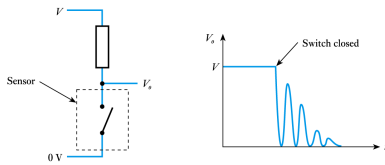
- can be very simple
 - e.g. in a potentiometer, with a fixed voltage across the outer terminals, the voltage on the third is directly related to position
 - where the resistance of the device changes with the quantity being measured, this change can be converted into a voltage signal using a potential divider – as shown
 - the output of this arrangement is *not* linearly related to the change in resistance.



Sensor interfacing (contd.)

- **Switches**

- switch interfacing is also simple
 - can use a single resistor as below to produce a voltage output
 - all mechanical switches suffer from **switch bounce**.



Sensor interfacing (contd.)

- **Capacitive and inductive sensors**

- Sensors that change their capacitance or inductance in response to external influences normally require the use of alternating current (AC) circuitry.
- Such circuits need not be complicated.
- We will consider AC circuits in later lectures.

Actuators

- In order to be useful an electrical or electronic system must be able to affect its external environment. This is done through the use of one or more **actuators**.
- As with sensors, actuators are transducers, which convert one physical quantity into another.
- Here we are interested in actuators that take electrical signals from our system and from them vary some external physical quantity.

Heat actuators

- Most heat actuators are simple **resistive heaters**.
- For applications requiring a few watts ordinary **resistors** of an appropriate power rating can be used.
- For higher power applications there are a range of **heating cables** and **heating elements** available.

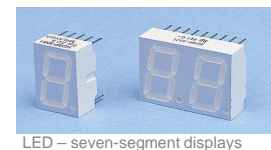
Light actuators

- For general illumination it is normal to use conventional **incandescent light bulbs** or **fluorescent lamps**.
 - power ratings range from a fraction of a watt to perhaps hundreds of watts
 - easy to use but relatively slow in operation
 - unsuitable for signalling and communication applications.

Light actuators (contd.)

- **Light-emitting diodes (LEDs)**

- produce light when electricity is passed through them.
- a range of semiconductor materials can be used to produce light of different colours.
- can be used individually or in multiple-segment devices such as the seven-segment display shown here.



Light actuators (contd.)

- **Liquid crystal displays**

- consist of 2 sheets of polarised glass with a thin layer of oily liquid sandwiched between them.
- an electric field rotates the polarization of the liquid making it opaque.
- can be formed into multi-element displays (such as 7-segment displays).
- can also be formed into a matrix display to display any character or image.



A custom LCD display

Light actuators (contd.)

- **Fibre-optic communication**

- used for long-distance communication
- removes the effects of ambient light
- fibre-optic cables can be made of:
 - **optical polymer**
 - inexpensive and robust
 - high attenuation, therefore short range (up to about 20 metres)
 - **glass**
 - much lower attenuation allowing use up to hundreds of kilometres
 - more expensive than polymer fibres
- light source would often be a **laser diode**.

Force, displacement and motion actuators

- **Solenoids**

- basically a coil and a ferromagnetic 'slug'
- when energised the slug is attracted into the coil
- force is proportional to current
- can produce a force, a displacement or motion
- can be linear or angular
- often used in an ON/OFF mode.



Small linear solenoids

Force, displacement and motion actuators (contd.)

- **Meters**

- **moving-iron**
 - effectively a rotary solenoid plus spring
 - can measure DC or AC
- **moving-coil**
 - most common form
 - deflection proportional to average value of current
 - full scale deflection typically 50 μ A – 1 mA



Moving-coil meters

Force, displacement and motion actuators (contd.)

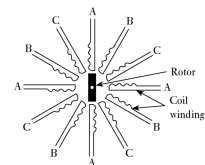
- **Motors**

- three broad classes
 - **AC motors**
 - primarily used in high-power applications
 - **DC motors**
 - used in precision position-control applications
 - **Stepper motors**
 - a digital actuator used in position control applications.

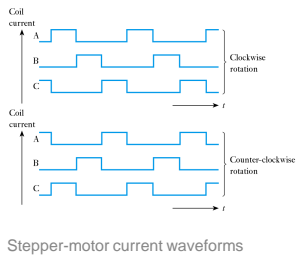
Stepper motors

- **Stepper motors**

- a central rotor surrounded by a number of coils (or windings)
- opposite pairs of coils are energised in turn
- this 'drags' the rotor round one 'step' at a time
- speed proportional to frequency
- typical motor might require 48-200 steps per revolution.



Stepper motors (contd.)



A typical stepper-motor

Stepper-motor current waveforms

Sound actuators

- **Speakers**
 - usually use a permanent magnet and a movable coil connected to a diaphragm.
 - input signals produce current in the coil causing it to move with respect to the magnet.
- **Ultrasonic transducers**
 - at high frequencies speakers are often replaced by piezoelectric actuators
 - operate over a narrow frequency range.

Actuator interfacing

- **Resistive devices**
 - Interfacing involves controlling the power in the device.
 - In a resistive actuator, power is related to the voltage.
 - For high-power devices the problem is in delivering sufficient power to drive the actuator.
 - High-power electronic circuits will be considered later.
 - High-power actuators are often controlled in an ON/OFF manner.
 - These techniques use electrically operated switches
 - discussed in later lectures.

Actuator interfacing (contd.)

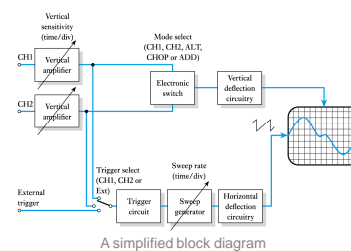
- **Capacitive and inductive devices**
 - Many actuators are capacitive or inductive (such as motors and solenoids).
 - These create particular problems – particularly when using switching techniques.
 - We will return to look at these problems when we have considered capacitors and inductors in more detail.

Laboratory measuring instruments

- Often the object of sensing a physical quantity is to **measure** it.
- Here we will look at three forms of measuring instrument:
 - analogue oscilloscope
 - digital oscilloscope
 - digital multimeter.

Analogue oscilloscope

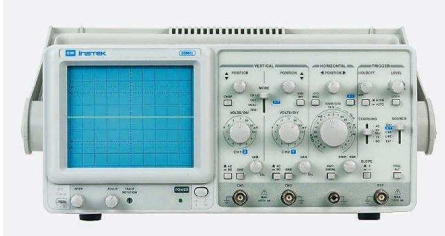
- An oscilloscope displays voltage waveforms.



A simplified block diagram

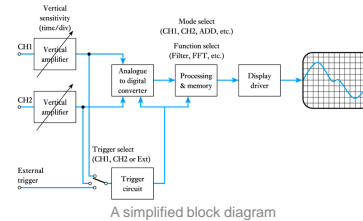
Analogue oscilloscope (contd.)

- A typical analogue oscilloscope



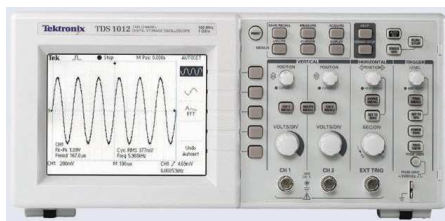
Digital oscilloscope

- Digital oscilloscopes use an analogue-to-digital converter (ADC) and appropriate processing.



Digital oscilloscope (contd.)

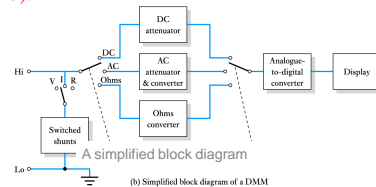
- A typical digital oscilloscope



Digital multimeters

- **Digital multimeters (DMMs)** are often (inaccurately) referred to as **digital voltmeters** or **DVMs**.

– At their heart is an analogue-to-digital converter (ADC).



Digital multimeters (contd.)

- Measurement of voltage, current and resistance is achieved using appropriate circuits to produce a voltage proportional to the quantity to be measured.
 - In simple DMMs alternating signals are rectified as in analogue multimeters to give their average value which is multiplied by 1.11 to directly display the r.m.s. value of sine waves.
 - More sophisticated devices use a **true r.m.s. converter**, which accurately produces a voltage proportional to the r.m.s. value of an input waveform.



A typical digital multimeter

Key points

- A wide range of sensors is available.
- Some sensors produce an output voltage related to the measured quantity and therefore supply power.
- Other devices simply change their physical properties.
- Interfacing may be required to produce signals in the correct form.
- Most actuators take power from their inputs in order to deliver power at the output – the efficiency is often low.
- We often sense quantities in order to measure them – there are a number of standard measuring instruments.