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.**

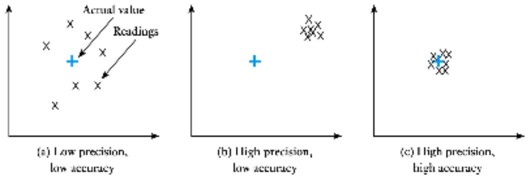
  A transducer is a device that converts one physical quantity into another.
  - examples include:
    - a mercury-in-glass thermometer (converts temperature into displacement of a column of mercury)
    - a microphone (converts sound into an electrical signal).
- We will look at both sensors and actuators 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

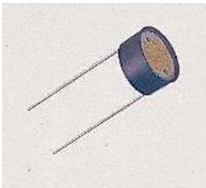
Light sensors

- **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.)

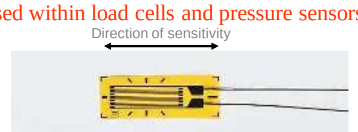
- **Photoconductive**
  - such devices do not produce electricity, but simply change their resistance.
  - photodiodes (as described earlier) can be used in this way to produce linear devices.
  - phototransistors act like photodiodes but with greater sensitivity.
  - light-dependent resistors (LDRs)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



A strain gauge

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.

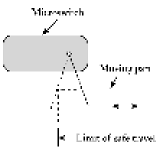
Displacement sensors (contd.)

- **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.

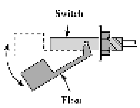
Inductive proximity sensors

Displacement sensors (contd.)

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



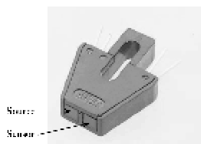
A limit switch



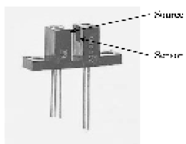
A float switch

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.



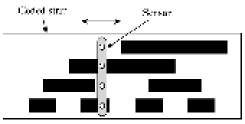
A reflective opto-switch



A slotted opto-switch

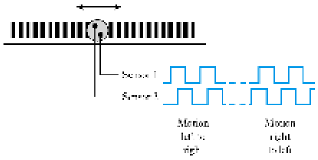
Displacement sensors (contd.)

- **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.



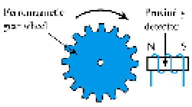
Displacement sensors (contd.)

- **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).

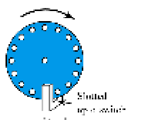


Displacement sensors (contd.)

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



Inductive sensor



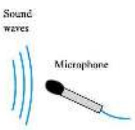
Opto-switch sensor

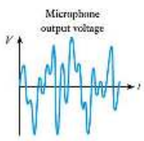
Motion sensors

- 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

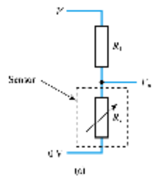
- **Microphones**
  - a number of forms are available
    - e.g. carbon (resistive), capacitive, piezoelectric and moving-coil microphones
    - moving-coil devices use a magnet and a coil attached to a diaphragm.





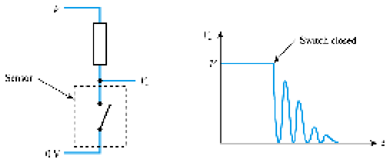
Sensor interfacing

- **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

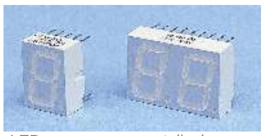
- Most heat actuators are simple **resistive heaters.**
- For applications requiring a few watts ordinary **resistors** of an appropriate power rating can be used.
- For higher power applications there are a range of **heating cables** and **heating elements** available.

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.



LED – seven-segment displays

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 µA – 1 mA

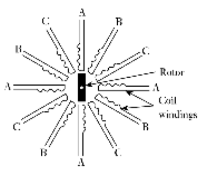
Moving-coil meters

Force, displacement and motion actuators (contd.)

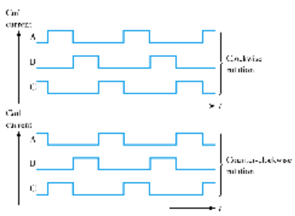
- **Motors**
  - three broad classes
    - **AC motors**
      - primarily used in high-power applications
    - **DC motors**
      - used in precision position-control applications
    - **Stepper motors**
      - a digital actuator used in position control applications.

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.)



Stepper-motor current waveforms

A typical stepper-motor

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.)

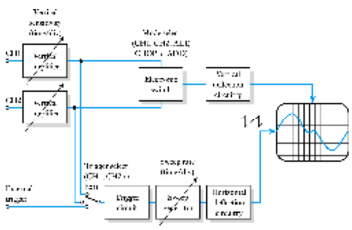
- **Capacitive and inductive devices**
  - Many actuators are capacitive or inductive (such as motors and solenoids).
  - These create particular problems – particularly when using switching techniques.
  - We will return to look at these problems when we have considered capacitors and inductors in more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



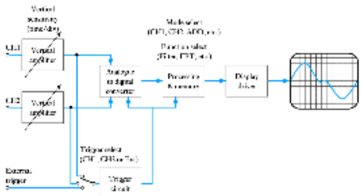
A simplified block diagram

Analogue oscilloscope (contd.)

- A typical analogue oscilloscope

Digital oscilloscope

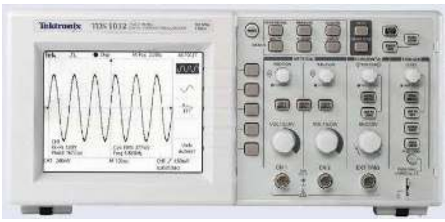
- Digital oscilloscopes use an analogue-to-digital converter (ADC) and appropriate processing.



A simplified block diagram

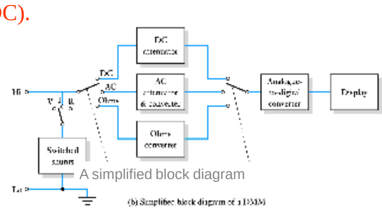
Digital oscilloscope (contd.)

- 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).



A simplified block diagram

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.