11

Sensors and Actuators

11.1 What are sensors and actuators?

Basically, sensors and actuators are components that enable interaction between the physical world and electrical circuits: a sensor converts a physical phenomenon into an electrical signal for processing and an actuator converts a processed electrical signal to a physical phenomenon.

Sensors

Sensors are used to explore (changes) in the environment and convert them into (changing) electrical signals. Depending on the application, the (changes in) environment can be (changes in) lightness, sound pressure level, pressure, temperature, magnetic field, acceleration, etc. For example, a lightness-meter on your photo camera is used to determine whether a flash is necessary or not, the thermometer in the thermostat that senses the temperature, the receiver in your television that is needed for your remote control. A simple switch can also be seen as a sensor. The output signal of this sensor can then be seen as 'high' or 'low' instead of continuous values.

The signal which is produced by the sensor often needs to be processed before you can know what the measured physical value was. You can think of amplification, linearization, comparation or other kinds of correction. In order to do this correction a sensor has several specifications:

Transfer function
: The relationship between the physical and electrical signals (looking at the complete input-range).

Sensitivity
: The amount of change in the electrical signal induced by a change in the physical signal (e.g. for a temperature sensor this value can be specified in x V/Kelvin).

Operating or dynamic range
: The range of the physical signal in which the sensor produces a useful and reliable signal. Outside this range the sensor becomes inaccurate or it may not work at all.

Hysteresis

The fact that when an input signal increases the output signal goes to a certain value, but when the input signal decreases to its original value again, the output signal does not. This was discussed in the chapter about operational amplifiers.

Resolution

The smallest change in the physical signal that induces a change in the electrical signal.

(Non-)linearity

Most of the times the transfer function of a function is a curve, but not necessarily a line. The largest error between the relationship and an approximated line is a measurement for the linearity. Note that non-linear behavior is not always an issue.

Response time

The time it takes for the sensor to react on a change in the physical signal. For example, if there is a step-like change in the input signal it will take some time before the output goes to a steady value. Most of the times the response time is specified as the time that it takes for the output to come to 60%-65% of the new steady value when an step-like change occurred in the input signal.

Actuators

Actuators are in fact the reciprocal of sensors. Therefore, they can be specified by the same specifications that were given for sensors. Although sensors might be more appealing to you, actuators are all around us as well: (electric) motors, speakers, (electric) heating elements, electric powered light sources, monitors, disk controllers, etc.

Like sensors, actuators can have continuous values and discrete values as well. For example, you can have discrete lighting (on/off), but you can have continuous lighting using a dimmer as well. Another common aspect between actuators and sensors is that the signals need to be processed before they can be used. For sensors this is usually postprocessing (i.e. after the conversion), whereas for actuators this is usually preprocessing (i.e. before the conversion). You can think of an amplifier which amplifies an electrical signal that is passed to the speaker (the actuator which converts electrical signals into an electro-magnetic field which is needed to create pressure-changes in the air).

In Figure 11.1 an example of a closed-loop control system (a central heating system) is given.

The temperature is measured by the sensor. This temperature is compared to a reference temperature, which can be set by the user. Depending on the comparison result, a current is fed (or not fed) through a heating element (which heats up when current is fed through it). Because the result (the temperature) is constantly measured and used for control, we speak of a closed-loop control system.

In Figure 11.1 the actuator is given as the heating element (resistor). Usually, actuators are depicted as the symbol given in Figure 11.2(a). Often, the universal symbol is not used, but the electrical equivalent, like drawn in Figure 11.2(b).

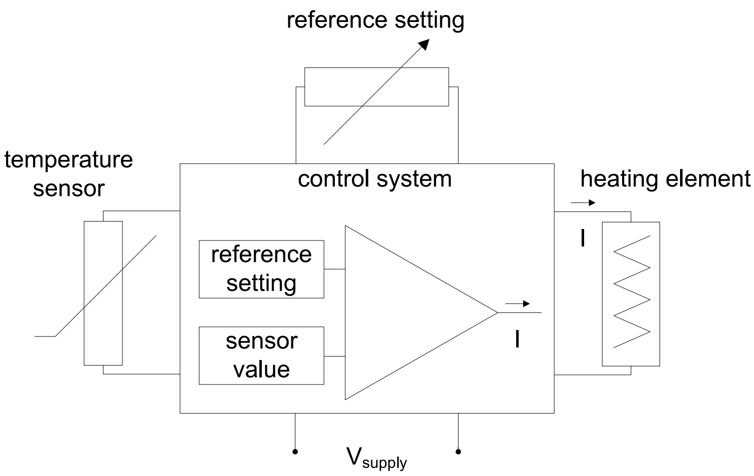

Figure 11.1: *Closed-loop temperature control system.*

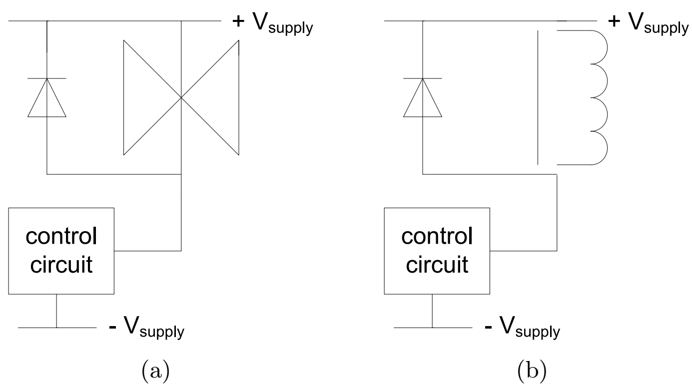

Figure 11.2: *Controlling an electro-magnetic (gas) trifler: (a) functional symbol and (b) electrical symbol.*

11.1.1 Examples of sensors

We cannot give a complete overview of all kinds of sensor and actuator for all physical quantities. Therefore, we just give a small list of the most commonly used sensors for light, magnetic field and temperature.

Light-sensitive: LDR

A Light Dependent Resistor (LDR) is, as the name implies, a resistor which resistance depends on the lightness of the light falling on it. When the lightness increases, the value of the resistance decreases. Typical resistance values are 5.5 kΩ in dark and 55 Ω in a light environment. The schematic symbol for an LDR is drawn in Figure 11.3. Note that, in contrary to the symbol of a LED where arrows are used to indicate some 'outbound value', arrows in the symbol for an LDR indicate some 'inbound value'.

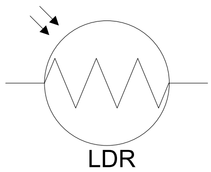

Figure 11.3: *Schematic symbol for an LDR*

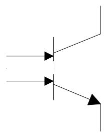

Figure 11.4: *Schematic symbol for a photo-transistor*

Light-sensitive: Photo-transistor

A photo-transistor is a transistor which starts conducting when light falls on it. More precise: a photo-transistor starts creating a base-current which depends on the lightness. You will often see photo-transistors in remote controlled applications (e.g. your television, or your stereo set). The schematic symbol for a photo-transistor is drawn in Figure 11.4.

Magnetic field-sensitive: Reed relay

A reed-relay or reed-contact is an electronic switch in a casing, which can be controlled by a magnetic field. This field can be generated by a permanent magnet, but also by an electro-magnet (inductor). The casing of the relay is often made of glass and contains some gas to keep the switch-contacts in good shape. In this way switching sparkles are prevented. Reed-relays can be used to switch small currents only. The working of the Reed relay is illustrated in Figure 11.5. Depending on the magnetic field, the contact switches on or off.

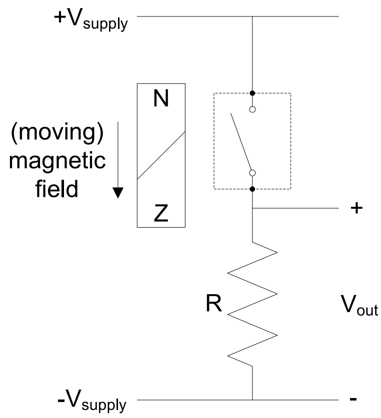

Figure 11.5: *Working of the Reed relay.*

In Figure 11.6 some types of reed relay are given.

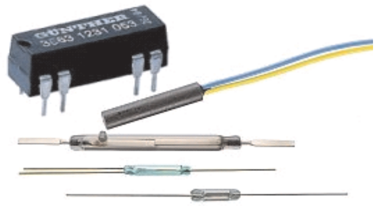

Figure 11.6: *Some types of Reed relay.*

Temperature-sensitive: NTC and PTC

There are resistors whose resistance value depends on the temperature. There are two types of them: ones that have a negative temperature coefficient (i.e. the resistance value decreases for increasing temperature) and ones that have a positive temperature coefficient. The former are called NTCs, whereas the latter are called PTCs. In Figure 11.7 the relationship between temperature and resistance value for three different NTCs is drawn.

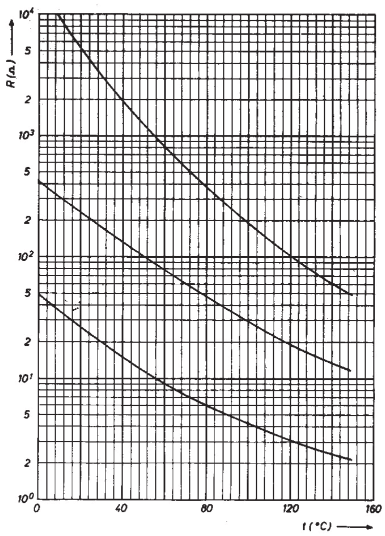

Figure 11.7: *Relationship between temperature and resistance value for three different NTCs.*

Note that the horizontal axis (temperature) is linear, whereas the vertical axis (resistance value) is logarithmic. When using such a sensor in (control) systems, one should be aware that the relation between resistance value and temperature is not linear!

In Figure 11.8 the schematic symbol for NTCs and PTCs is given.

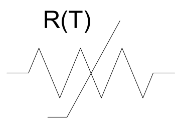

Figure 11.8: *Schematic symbol for NTCs and PTCs.*