Sensors and Transducers

This lecture describes the principles of operation of various types of transducers.
After this lecture you should be able to select a transducer for a given application.

Introduction

Transducers and sensors are used to convert a physical quantity into an electrical value that is then converted into a digital value (a number) that can be used by a computer or digital controller.

Some sensors work by generating binary digital signals directly (e.g. switches, optical encoders). Other sensors convert the physical quantity (temperature, position, light intensity, etc.) into a continuous electrical quantity (voltage, current, etc.). This quantity must then be amplified and A/D converted to get a the digital value.

There are thousands of different types of sensors. In this lecture we will only cover some of most important principles used in these sensors and some typical applications. As usual, the best source of information is manufacturers' specification sheets and application notes.

Mechanical On/Off Switches

The simplest type of sensor is a switch that opens and closes an electrical circuit. Switches are widely used to detect the presence of a physical object (e.g. an open door in a burglar alarm, a piece of paper in a photocopier). Switches are also used together with other mechanical devices to detect when a quantity has reached a certain value (e.g. with a spring to detect a certain force or attached to a float to detect a certain water level). Some switches are relays operated by the presence of magnetic field from a magnet.

Potentiometers

Some sensors use mechanical movement to move a contact along a resistance element causing the resistance to change. These devices are called potentiometers and are available in rotary and linear configurations. Devices are available for which the resistance changes linearly or logarithmically.

Some typical applications are volume controls, accelerator pedal position sensor and angle sensors for robot arms.

Magnetic Field Sensors

A Hall effect device can detect a magnetic field by measuring the change in current flow through a semiconductor due to the magnetic field. These sensors are available as three-terminal semiconductor packages. Unlike other types of magnetic sensors (e.g. fixed magnets moving past coils) they can be used to detect fixed magnetic fields. Hall effect sensors are often used in a magnetic circuit to detect the presence of ferrous metals (e.g. mounted beside a gear to count teeth).

Light Sensors

Semiconductor junctions can be used to measure light intensity. Various types of packages are available, often with an attached LED that supplies a light source. Linear and rectangular arrays of sensors are also available to produce images. Typical examples include light pens used to read bar codes, and optical sensors used to detect reflective markings on devices.

Temperature Sensors

Many devices change their properties as a function of temperature. Semiconductor temperature sensors are available that give accurately calibrated voltage outputs as a function of temperature. These devices are relatively inexpensive but are limited to temperatures below about 200C.

Thermocouples are made by connecting two wires of different types of metal. They can be used to measure temperatures up to 2500C. A voltage is generated that is a function of the temperature at the junction. Usually a reference junction is used in addition to the measurement junction.

Typical applications include thermostats (although these are often implemented by using temperature-sensitive materials to move switches), industrial process control systems, and engine control systems.

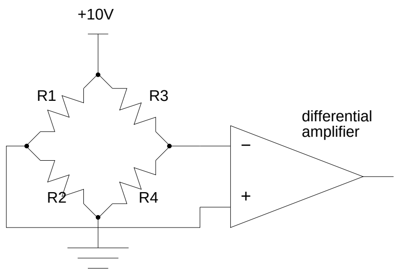
Often temperature changes are used to indirectly measure other quantities such as air or fluid flow by supplying a fixed amount of heat and measuring the temperature drop.

Dynamic Microphones and Phonograph Cartridges

These are examples of sensors that use the movement of a magnet across a wire (usually a coil) to generate a voltage. The quantity to be measured (and thus the magnetic field) must be changing with time. Typical examples include the heads on a tape recorder and the readers for the magnetic stripes on credit cards.

Strain Gauges

A strain gauge measures strain by measuring the change in resistance as a conductor is stretched. Strain gauges are made of thin conductive traces printed on a film. Because the changes in resistance are very small and the resistance also varies with temperature, two or four strain gauges can be used together in a circuit called a bridge. If the ratio of resistances R1/R2 is equal to the ratio R3/R4 in the circuit shown below, then bridge is “balanced” and the differential amplifier sees no voltage difference. If, for example, R3 and R4 were both the same type of strain gauge then temperature or other differences which scale the two resistances equally will cancel out.



Variable Frequency Oscillators

An oscillator can be built whose frequency is a function of some device whose electrical characteristics change with the quantity being measured. For example, an oscillator can be built whose frequency is a function of the capacitance between two plates. When the plates are moved close together the capacitance increases and the oscillator frequency decreases. The same principle can be used with using piezo-electric quartz crystals to build pressure and temperature sensors with very high resolution and accuracy.

Period or Frequency Measurement

Both time and frequency can be accurately measured using digital counters. Frequency can be measured by counting the number of pulses for a given time. The period of a pulse can be measured by counting the number of pulses of a known frequency during the duration of the pulse. Frequency and period can be computed from each other and the best measurement technique to use will vary depending on the magnitude of the frequency or period and the available hardware. If the frequency or period is changing randomly with time various measurements can be averaged.

Optical Encoders

Optical encoders use light sources (typically LEDs) shining through a moving mask onto photodetectors to convert the mask's position directly to a multi-bit electrical quantity. They can measure either circular or linear displacement and can provide either absolute (position) or differential outputs (e.g. four steps per rotation). The digital outputs are often Gray-coded.