Sensors and Transducers

Simple stand alone electronic circuits can be made to repeatedly flash a light or play a musical note, but in order for an electronic circuit or system to perform any useful task or function it needs to be able to communicate with the "real world" whether this is by reading an input signal from an "ON/OFF" switch or by activating some form of output device to illuminate a single light. In other words, an electronic circuit or system must be able to "do" something and Transducers are the perfect component for this.

The word "Transducer" is the collective term used for both Sensors which can be used to sense a wide range of different energy forms such as movement, electrical signals, radiant energy, thermal or magnetic energy etc, and Actuators which can be used to switch voltages or currents.

There are many different types of both analogue and digital input and output devices available to choose from. The type of input or output transducer being used, really depends upon the type of signal or process being "Sensed" or "Controlled" but we can define a transducer as a device that converts one physical quantity into another.

Devices which perform an "Input" function are commonly called Sensors because they "sense" a physical change in some characteristic that changes in response to some excitation, for example heat or force and covert that into an electrical signal. Devices which perform an "Output" function are generally called Actuators and are used to control some external device, for example movement or sound.

Electrical Transducers are used to convert energy of one kind into energy of another kind, so for example, a microphone (input device) converts sound waves into electrical signals for the amplifier to amplify (a process), and a loudspeaker (output device) converts these electrical signals back into sound waves and an example of this type of simple Input/Output (I/O) system is given below.

Simple Input/Output System using Sound Transducers

There are many different types of transducers available in the marketplace, and the choice of which one to use really depends upon the quantity being measured or controlled, with the more common types given in the table below.

Common Transducers
<table>
<thead>
<tr>
<th>Quantity being Measured</th>
<th>Input Device (Sensor)</th>
<th>Output Device (Actuator)</th>
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| Light Level             | Light Dependant Resistor (LDR)  
Photodiode  
Photo-transistor  
Solar Cell | Lights & Lamps  
LED's & Displays  
Fibre Optics |
| Temperature             | Thermocouple  
Thermistor  
Thermostat  
Resistive temperature detectors (RTD) | Heater  
Fan |
| Force/Pressure          | Strain Gauge  
Pressure Switch  
Load Cells | Lifts & Jacks  
Electromagnet  
Vibration |
| Position                | Potentiometer  
Encoders  
Reflective/Slotted Opto-switch  
LVDT | Motor  
Solenoid  
Panel Meters |
| Speed                   | Tacho-generator  
Reflective/Slotted Opto-coupler  
Doppler Effect Sensors | AC and DC Motors  
Stepper Motor  
Brake |
| Sound                   | Carbon Microphone  
Piezo-electric Crystal | Bell  
Buzzer  
Loudspeaker |

Input type transducers or sensors, produce a voltage or signal output response which is proportional to the change in the quantity that they are measuring (the stimulus). The type or amount of the output signal depends upon the type of sensor being used. But generally, all types of sensors can be classed as two kinds, either passive or active.

Active sensors require some form of external power to operate, called an excitation signal which is used by the sensor to produce the output signal. Active sensors are self-generating devices because their own properties change in response to an external effect producing for example, an output voltage of 1 to 10v DC or an output current such as 4 to 20mA DC.

A good example of an active sensor is a strain gauge which is basically a pressure-sensitive resistive bridge network. It does not generate an electrical signal itself, but by passing a current through it (excitation signal), its electrical resistance can be measured by detecting variations in the current and/or voltage across it relating these changes to the amount of strain or force being applied.

Unlike an active sensor, a passive sensor does not need any additional energy source and directly generates an electric signal in response to an external stimulus. For example, a thermocouple or photodiode. Passive sensors are direct sensors which change their physical properties, such as resistance, capacitance or inductance etc. As well as analogue sensors, Digital Sensors produce a discrete output representing a binary number or digit such as a logic level "0" or a logic level "1".
Analogue and Digital Sensors

Analogue Sensors

Analogue Sensors produce a continuous output signal or voltage which is generally proportional to the quantity being measured. Physical quantities such as Temperature, Speed, Pressure, Displacement, Strain etc are all analogue quantities as they tend to be continuous in nature. For example, the temperature of a liquid can be measured using a thermometer or thermocouple which continuously responds to temperature changes as the liquid is heated up or cooled down.

Thermocouple used to produce an Analogue Signal

Analogue sensors tend to produce output signals that are changing smoothly and continuously over time. These signals tend to be very small in value from a few micro-volts (μV) to several milli-volts (mV), so some form of amplification is required. Then circuits which measure analogue signals usually have a slow response and/or low accuracy. Also analogue signals can be easily converted into digital type signals for use in microcontroller systems by the use of analogue-to-digital converters, or ADC’s.

Digital Sensors

As its name implies, Digital Sensors produce a discrete output signal or voltage that is a digital representation of the quantity being measured. Digital sensors produce a Binary output signal in the form of a logic “1” or a logic “0”, (“ON” or “OFF”). This means then that a digital signal only produces discrete (non-continuous) values which may be outputted as a single “bit”, (serial transmission) or by combining the bits to produce a single “byte” output (parallel transmission).

Light Sensor used to produce an Digital Signal
In our simple example above, the speed of the rotating shaft is measured by using a digital LED/Opto-detector sensor. The disc which is fixed to a rotating shaft (for example, from a motor or robot wheels), has a number of transparent slots within its design. As the disc rotates with the speed of the shaft, each slot passes by the sensor in turn producing an output pulse representing a logic "1" or logic "0" level.

These pulses are sent to a register of counter and finally to an output display to show the speed or revolutions of the shaft. By increasing the number of slots or "windows" within the disc more output pulses can be produced for each revolution of the shaft. The advantage of this is that a greater resolution and accuracy is achieved as fractions of a revolution can be detected. Then this type of sensor arrangement could also be used for positional control with one of the discs slots representing a reference position.

Compared to analogue signals, digital signals or quantities have very high accuracies and can be both measured and "sampled" at a very high clock speed. The accuracy of the digital signal is proportional to the number of bits used to represent the measured quantity. For example, using a processor of 8 bits, will produce an accuracy of 0.195% (1 part in 512). While using a processor of 16 bits gives an accuracy of 0.0015%, (1 part in 65,536) or 130 times more accurate. This accuracy can be maintained as digital quantities are manipulated and processed very rapidly, millions of times faster than analogue signals.

In most cases, sensors and more specifically analogue sensors generally require an external power supply and some form of additional amplification or filtering of the signal in order to produce a suitable electrical signal which is capable of being measured or used. One very good way of achieving both amplification and filtering within a single circuit is to use Operational Amplifiers as seen before.

**Signal Conditioning**

As we saw in the Operational Amplifier tutorial, op-amps can be used to provide amplification of signals when connected in either inverting or non-inverting configurations. The very small analogue signal voltages produced by a sensor such as a few milli-volts or even pico-volts can
be amplified many times over by a simple op-amp circuit to produce a much larger voltage signal of say 5v or 5mA that can then be used as an input signal to a microprocessor or analogue-to-digital based system. Therefore, an amplification of a sensors output signal has to be made with a voltage gain up to 10,000 and a current gain up to 1,000,000 with the amplification of the signal being linear with the output signal being an exact reproduction of the input, just changed in amplitude.

Then amplification is part of signal conditioning. So when using analogue sensors, generally some form of amplification (Gain), impedance matching, isolation between the input and output or perhaps filtering (frequency selection) may be required before the signal can be used and this is conveniently performed by Operational Amplifiers.

Also, when measuring very small physical changes the output signal of a sensor can become "contaminated" with unwanted signals or voltages that prevent the actual signal required from being measured correctly. These unwanted signals are called "Noise". This Noise or Interference can be either greatly reduced or even eliminated by using signal conditioning or filtering techniques as we discussed in the Active Filter tutorial.

By using either a Low Pass, or a High Pass or even Band Pass filter the "bandwidth" of the noise can be reduced to leave just the output signal required. For example, many types of inputs from switches, keyboards or manual controls are not capable of changing state rapidly and so low-pass filter can be used. When the interference is at a particular frequency, for example mains frequency, narrow band reject or Notch filters can be used to produce frequency selective filters.

**Typical Op-amp Filters**

Were some random noise still remains after filtering it may be necessary to take several samples and then average them to give the final value so increasing the signal-to-noise ratio. Either way, both amplification and filtering play an important role in interfacing microprocessor and electronics based systems to "real world" conditions.

Source:

http://www.electronics-tutorials.ws/io/io_1.html