SENSORS AND TRANSDUCERS

INTRODUCTION

A sensor is a hardware device that measures a physical quantity and produces a signal which can be read by an observer or by an instrument. For example, a thermocouple converts temperature to an output voltage, which can be read by a voltmeter. For accuracy, all sensors are calibrated against known standards. A transducer is a device that is actuated by power from one system and supplies power usually in another form to a second system. For example, a loudspeaker is a transducer that transforms electrical signals into sound energy or a thermocouple sensor transforms heat energy into electrical energy. However the words sensor and transducer are used synonymously, specific names being given depending on the application. Also, suffixed derivatives ending in -meter such as accelerometer, flowmeter and tachometer are used. For convenience, the basic sensor will be used in this chapter to describe these units.

Analog sensors produce a continuous output signal or voltage, which is generally proportional to the quantity being measured. Physical quantities such as temperature, velocity, pressure and displacement are all analog 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. Transducers on the output of a system are often called actuators and convert electrical system outputs into some other type of energy such as heat or mechanical energy.

See the linked page for bulleted summary of analog sensors and transducers:

Digital sensors produce a discrete output signal or voltage that is a digital representation of the quantity being measured. Digital sensors produce a discrete (non-continuous) value, which may be outputted as a single bit or a combination of the bits to produce a single byte output.

A type of sensor related to the digital sensor is the Smart sensor. Specifically, a microsensor integrated with signal-conditioning electronics such as analog-to-digital converters on a single silicon chip to form an integrated micro-electro-mechanical component that can process information itself or communicate with an embedded microprocessor. Also known as intelligent sensor.

TYPES OF SENSORS

In almost every product for commercial and military application, the number of sensors and transducers continues to increase. The application of “smart sensors” with digital communication techniques and resulting improved accuracy and self-healing sensor networks has created an ever-increasing application of sensor technology. Table
19-1 is a partial listing of the applications for sensors and transducers.

**Typical Sensor Applications**

<table>
<thead>
<tr>
<th>Sensor Classification</th>
<th>Typical Sensor/Transducer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal</td>
<td>Thermostat, thermistor, thermocouple, thermopile</td>
</tr>
<tr>
<td>Force</td>
<td>Mechanical force, strain gauge, torque</td>
</tr>
<tr>
<td>Positional</td>
<td>Potentiometer, LVDT, rotary encoder</td>
</tr>
<tr>
<td>Fluid</td>
<td>Pressure, flow, viscometer</td>
</tr>
<tr>
<td>Optical</td>
<td>Photodiode, phototransistor, photodetector, infrared, fiber optic</td>
</tr>
<tr>
<td>Motion</td>
<td>Displacement, velocity, acceleration, vibration, shock</td>
</tr>
<tr>
<td>Presence</td>
<td>Proximity</td>
</tr>
<tr>
<td>Environmental</td>
<td>Temperature, altitude, humidity, smoke</td>
</tr>
</tbody>
</table>

The compass, memsic dual-axis accelerometer, ultrasonic distance sensors from Parallax are examples of Smart variations on the sensors above.

**Thermal Sensors**

Thermal sensors vary from simple ON/OFF thermostatic devices that control a domestic hot water system to highly sensitive semiconductor types that control complex processing facilities. Temperature sensors measure the amount of heat energy within an object and detect any physical change to that temperature. There are many different types of thermal sensors and all have different characteristics depending upon their actual application. Typical thermal sensors include the following:

- Resistance Temperature Detector (RTD): In your early studies of electronics, you learned that the resistance of conductors varies with temperature. This characteristic can be used to measure temperature. A commonly used conductor is platinum, which is stable over a wide temperature range. This sensor has a thin platinum wire is wound in a coil on a ceramic core. Sometimes platinum metal film is used to make sensors, which are very small and economical, but it is not as stable as pure platinum wire. RDTs can be obtained in resistance values from 10 Ω to several KΩs, but by far the most commonly used value is 100 Ω. The temperature coefficient for platinum (Pt) is .00385/°C, and is called a (alpha). This means that a 100Ω sensor will increase resistance by 0.385Ω for each degree increase in temperature. The equation below relates the change in resistance for a small change in temperature.

\[
R = R_0 (1 + \alpha \Delta T)
\]
\[
R = \text{resistance at new temperature} \\
R_0 = \text{resistance at reference temperature (0°C)} \\
\alpha = \text{temperature coefficient of wire (0.00385/°C for pt)} \\
\Delta T = \text{change in temperature}
\]

**Example: Given:** The resistance of a RTD sensor at 0°C =100 ohms.  
**Find:** The sensor’s resistance at 20°C.

\[
R = R_0 \left(1 + \alpha \Delta T\right) \\
R = 100 \left(1 + 0.00385/C^0 \times 20 C^0\right) \\
R = 107.7 \text{ ohms}
\]

RTDs are more linear than thermocouples, they are still not linear over wide temperature ranges. The NBS has published temperature-versus-resistance tables for platinum, so quite accurate temperature measurements can be made. Two of the most common methods of using an RTD are to make it one leg of a bridge and correlative output voltage across the bridge with temperature changes and the other is to drive a constant current through the RTD and relate the voltage across it to temperature.

![Diagram of a bridge circuit with RTD](image)

Work through the module on WISC-Online RTD module: [http://www.wisc-online.com/Objects/ViewObject.aspx?ID=ELE2808](http://www.wisc-online.com/Objects/ViewObject.aspx?ID=ELE2808). For the circuit on the right the voltage change across the RTD is proportional to the change in temperature. The larger the amplitude of current flow, the greater the output voltage for a given temperature change. Many would assume that a fairly large current to flow through it would be a good idea. However, a problem comes from the current flow. The current flow through any resistor including a RTD develops heat in the RTD. This heat further increases its temperature, which further increases its resistance, thus causing an error. So a correction factor must be used to account for the self-heating. The correction factor, called \( T_c \), is 0.5 °C/mW in free air.

**Example Problem: Given:** A RTD with a resistance is 100 Ωs at 0° C, and a bias current through it of 10 mA. At a higher temperature the voltage measured across the RTD is 1.5 V.  **Find:** the correction factor \( T_c \).

*The power dissipated in the RTD:*  
\[
P = V \times I = 1.5 \times 0.01 = 0.015 W
\]

*The Correction Factor*  
\[
T_c = 15mW \times 0.5° C / mW = 7.5° C
\]
Subtract 7.5°C from your measured temperature. The less current that flows through the RTD, the less error there will be. Of course, when used with computerized equipment, the correction factor can easily be accomplished by the software. RTDs are packaged in many of the same kinds of industrial assemblies that thermocouples.

- Thermistor: A thermistor is a passive resistive device that changes its physical resistance with temperature producing a measurable voltage depending on the current through the device. A thermistor is generally made from ceramic type semiconductor materials such as oxides of nickel, manganese or cobalt coated in glass. Thermistors are generally connected in series with a suitable biasing resistor to form a potential divider network and the choice of resistor gives a voltage output at some predetermined temperature point or value. Work through the module on WISC-Online Thermistor Temperature Alarm Circuit module:


- Thermocouple: A thermocouple converts thermal energy into electrical energy. It consists of two junctions of dissimilar metals, such as copper and constantan that are welded or crimped together. A thermocouple is created whenever two dissimilar metals touch and the contact point produces a small thermoelectric voltage as a function of temperature (Seebeck voltage – expressed as µV/°C in tables). See below for a Table of types of thermocouples with their Seebeck voltages and temperature ranges...

<table>
<thead>
<tr>
<th>Type</th>
<th>Metals</th>
<th>Coefficient (µV/°C)</th>
<th>Operating temp range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>Chromel-constantan</td>
<td>62</td>
<td>-265 to 1000</td>
</tr>
<tr>
<td>J</td>
<td>Iron-constantan</td>
<td>51</td>
<td>-205 to 750</td>
</tr>
<tr>
<td>K</td>
<td>Chromel-alumel</td>
<td>40</td>
<td>-270 to 1365</td>
</tr>
<tr>
<td>S</td>
<td>Platinum-rhodium</td>
<td>7</td>
<td>0 to 1750</td>
</tr>
</tbody>
</table>
The thermocouple is a commonly used temperature sensor because of its simplicity, small size, ease of application and speed of response to changes. A thermopile is composed of thermocouples connected in series. Read the Tutorial on Thermocouples on the Radio-Electronics.com Web site: http://www.radio-electronics.com/info/t_and_m/data-acquisition/thermocouples.php and then complete the exercise module from WISC-Online: http://www.wisc-online.com/Objects/ViewObject.aspx?ID=ELE2708

<table>
<thead>
<tr>
<th>T</th>
<th>Copper-constantan</th>
<th>40</th>
<th>-265 to 400</th>
</tr>
</thead>
</table>

The Seebeck coefficients in the Table above can be used in the following equation to find the voltage at the measuring end of the sensor.

\[ V = s \ (\Delta T), \quad \text{where } V \text{ is in volts, } s \text{ is the Seebeck coefficient, } \Delta T \text{ is the difference in temperature between the two ends} \]

**Example Problem.** Given: A chromel-alumel thermocouple is heated to 300°C. Find: What is the thermocouple voltage assuming that the cold ends are held at 0°C?

\[ V = s \times \Delta T = 40\mu V/\degree C \times 300\degree C = 1200 \mu V = 1.2mV \]


**Force Sensors**
Force sensors are used to obtain an accurate determination of pulling and/or pressing forces. The force sensor creates an electrical signal which corresponds to the force measurement to be used for further evaluation or process control. Force sensors are commonly used in automotive vehicle assemblies such as brakes, suspension units and air-bag systems.

A force sensor generally measures the applied force from the proportional deformation of a spring element; the larger the force, the more this element deforms. Many force sensors employ the piezoelectric principle exhibited by quartz. Under load, quartz crystals produce an electric charge proportional to the mechanical load applied; the higher the load, the higher the charge. Thus, in piezoelectric force sensors, quartz serves as both the spring element and the measurement transducer.

A strain gauge is a device used to measure the strain of an object. The strain gauge is the fundamental sensing element for many types of sensors, including pressure sensors, load cells, torque sensors and position sensors. The majority of strain gauges are foil types. They consist of a pattern of resistive foil which is mounted on a backing material and as the foil is subjected to stress, the resistance of the foil changes. This results in a signal output, related to the stress value.

Strain is defined as the deformation caused by the action of stress (i.e. force per unit area on a given plane) on a body.

Strain is the change in shape (specifically length) and/or size caused by a stress.

\[ \text{Strain} = \frac{\Delta L}{L_0} \]

\[ \text{Stress} = \frac{F}{A} \]

Where \( \Delta L \) = change of length, \( L_0 \) = Original length, \( F \) = Total force applied to gage, \( A \) = Cross sectional area of gage.

Solid metal bars don't stretch much, but all metals are somewhat elastic provided that the force has not exceeded the elastic limit of the metal. That is, a piece of metal does stretch when a force is applied, but it returns to its original dimensions when the force is removed. If the metal object is subjected to a force above its elastic limit the metal object will be deformed and will not return to its original dimensions when the force is removed.
The ratio of stress to strain is a constant value for materials such as steel, brass and/or aluminum and the dimensions of the material don’t matter. This ratio of stress to strain, called Young's modulus, and is recalculated and listed in engineering reference materials.


Calculations involving Young’s modulus exceed the scope of the course, but look at how to measure the strain. Tests show that most metals won’t stretch more than about 0.5% of their original length before permanent deformation occurs. This corresponds to a strain of 0.005 inch/inch. Since the change in length is so small, we obviously can’t measure strain with a meter stick. In other words, if we want to measure the strain in a metal bar, we need some device that will give us an accurate measurement even when the change in length is very small. The strain gage is such a sensor.

The resistance of a conductor is determined by the equation \( R = \frac{pL}{A} \) In this equation, \( R \) is the resistance in ohms, \( p \) (rho) is the resistivity of the material, \( L \) is the length of the conductor, and \( A \) is the cross-sectional area. If the sensor wire is attached closely to the metal under stress such that it will be stretched/compressed the same amount, the change in length will correspond to the change in resistance. Rather than use a single strand of wire for the strain gage, commercially available gages are made of metal or semiconductor foil woven back and forth to increase the length. The gage is then bonded to a plastic-like base material for easy handling and mounting. Commercially available strain gages are sold in resistance values from 30 to 3000 \( \Omega \). But the two most commonly used values are 120 and 35 \( \Omega \). Commercially available strain gages actually exhibit a greater percentage change in resistance than the change in length: This property is called the gage factor (GF). For example, if a 1% change in length causes a 2% change in resistance, the gage is said to have a gage factor of 2. The equation below finds the resistance of a strain gage if its original resistance, change in length, and gage factor are known.

\[
R = R_0 \left( 1 + \frac{\Delta L}{L_0} \times GF \right)
\]

Where \( R = \) gage resistance under stress, \( R_0 = \) original resistance of gage, \( \Delta L = \) change of length, \( L_0 = \) original length, \( GF = \) gage factor.
Example Problem: **Given:** A 350Ω strain gage with a gage factor of 2 is mounted on a metal bar originally 1 m long. The bar is then stretched 3 mm. **Find:** The new gage resistance under stress?

\[ R = R_o \left( 1 + \frac{\Delta L}{L_o} \times GF \right) = 350 \left( 1 + \frac{0.003}{1} \times 2 \right) = 352.1Ω \]

**Positional Sensors**

A positional sensor is one that permits a linear or angular position measurement. It can either be an absolute positional sensor or a relative one (displacement sensor).

A conventional potentiometer is an analog device that can be used as a positional sensor to vary, or control, the amount of current that flows through an electronic circuit. The potentiometer can be either angular (rotational) or linear (slider type) in its movement providing an electrical signal output that has a proportional relationship between the actual wiper position and its resistance change. A digital potentiometer consists of resistor arrays, switches, logic gates, multiplexers, and data converters. Digital potentiometers can be set under program control, better resolution, and lower noise levels than conventional potentiometers. They are more stable over time and their resistance drifts minimally. They are more reliable and exhibit a lower temperature coefficient of resistance than analog potentiometers. Read about the potentiometer as a positional sensor in the linked document: [http://www.electronics-tutorials.ws/io/io_2.html](http://www.electronics-tutorials.ws/io/io_2.html).

The Linear Variable Differential Transformer (LVDT) is an inductive type positional device that works on the same principle as an AC transformer. It is a very accurate device for measuring linear distances with an output proportional to the position of its moveable core. It basically consists of three coils wound on a hollow tube, one forming the primary coil and the other two coils forming identical secondary coils 180° out of phase from either side of the primary coil. An armature connected to the object being measured slides up and down inside the tube. The AC excitation voltage applied to the primary winding induces an EMF signal into the two secondary windings providing an amplitude that is a linear function of core displacement.

The LVDT must be calibrated for the particular application. Any mechanical change in the application such as a part that has been moved or replaced requires recalibration. It is important that the calibration of an LVDT take place in contact with the part it is to measure. Read about the LVDT as an inductive positional sensor in the linked document: [http://www.electronics-tutorials.ws/io/io_2.html](http://www.electronics-tutorials.ws/io/io_2.html).

Rotary Encoders resemble potentiometers but are non-contact optical devices used for converting the angular position of a rotating shaft into an analog or digital data code. Rotary encoders utilize light from an LED or infrared light source that is passed through a rotating high-resolution encoded disk containing the required code patterns. Photodetectors scan the disk as it rotates and an electronic circuit processes the information into a digital form as a stream of binary output pulses that are fed to counters.
or controllers which determine the actual angular position of the rotating shaft. Read about the rotary encodes as a positional sensor in the linked document: [http://www.electronics-tutorials.ws/io/io_2.html](http://www.electronics-tutorials.ws/io/io_2.html).

**Optical Sensors**

Optical sensors are passive devices that convert radiant light energy into an electrical signal output. The most common type of photoconductive device is the photo-resistor which changes its electrical resistance in response to changes in the light intensity.


![Sample Photocell circuits](image)

Photo-junction devices are PN-Junction light sensors or detectors made from silicon semiconductors that can detect both visible light and infrared light levels. This class of photoelectric light sensors includes the photodiode and the phototransistor. Phototransistor light sensors operate the same as photodiodes except that they can provide current gain and are much more sensitive than the photodiode.
Photodiodes are a diode that is forward biased by light. It has very fast reactions to changing light levels. Has the same physical size as LEDs and have small windows through which light is sensed. See above for a simple sample circuit above. Testing is simple: when the window is blocked - high resistance is read; shine a bright light (several foot-candles) on it while still connected to an ohmmeter - the resistance will drop significantly.

Phototransistors are usually used instead of photodiodes when low light levels are measured. Typical ratings are similar to low power transistors:

- 30-50V maximum collector to emitter voltages
- Max collector currents of 25mA

For the example circuit shown above when the light falling on the phototransistor (Q1) is blocked, its conductance will decrease and the voltage across Q1 will rise. When the voltage rises above 1/2 of the supply voltage the output of the comparator will go towards the negative supply voltage. The only critical part of this circuit is the value of resistor R1 which in most cases can be 4.7K ohms but may have to be increase if the room is dark or decreased if the room is well lit.

Photodetectors, also known as proximity sensors, are used to determine if a moving object enters the range of a sensor. The most commonly found photodetector is the “electric eye”. This type of sensor works by projecting a beam of light from a transmitter to a receiver across a specific distance. As long as the beam of light maintains a connection with the receiver, the circuit remains closed. If an object passes through the beam of light, the continuity of the circuit is lost, and the circuit opens. An example of this type of sensor is a garage door opener safety sensor that will halt the closing of the door if an object breaks the beam. Review the WISC-Online simulation http://www.wisc-online.com/Objects/ViewObject.aspx?ID=IAU14808 . Another example would be the reel position detectors used in Slot machines that have physical reels; see below: Another useful simulation of simulation of Thru-beam photoelectric sensors link follows - https://www.wisc-online.com/learn/career-clusters/stem/iau15810/thru-beam-photoelectric-sensors
Active infrared sensors project a beam of light in the infrared spectrum and receive the returning reflection from objects in the sensor's range. Infrared sensors can be used as proximity sensors, such as in automatic doors. Passive infrared sensors are used to measure the radiation of heat within its range. Examples of passive infrared sensors include “heat-seeking” missile guidance systems and infrared thermography systems.

Fiber optic sensors can be used to measure a wide range of physical phenomena, depending on the configuration of the sensor. Optical fibers can be coated with materials that respond to changes in strain, temperature, or humidity. Optical gratings can be etched into the fiber at specific intervals to reflect specific frequencies of light. As the fiber is strained, the distances between the gratings change, allowing the physical strain to be measured.

**Presence Sensors**

A proximity sensor is a sensor able to detect the presence of nearby objects without any physical contact. A proximity sensor often emits an electromagnetic or electrostatic field, or a beam of electromagnetic radiation (infrared, for instance), and looks for changes in the field or return signal. The object being sensed is often referred to as the proximity sensor's target. Different proximity sensor targets demand different sensors. For example,
a capacitive or photoelectric sensor might be suitable for a plastic target while an inductive proximity sensor requires a metal target.

Proximity sensors can have a high reliability and long functional life because of the absence of mechanical parts and lack of physical contact between sensor and the sensed object. The maximum distance that this sensor can detect is defined as its "nominal range". Some sensors have adjustments of the nominal range or means to report a graduated detection distance. Proximity sensors are also used in machine vibration monitoring to measure the variation in distance between a shaft and its support bearing. This is common in large steam turbines, compressors, and motors that use sleeve-type bearings.

Some proximity sensors is divided in two halves and if the two halves move away from each other, then a signal is activated. An example application of a proximity sensor is for window security. When the window opens an alarm is activated.

We will look in-depth at those that use any object as target part of the sensor. These are often described as only having one part, however the second part is an object that is detected by the sensor. The two most common types these are inductive and capacitive proximity sensors. Review the WISC-Online simulations for capacitive proximity detectors:

a. Capacitive Proximity Sensors
b. Capacitive Proximity Sensor Target Considerations
c. Internal Circuits of a Capacitive Proximity Sensor

Review the WISC-Online simulations for Inductive proximity detectors:

a. Inductive Proximity Sensors
b. Inductive Proximity Sensor Target Considerations
c. Internal Circuits of an Inductive Proximity Sensor

Smart Sensors

Inside every smart sensor is one or more primitive sensors and support circuitry. The thing that makes a smart sensor "smart" is the additional, built-in electronics. The electronics make these sensors able to do one or more of the following:

• Pre-process their measured values into meaningful quantities
• Communicate their measurements with digital signals and communication protocols
• Orchestrate the actions of primitive circuits and sensors to "take" measurements
• Make decisions and initiate action based on sensed conditions, independent of a Microcontroller
• Remember calibration or configuration settings

Read chapters 2 through 5 of the Parallax book “Smart Sensors & Applications” which is linked on the Learning Module and here. Also read about an IEEE standard for smart
sensor interface and protocol by which a sensor can describe itself over a network

**Motion Sensors**

Motion sensors are designed to measure the rate of change of position, location, or displacement of an object that is occurring. If the position of an object is changing as a function of time the first derivative gives the speed of the object and if the speed of the object is also changing, then the first derivative of the speed gives the acceleration.

Displacement sensors measure the distance an object moves and they can also be used to measure object height and width. Optical and magnetic displacement sensors are used to detect the amount of a linear displacement. Linear and angular displacement sensors are used for high-precision machining and measuring, for manufacturing and testing components with very tight dimensional tolerances. Magnetic displacement sensors consist of one or more magnets producing an induction field and typically measure linear or rotational displacement providing an output proportional to absolute linear or rotary position displacement of the elements.

Velocity sensors measure the linear velocity of an object using either contact or non-contact techniques. In cable-extension linear velocity sensors, the moving object is attached to a cable, which is typically connected to a potentiometer. As the object moves, the potentiometer's resistance value changes. Magnetic induction sensors are non-contact linear velocity sensors that use an induced current from a magnetic field to measure the linear velocity. Microwave sensors use microwave technology to determine speed, whereas fiber optic sensors use fiber optics or laser technology to determine speed. Piezoelectric linear velocity sensors utilize a piezoelectric material that is compressed generating a charge that is measured by a charge amplifier. Often, piezoelectric sensors are used in vibration velocity measurement applications.

The simplest acceleration type measures mass motion by attaching the spring mass to the wiper arm of a potentiometer. In this manner, the mass position is conveyed as a changing resistance. The Linear Variable Differential Transformer (LVDT) takes advantage of the natural linear displacement to measure mass displacement. In these instruments, the LVDT core itself is the seismic mass. Displacements of the core are converted directly into a linearly proportional voltage. These accelerometers generally have a natural frequency less than 80 Hz and are commonly used for steady-state and low-frequency vibration.

Vibration sensors are sensors for measuring, displaying and analyzing linear velocity, displacement and proximity, or acceleration. They can be used on a stand-alone basis, or in conjunction with a data acquisition system. Vibration sensors are available in many forms. They can be raw sensing elements, packaged transducers, or as a sensor system or instrument, incorporating features such as local or remote display, and data recording. The primary elements of importance in shock measurements are that the device has a natural frequency that is greater than 1 kHz and a range typically greater than 500 g. The primary accelerometer that can satisfy these
requirements is the piezoelectric type.

**Fluid Sensors**

A fluid pressure sensor detects a pressure difference between a detecting pressure and reference pressure and converts the difference into an electric signal. Pressure sensors are used to measure pressures of gases or liquids. Pressure measurements typically are made as absolute, gauge, or differential measurements. Absolute pressure sensors measure a pressure relative to a vacuum, gauge sensors measure a pressure relative to atmospheric pressure, and differential sensors measure a pressure difference between two inputs.

Generally, a pressure sensor for sensing a gas or liquid pressure has a diaphragm that acts as a pressure sensing element and is configured such that deflection (pressure deformation) of a diaphragm under a fluid pressure applied through a pressure port is converted to an electrical signal, thereby enabling the fluid pressure to be measured.

A fluid flow sensor is a device for sensing the rate of fluid flow. Typically a flow sensor is the sensing element used in a flowmeter or data logging device to record the flow of fluids. There are various kinds of flow sensors and flowmeters including some that have a vane that is pushed by the fluid and can drive a rotary potentiometer or similar device. Other flow sensors are based on sensors which measure the transfer of heat caused by the moving medium.

The flow sensor can normally measure velocity, flow rate or totalized flow. Flow sensors are sometimes related to sensors called velocimeters that measure speed of fluids flowing through them. The flow sensor technology can be based on such things as light, heat, electromagnetic properties, ultrasonic and many other technologies in a wide spectrum. A flow sensor can work by direct measurement or inferential measurement. Several types of flow sensors are non-mechanical and normally work by the inferential method. As an example of an inferential liquid flow sensor please review the WISC-Online simulation of the operation of ultrasonic flowmeters - [http://www.wisc-online.com/Objects/ViewObject.aspx?ID=ELE5208](http://www.wisc-online.com/Objects/ViewObject.aspx?ID=ELE5208). As is true for all sensors, accuracy of a fluid sensor measurement requires a calibration applicable to the sensor function.

A viscometer is an instrument used to measure the viscosity of a fluid. Viscometers only measure one flow condition. In general, either the fluid remains stationary and an object moves through it, or the object is stationary and the fluid moves past it. The drag caused by relative motion of the fluid and a surface is a measure of the viscosity.
Environmental Sensors

Environmental sensors include those used to measure temperature, humidity, wind speed, barometric pressure, etc. They are often connected in a network. Temperature sensors are discussed in a previous. An analog humidity sensor gauges the humidity of the air relatively using a capacitor-based system. The sensor is made out of a film usually made of either glass or ceramics. The insulator material which absorbs the water is made out of a polymer which takes in and releases water based on the relative humidity of the given area. This changes the level of charge in the capacitor of the electrical circuit.

A digital humidity sensor works via two micro sensors that are calibrated to the relative humidity of the given area. These are then converted into the digital format with an analog to digital conversion.

Most smoke detectors work either by optical detection (photoelectric) or by physical process (ionization). They may also use both detection methods to increase sensitivity to smoke. In a photoelectric device, smoke can block a light beam reducing the light reaching a photocell used to set off an alarm. Ionization detectors have an ionization chamber and a source of ionizing radiation. Released radiation particles ionize the oxygen and nitrogen atoms in the chamber. These positively-charged atoms are attracted to the negative plate in the chamber and the electrons are attracted to the positive plate, generating a small, continuous electric current. When smoke enters the ionization chamber, the smoke particles attach to the ions and neutralize them, so they do not reach the plate. The drop in current between the plates triggers the alarm.

The above document’s framework comes from Chapter 19 of the USN’s NSWC-11, aka Reliability Prediction Procedures for Mechanical Equipment. I supplemented parts of the document and provided links to other supplemental materials.