Sensors

From LabAutopedia (http://www.labautopedia.org/mw/index.php/Sensors)

A sensor is a device that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument. In the case of laboratory automation sensors are used to detect errors and evaluate their cause, for identification of samples, vessels or system operators, to quantify solid or liquid mass or volume, to isolate the system from inadvertent human intervention and to evaluate the physical position of moving components. In short, sensors play a key, pivotal role in laboratory automation systems.

Types

There are many types of sensors. This article will focus only on those in common use within laboratory automation systems.

Mechanical

Switches are contact-based mechanical devices used to connect and disconnect an electric circuit at will. Switches may take several forms, with the simplest consisting of two pieces of metal called contacts that touch to make a circuit, and separate to break the circuit. Switches cover a wide range of types, from subminiature up to industrial plant switching megawatts of power on high voltage supply and distribution lines. Switches contain moving parts and contact surfaces that may become worn or fouled after repeated use. Switches can be designed to respond to a variety of mechanical stimuli, such as vibration (trembler switch), tilt, air pressure, fluid level (float switch), the turning of a key (key switch), linear or rotary movement (limit switch or microswitch), or presence of a magnetic field (reed switch). Switches are generally configured to be normally open (n.o.) or normally closed (n.c.). In the laboratory, the reliability of liquid movement through valves can be enhanced by using switches to verify proper valve positioning. Robotic devices may use switches to confirm home locations. Switches can be used to verify the proper positioning of auxilary devices such as doors.

Microscale switches can be fabricated using Micro-Electro Mechanical Systems (MEMS) technology. Micromechanical switches can utilize one of many actuation mechanisms, including magnetic, piezoelectric, thermal, and most commonly electrostatic forces. Switches that operate electrostatically require very little energy, usually on the order of tens of nanojoules per switch cycle.

Electromechanical

Force transducer sensors, or load cells convert a force indirectly into an electrical signal. Through a mechanical arrangement, the force being sensed deforms a strain gauge. The strain gauge converts the deformation (strain) to electrical signals, which in turn can be calibrated and used to calculate force, mass, or weight. Force transducers can be placed on the end effector of robots to measure gripping force. MEMS-scale transducers can be placed in flowing liquid channels to measure fluidic pressure. The common laboratory balance is a load cell. It is common to integrate small load cells or balances into laboratory automation systems for monitoring the volume of reagents in bulk vessels, or the quantity of material dispensed into a vessel, in some cases in real-time as the dispensing occurs. Load cells can be used to calculate the level or quantity of a well-behaved, known material inside a vessel of known geometry and/or known empty weight. With knowledge of the specific gravity of the material and the geometry and empty weight of the vessel, the level of material in a vessel can be calculated from the weight of the full vessel. For highly accurate calculations, other factors such as temperature and pressure must also be determined and included in the calculation. This method works best for liquids or solids of low viscosity and high uniformity, and less well or not at all for materials of higher viscosity or non-uniformity.

Thermal sensors measure temperature either by contact or indirectly. Contact temperature sensors measure their own temperature. One infers the temperature of the object to which the sensor is in contact by assuming or knowing that the two are in thermal equilibrium, that is, there is no heat flow between them. Contact sensors include:

- Thermocouples: Among the easiest temperature sensors to use and obtain and are widely used in science and industry. They are based on the Seebeck effect that occurs in electrical conductors that experience a temperature gradient along their length. They are "simple", rugged, need no batteries, measure over very wide temperature ranges and more.
- Thermistor: A thermally sensitive resistor that exhibits a change in

electrical resistance with a change in its temperature. The resistance is measured by passing a small, measured direct current (dc) through it and measuring the voltage drop produced.

- Resistance Temperature Detectors (RTD): Wire wound and thin film devices that measure temperature because of the physical principle of the positive temperature coefficient of electrical resistance of metals. The hotter they become, the larger or higher the value of their electrical resistance.

Optical

Optical sensors are contactless devices that detect the presence or intensity of light and convert that to an electrical signal. They offer a substantially larger detection range compared to inductive or capacitive sensors. They are also more complex, expensive and prone to their own unique failure modes.

Active optical sensors detect the decrease or change in transmission of light emitted from a laser or diode (LED). Through-beam models have a separate beam transmitter and detector and retroreflective models contain the transmitter and detector in the same housing, with the beam bounced off a reflector. Optical sensors utilize various spectral regions. Infrared sensors avoid interference from ambient light. Red light sensors offer a visible beam that can be sensitive to the color of the target. Laser sensors can be used for highly accurate distance measurements. Interruption of an optical beam can be used to confirm the presence of common laboratory consumables, such as pipette tips or filters, without disrupting the normal flow of system operations. With the proper choice of construction materials and mounting location, these sensors can be used to detect aqueous, organic, and corrosive liquids.

Rotary or linear positional encoders use light shining onto a photodiode through slits in a metal or glass disc, that rotates as an attached mechanical device moves. This generates electrical pulses that can be tracked via microprocessor as part of a proportional integral derivative (PID) feedback control system to determine translation distance, rotational velocity, and/or angle of a moving robot or robot part.

Active motion sensors are often based on infrared optical sensors

Passive optical sensors detect natural energy (radiation) that is emitted or reflected by the object or scene being observed. A Passive InfraRed sensor (PIR sensor) is an electronic device which measures infrared light radiating from objects in its field of view. Apparent motion is detected when an infrared source with one temperature, such as a human, passes in front of an infrared source with another temperature, such as a wall. All objects emit what is known as black body radiation. This energy is invisible to the human eye but can be detected by electronic devices designed for such a purpose. The term passive in this instance means the PIR sensor does not emit energy of any type but merely passively accepts incoming infrared radiation. A PIR could be used, for instance, as a simple means to detect continued motion of an unattended automated system, with non-motion indicating a possible error condition. PIR's may also be used to monitor temperature of remote objects. The output signal is evaluated according to a calibration for the IR spectrum of a specific type of matter to be observed. Relatively accurate and precise temperature measurements may be obtained remotely. Without calibration to the type of material being observed, a PIR thermometer device is able to measure changes in IR emission which correspond directly to temperature changes, but the actual temperature values cannot be calculated.

Imaging sensors, such as CCD or CMOS devices, are a highly flexible and can be a nearly universal sensor, but are also complex and data intensive. Whereas many sensors generally generate a relatively simple digital signal, imaging devices yield a very rich, detailed set of information about the scene being observed. This can be an advantage when a complex situation is being evaluated or a disadvantage when the situation being evaluated is buried within an excessive amount of information. Imaging sensors require image capture hardware and software as well as image interpretation software. They also require careful control of lighting conditions to assure consistent images over the course of time. Today, most digital imaging devices use either a CCD image sensor or a CMOS sensor. Both types of sensor accomplish the same task of capturing light and converting it into electrical signals.

- A Charge Coupled Device (CCD) is an analog device consisting of an array of photosensitive diodes. When light strikes the chip it is held as a small electrical charge in each photo sensor. The charges are converted to voltage one pixel at a time as they are read from the chip. Additional circuitry in the camera converts the voltage into digital information.
- A Complementary Metal–Oxide Semiconductor (CMOS) chip is a type of active pixel sensor made using the http://en.wikipedia.org/wiki/CMOS

semiconductor process. Extra circuitry next to each photo sensor converts the light energy to a voltage. Additional circuitry on the chip converts the voltage to digital data.

Neither technology has a clear advantage in image quality. CMOS can potentially be implemented with fewer components, use less power and provide data faster than CCDs. CCD is a more mature technology and is in most respects the equal of CMOS.[1][2]

The LabAutopedia article on Digital imaging offers an indepth discussion of the laboratory applications.

Acoustic

Ultrasonic sensors are non-contact devices which use the sonar principal in air, sending out an ultrasonic chirp, then switching to the receive mode to detect a return echo from the surface of the target. With the speed of sound in air (or other gas) as a given, distance to the target can be calculated. Variables such as temperature and humidity may be sensed and compensated for, resulting in highly accurate readings.   Turbulence, foam, vapors, and changes in the concentration of the process material also affect the ultrasonic sensor’s response. Turbulence and foam prevent the sound wave from being properly reflected to the sensor; Vapors distort and/or absorb the sound wave; and variations in concentration cause changes in the amount of energy in the sound wave that is reflected back to the sensor. Ultrasonic sensors have been used to determine the level of fill in a laboratory vessel, tube or microplate.

Active motion detection sensors can be bulit with ultrasonic sensors, using circuitry to compare the difference in the ultrasonic echo over a time period or against a baseline signal.

Capacitive

Capacitive sensors use the electrical property of "capacitance" to make measurements. Capacitance is a property that exists between any two conductive surfaces within some reasonable proximity.A capacitor consists of two conductors (plates) that are electrically isolated from one another by a nonconductor (dielectric). When the two conductors are at different potentials (voltages), the system is capable of storing an electric charge. The storage capability of a capacitor is measured in farads. In a capacitive sensor, the sensor surface consists of these two capacitor conductive plates. The sensing action is based on the difference in dielectric constant between the sensor surface and the material being detected. This is measured directly in picofarads, but this signal is often converted electronically to a more convenient-to-measure voltage. These sensors can be used to detect the presence of a wide range of material, but require relatively close range. The sensor contains no moving parts, is rugged, simple to use, easy to clean. Capacitive sensors have a variety of uses, such as:

- **Flow**-Many types of flow meters convert flow to pressure or displacement, using an orifice for volume flow or Coriolis effect force for mass flow. Capacitive sensors can then measure the displacement.
- **Pressure**-A diaphragm with stable deflection properties can measure pressure with a spacing-sensitive detector.
- **Liquid level** -Capacitive liquid level detectors sense the liquid level in a reservoir by measuring changes in capacitance between conducting plates which are immersed in the liquid, or applied to the outside of a non-conducting vessel.
- **Spacing**-If a metal object is near a capacitor electrode, the mutual capacitance is a very sensitive measure of spacing.
- **Thickness measurement**-Two plates in contact with an insulator will measure the insulator thickness if its dielectric constant is known, or the dielectric constant if the thickness is known.
- **Vibration, strain & acceleration** - Capacitive sensing of the distance between two fixed plates can be used to measure strain, acceleration or vibration. Analog Devices has introduced integrated accelerometer ICs with a sensitivity of 1.5g. With this sensitivity, the device can be used as a tiltmeter.
- **Ice detector**-Airplane wing icing can be detected using insulated metal strips in wing leading edges.
- **Limit switch**-Limit switches can detect the proximity of a metal machine component as an increase in capacitance, or the proximity of a plastic component by virtue of its increased dielectric constant over air.

Electromagnetic

Microwave sensors, or radar sensors, are non-contact devices based on "time-of-flight" measurements of the outgoing and reflected signal. Microwave sensors are executed at various frequencies, from 1 GHz to 30 GHz. Generally, the higher the frequency, the more accurate, and the more costly. Microwaves will penetrate temperature and vapor layers that may cause problems for other techniques, such as ultrasonic. Microwaves are electromagnetic energy and therefore do not require air molecules to transmit the energy making them useful in vacuums. Microwaves, as electromagnetic energy, are reflected by objects with high dielectric properties, like metal and conductive water. Alternately, they are absorbed in various degrees by low dieletric or insulating mediums such as plastics, glass, paper, many powders and food stuffs and other solids. Microwave is a non-contact technique, monitoring a microwave signal that is transmitted through the medium (including vacuum), or can be executed as a “radar on a wire” technique. In the latter case, performance improves in powders and low dielectric mediums that are not good reflectors of electromagnetic energy transmitted through a void (as in non-contact microwave sensors).

Active motion detection sensors

Magnetic sensors[3] detect changes, or disturbances, in magnetic fields that have been created or modified, and from them derive information on properties such as direction, presence, rotation, angle, or electrical currents. The output signal of these sensors requires signal processing for translation into the desired parameter. Although magnetic detectors are somewhat more difficult to use, they do provide accurate and reliable data — without physical contact. The reed switch is the simplest magnetic sensor. It consists of a pair of flexible, ferromagnetic contacts hermetically sealed in an inert gas filled container, often glass. The magnetic field along the long axis of the contacts magnetizes the contacts and causes them to attract each other, closing the circuit. Because there is usually considerable hysteresis between the closing and releasing fields, the switches are quite immune to small fluctuations in the field. Reed switches are maintenance free and highly immune to dirt and contamination.

Hall effect sensor is a transducer that varies its output voltage in response to changes in magnetic field. Hall sensors are used for proximity switching, positioning, speed detection, and current sensing applications. Hall sensors are commonly used to time the speed of wheels and shafts. They are used in brushless DC electric motors to detect the position of the permanent magnet. Hall sensors are commonly used to produce a digital indicator of the position of a pneumatic cyclinder, which used a magnetized shaft to trigger the Hall effect. Strips of magnetised material placed on a rotating disc can be sensed by a Hall-effect sensor or magnetoresistive sensor to serve as a rotary positional encoder, such as for determining centrifuge rotor position.

Inductive sensors are a non-contact device which detects metallic objects. Electric current in an induction loop generates a magnetic field, which collapses generating a current. The inductance of the loop changes according to the material inside it and since metals are much more effective inductors than other materials the presence of metal increases the current flowing through the loop. This current change can be converted to a signal to indicate the presence of an inductive material, such as metal. Compared to mechanical switches, inductive sensors have a long functional life because of the absence of mechanical parts and lack of physical contact between sensor and the sensed object. They generally have a relatively short range and the calibration of the output state can be highly dependent on the exact detection configuration and nature of materials involved. Slight changes in such may require recalibration. Inductive proximity sensors are often used to detect small parts such as chromatography vial caps or the movement of metal objects such as racks or drawers

Applications

Motion

A motion sensor is a device that contains a physical mechanism or electronic sensor that quantifies motion that can be either integrated with or connected to other devices that alert the user of the presence of a moving object within the field of view. Motion sensors can be based on optical, acoustic, or electromagnetic sensors.

Distance

A distance sensor is a device that contains a physical mechanism or electronic sensor that quantifies distance between the source and target. Distance sensors are generally based on either optical or acoustic technology.

Infrared distance sensors are of three types:

- Reflection: Range 2 - 3cm. This type uses an IR-LED and IR-diode (or phototransistor). When an object is close to the sensor it reflects the light emitted by the LED to the IR-diode.
- Triangulation: Range 10 - 30cm e.g. Consists of an IR-LED and multiple IR-diodes. Combined with built-in optical lenses, the reflected beam's position on the multiple IR-diodes indicates how far the object is.
- Line detection: Similar to the reflection IR-sensor, but aimed downwards to detect lines on the ground. This sensor makes use of the difference in IR reflection between a background and a line. This technology is

used to guide mobile robots. More advanced robots use multiple line detection sensors to follow a line more cleanly.

Ultrasonic distance sensors use sound to measure distances ranging from several centimeters up to a few meters. These sensors emit an ultrasone pulse train and then measure the time until the pulse is reflected. Since the speed of sound is (more or less; excluding temperature and wind) constant in air (approx. 344m/s) it is easy to calculate the distance to the reflecting object.

Laser based distance sensors use the same principle as ultrasonic distance sensors, using light instead of sound. These sensors are designed for longer distances, meters to kilometers, and are the most accurate of the available sensors.

Temperature

Thermal sensors measure temperature either by contact or indirectly. Contact temperature sensors measure their own temperature. One infers the temperature of the object to which the sensor is in contact by assuming or knowing that the two are in thermal equilibrium, that is, there is no heat flow between them. Contact sensors include:

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Noncontact temperature sensors measure the thermal radiant power of the Infrared or Optical radiation that they receive from a known or calculated area on its surface, or a known or calculated volume within it. The output signal is evaluated according to a calibration for the IR spectrum of a specific type of matter to be observed. Relatively accurate and precise temperature measurements may be obtained remotely. Without calibration to the type of material being observed, a PIR thermometer device is able to measure changes in IR emission which correspond directly to temperature changes, but the actual temperature values cannot be calculated.

Level Sensor

A level sensor is used to detect liquid or solid level. In laboratory automation, the material is usually contained in a vessel or tubing and is most commonly a liquid. The suitable level sensor for a given application depends on a number of variables: dielectric constant of the material, density or specific gravity of material, vessel composition size and shape, temperature, pressure, agitation or movement, and acoustical or electrical noise. Application considerations include price, accuracy, physical size and mounting, response rate, and ease of calibration or programming. The level measurement can be either continuous or at discrete points. Continuous level sensors measure level within a specified range and are used to know the exact amount of liquid in a certain place. Point level sensors only measures a specific level, generally this is used to detect high level alarms or low level alarms. Level sensors may be based on optical, capacitive, ultrasonic or electromagnetic sensors.

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