Overview of Sensors for Wireless Sensor Networks

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Abstract - *In a wireless sensor network sensors play an important part, as sensing is one of its central roles. A number of characteristics are important when choosing the right sensor for an application. Sesnors can be clasiffied accoridng two to basic criteria: principal by which they function, and by the function the sensor performs. Mechanical sensors detect mechanical properties and actions. Temperature sensors are some of the most widely used, and a variety of temperature sensors exist.*
Chemical, bio, and radiation sensors play an increasing role in a many WSN applications.

Keywords - *wireless sensor networks, sensors, microsesnsor*

Introduction

A sensor is an electronic device used to detect or measure a physical quantity and convert it into an electronic signal. In other words, sensors are devices that translate aspects of physical reality into a representations understandable and processable by computers.

In a wireless sensor network sensors play an important part, as sensing is one of its central roles. Technology behind sensors, however, is not of major interest when considering sensor networks, with the emphasis being more on communication, network management, and data manipulation. Most sensors used in WSN systems have been developed independently of WSN technology, and these two fields continue to develop somewhat independently.

Nevertheless, any in-depth discussion of wireless sensor networks, especially when aimed towards providing the reader with a holistic picture of current capabilities and limitations of wireless sensor networks, must include sensors.

Sensor characteristics

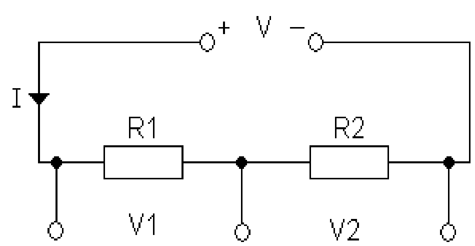
When choosing the right sensors for an application it is important to understand the basic characteristics of sensors found in the datasheets. Detailed explanation of of these characteristics is outside of scope of this article, so only a list is provided:

- Transfer Function
- Hysteresis
- Linearity
- Sensitivity
- Accuracy
- Dynamic Range
- Noise
- Resolution
- Bandwidth

Clasificaion

There are two basic ways to categorize sensors. First is based on the principal by which they function, and the second is based on the function the sensor performs.

Most sensors act like passive devices (i.e. capacitors or resistors). These sensor require external circuitry for biasing and amplification of the output signal.
Resistive sensors are devices whose resistance changes with the value of input signal being measured. These sensors can be used in a simple voltage-divider configuration (Picture 1). For more precise measurements a variety of configurations can be used (e.g. the Whetstone bridge circuit).



Picture 1: Voltage divider Legend: R1: Resistive sensor, R2: Reference resistor, V1: Voltage on the resistive sensor, V2: Voltage on the reference resistor, V: reference voltage.

Capacitive sensors produce a change in capacitance proportionate to the value of the measured input signal. Detection of this change is done quite similarly as with the resistive sensors, only in this case the impedance of the capacitor is observed, which means that an AC bias must be provided. Inductance based sensors can be observed in much the same way.

As opposed to these sensors some sensors produce their own bias voltage, and can directly be connected to an AD converter, or an amplifier if amplification is required.

Perhaps the more logical way to classify sensors is with regards to the physical property they measure. The most common categories include:

- Mechanical
- Thermal
- Electrical
- Magnetic
- Radiant
- Chemical and bio-chemical

Mechanical sensors

Mechanical sensors detect mechanical properties and actions. This includes (among other things) pressure, velocity, vibration sensors and accelerometers.

Pressure sensors

Pressure is one of the most important physical properties, and thus, pressure micro-sensors were the first micro-sensors developed and used by the industry. A wide variety of applications calls for a wide variety of pressure sensors, but most belong in one of three major categories.

Piezorezistive pressure sensors

Piezorezistive pressure sensors have a piezoresistor integrated in a membrane. Pressure is applied to the membrane, causing it to deform. This in turn, causes a change in resistance, proportionate to the applied force.

Capacitive pressure sensors

In capacitive pressure sensors (whether membrane or comb based) pressure is applied on the sensor surface, causing a membrane to deflect and the capacitance to change. These senosors generally have greater sensitivity and linearity, while exhibiting very little or no hysteresis. However, these sensors also have higher production costs when compared to piezoresistive pressure sensors.

Optical pressure sensors

Optical pressure sensors operate on the principal of the Mach-Zehnder interferometer. Laser light is brought into the sensor via an optical fiber. This light is split into two beams. One of the two beams crosses through one of the beams which is deformed by the pressure. This deformation changes the light's properties. The two beams are combined and brought to a photodiode. Different propagation speeds create a phase shift between these beams which is detected at the diode.

Position and Motion Sensors

Position sensors play an important role in a wide variety of applications. Numerous ways of detecting position are available, ranging from simple contact sensors to more complex contact-free ones. Position measurement can either be relative (displacement sensors) or absolute, linear or angular.

Accelerometers

Accelerometers are sensors that measure acceleration they are subjected to. Most are based on resistive or capitative and piezoelectric methods.

Resistive and capacitive accelerometers

With these micro-sensors an elastic cantilever with an attached mass is usually used. When the sensor is subjected to acceleration, a force proportionate to this acceleration deforms the cantilever. With piezoresistive sensors a piezoresistor is integrated into the cantilever, whose deformation causes a change in its' resistance. With capacitive sensors the cantilever acts as one electrode, with a electrode strip acting as the other. As the cantilever is deformed it is brought closer to the electrode strip, which in turn effects the capacitance between the two electrodes.

Resistive and capacitive accelerometers can be used to measure constant acceleration, such as that of earth’s gravity. They are generally used for measuring low frequency vibrations.

Piezoelectric accelerometers

Piezoelectric accelerometers are based on the piezoelectric effect. This means that an electric charge is created when the sensing material is squeezed or strained. Several methods of straining of the material can be used, three of the basic being: compression, flexural, and shear, with the shear being the most common one. These accelerometers are generally durable, protected from contamination, impervious to extraneous noise influences.

Temperature sensors

Temperature sensors detect a change in a physical parameter (resistance or output voltage) that corresponds to a temperature change. Three basic types of temperature sensors are electro-mechanical, electronic, and thermo-resistive.

Electromechanical temperature sensors

These sensors are based on expanding or contracting properties of materials when subjected to a temperature change. Bi-metal thermostats are created by bonding two metals into a single strip of material. Different expansion rates of the metals create electro-mechanical motion when the material is subjected to a temperature change. In capillary thermostats the capillary motion of expanding or contracting fluid is used to make or break a number of electrical contacts.

Resistive Temperature sensors

Resistive temperature sensors are devices whose resistance changes with the temperature.

Thermistors

A thermistor is a type of resistor with resistance varying according to its temperature. They typically consist of a combination of two or three metal oxides that are sintered in a ceramic base material.

Thermistors can be classified into two types: positive temperature coefficient (PTC) and negative temperature coefficient (NTC). PTC devices exhibit an increase in resistance as temperature rises, while NTC devices exhibit a decrease in resistance when temperature increases.

The main disadvantage of the thermistor is its strong non-linearity. Cheap thermistors have large spread of parameters (“tolerance”) and calibration is usually necessary.

Resistive temperature detectors (RTDs)

Unlike thermistors that use a combination of metal oxides and ceramics resistive temperature detectors are made from pure metal (copper, nickel or platinum are usually used). RTDs are useful over larger temperature ranges, while thermistors typically achieve a higher precision within a limited temperature range.

As a RTD is a resistance device and it needs measuring current to generate a useful signal. Because this current heats the element above the ambient temperature (P = I2.R), errors can occur, unless the extra heat is dispersed. This forces us to choose a small-sized resistance device with a quick response or a larger resistance device and better heat release.

A second solution is to keep the measuring current low (usually between 1 mA and 5 mA).

Humidity sensors

Humidity is the amount of water vapor in the given substance (usually a gas). It is an important parameter in a variety of fields, including room air humidity in patient monitoring and exhibit perseveration in museums, meteorological observations, soil humidity in agriculture, and process control in the industrial applications.

Humidity can be measured as the absolute humidity (ratio of water vapor to the volume of substance), relative (compared to the saturated moisture level) or dew point (temperature and pressure at which the observed gas starts to turn into liquid). Most common humidity sensors are based capacitive, resistive, and thermal conductivity measurement techniques.

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Capacitive RH Sensors
In a capacitive RH sensor, change in dielectric constant is almost directly proportional to relative humidity in the environment. Relative humidity sensors have three-layer capacitance construction and consists of thermoset polymer, platinum electrodes, and a silicon chip with integrated voltage output signal conditioning.

These sensors have low temperature coefficient, and response times that range from 30 to 60 seconds.

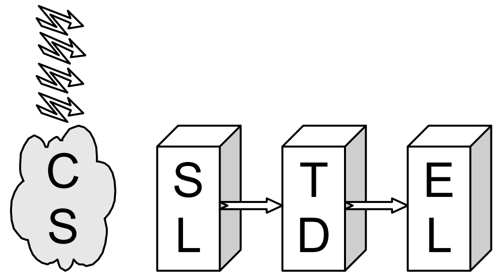
They offer near-linear voltage outputs, wide RH ranges and condensation tolerance, and are stable over long-term use. However, the capacitive effect of the cable connecting the sensor to the signal conditioning circuitry is large compared to the small capacitance changes of the sensor. This limits the distance from sensing element to signal conditioning circuitry.

Resistive Humidity Sensors
Resistive humidity sensors measure the resistance change in a medium such as a conductive polymer or a salt. Resistance usually has an inverse exponential relationship to humidity. Response times of these sensors is 10-30 seconds.
Resistive humidity sensors are small size, low cost, and are usable from remote locations.

Chemical sensors

Chemical sensors are detect the presence or concentration of particlar chemical elements or compounds in a given sample. A chemical sensor usually consists of a chemically sensitive film or a membrane and a transducer.

A chemical process occurring in or on a chemically sensitive film or membrane is causes a signal to be generated generation at the transducer. Examples of mechanisms commonly employed include host-guest binding, catalytic reactions or a redox process.
Chemical sensors have a wast variety of applications ranging form medical diagnostics and nutritional sciences through security to automotive industry.



Picture 2: Structure of a chemical sensor Legend: CS: Chemical substance, SL: Sensitive layer, TD: Transducer, EL: Electronics Explanation: Chemical substance reacts with the chemical layer. Reaction causes a signal to be generated generation at the transducer. The signal is then processed by electronics and converted into a format suitable for further processing.

Interdigital transducer sensors
Interdigital transducers using capitative measurement are often used in chemical sensors. Sensitive layer is used as the dielectric between two electrodes. The dielectric properties of the sensitive layer are changed when it interacts with certain substances, effecting the capacitance between the two electrodes.

Conductivity sensors
In these sensors the sensitive layer is used as a conductor of electricity. Interactions with certain chemicals (e.g. absorption of gasses) modifies the conductivity of this layer. There are two types of sensing layers: Metal Oxide and Conducting Polymers.
Metal Oxide sensitive layers are typically made of SnO_2 doped with Pt or Pd. These sensors can operate at high temperatures (300-5000 C) which makes them especially suitable for combustion gases.
Conductive Polymer sensitive layers are usually based on pyrrole, aniline or thiophene. These sensor operate best at room temperatures. Compared to Metal Oxide sensors these sensors have lower power consumption, and faster response and recovery times. However, they are have lower sensitivity and are sensitive to humidity.

Optical chemical sensors
In optical sensors an optical waveguide is used as the sensitive layer. Chemical reactions between the waveguide and the target chemical substance cause a change in the optical

properties of the waveguide (e.g. the index of reflection). As a result the amount (or the wavelength) of the light striking the sensor on the end of the waveguide varies.

These sensors are highly sensitive, can handle small quantities, inexpensive, and easy to sterilize.

Majority (about 60%) of chemical sensors are gas sensors. Most commonly used chemical sensors include: O2, pH, CO, CO2, NOX, Methane, etc.

Ion sensitive FET sensor
An ion sensitive field effect transistor (ISFET) is an ion-sensitive field effect transistor used to measure ion concentrations in solution; when the ion concentration (such as pH) changes, the current through the transistor will change accordingly. Here, the solution is used as the gate electrode. A voltage between substrate and oxide surfaces arises due to an ions sheath.

An ISFET's source and drain are constructed as for a MOSFET. The gate electrode is separated from the channel by a barrier which is sensitive to hydrogen ions and a gap to allow the substance under test to come in contact with the sensitive barrier. An ISFET's threshold voltage depends on the pH of the substance in contact with its ion-sensitive barrier.
The surface hydrolization of OH groups of the gate materials varies in aqueous solutions due to pH value. Typical gate materials are Si3N4, Al2O3 and Ta2O5.

ISFET sensors are used in devices for continuos measurements like those for continuous measurement of pH value and gases in blood (O2, CO2).

Piezoelectric chemical sensors
Piezoelectric effect is the generation of an electric charge in a crystalline material upon subjecting it to stress. A piezoelectric chemical sensor is a piezoelectric oscillator that responds to changes in the chemical composition of its environment with changes of the resonant frequency, or wave speed.
Complex nature of these sensors make them unsuitable for a brief overview of operating principals, as is suitable for this book. However, as these sensors are undergoing a rapid expansion, readers are encouraged to turn to references for more detailed explanations.

Biosensors

Detection of presence and concentrations of bacteria, viruses, or molecules and molecular complexes like proteins, enzymes, antibodies, DNA, etc. is essential to a wide range of applications.

Traditionally, this has been done through time-consuming chemical analysis methods, that require laboratory conditions and employ expensive reagents and equipment. Technological advancements and introduction of micro-sensor technology to this field has led to development of biosensors.

Much like a chemical sensor, biosensor consists of three parts: a sensitive layer, transducer and electronic circuitry to process the signal from the transducer.

Sensitive layer in a biosensor is a biosensitive biological component, like enzymes, antibodies, cell membrane receptors, tissue slices, etc.

Radiation sensors

Ionizing radiation consists of subatomic particles or waves that are energetic enough to detach electrons from atoms or molecules, ionizing them. Exposure to radiation causes microscopic damage to living tissue, resulting in skin burns and radiation sickness at high doses and cancer, tumors and genetic damage at low doses. Therefore, monitoring radiation levels is imperative in many industrial applications where human interaction with radioactive materials exists, as well as in guarding against intentional or accidental exposure of wider population to radiation. Wireless sensor networks provide ideal infrastructure for these kinds of systems.

Geiger-Müller counter
Geiger counters are used to detect radiation usually gamma and beta radiation, but certain models can also detect alpha radiation. The sensor is a Geiger-Müller tube, an inert gas-filled tube (usually helium, neon or argon with halogens added) that briefly conducts electricity when a particle or photon of radiation temporarily makes the gas conductive. The tube amplifies this conduction by a cascade effect and outputs a current pulse.

Quartz fiber dosimeter

A quartz fiber dosimeter is a pen-like device that measures the cumulative dose of ionizing radiation received by the device. The device is mainly sensitive to gamma and x-rays, but it also detects beta radiation above 1 MeV. Neutron sensitive versions have been made.

Film badge dosimeter

The film badge dosimeter, or film badge, is a dosimeter used for monitoring cumulative exposure to ionizing radiation. The badge consists of two parts: photographic film, and a holder.

The film is sensitive to radiation and, once developed, exposed areas increase in optical density (i.e. blacken) in response to incident radiation. One badge may contain several films of different sensitivities or, more usually, a single film with multiple emulsion coatings. This allows for separate measurement of neutron, beta, and gamma exposure, and estimation of energy spectra. The holder may contain a number of filters that attenuate certain types of radiation, such that only the target radiation is monitored. To monitor gamma rays or x-rays, the filters are metal, usually tin or lead. To monitor beta particle emission, the filters use various densities of plastic.

Thermoluminescent Dosimeter

A thermoluminescent dosimeter, or TLD, is a type of radiation dosimeter. A TLD measures ionizing radiation exposure by measuring the amount of visible light emitted from a crystal in the detector when the crystal is heated. The amount of light emitted is dependent upon the radiation exposure.

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