Sheikh Hasina University, Netrokona

Department of Computer Science and Engineering

CSE-2205: Introduction to Mechatronics

Lec-2: Fundamentals of Mechatronics

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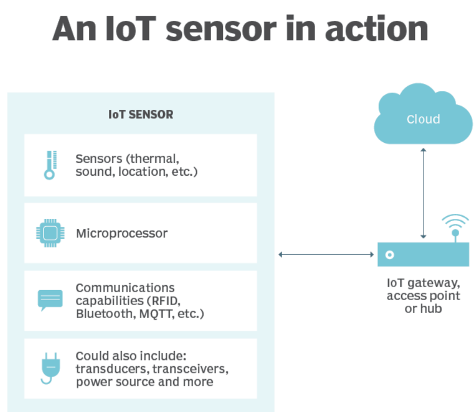
Sensors and Transducers

Sensor and Transducer

1. **Sensor:**

A sensor is a device that detects and responds to some type of input from the physical environment. The input can be light, heat, motion, moisture, pressure or any number of other environmental phenomena. The output is generally a signal that is converted to a human-readable display at the sensor location or transmitted electronically over a network for reading or further processing.



Sensors play a pivotal role in the internet of things (IoT). They make it possible to create an ecosystem for collecting and processing data about a specific environment so it can be monitored, managed and controlled more easily and efficiently. IoT sensors are used in homes, out in the field, in automobiles, on airplanes, in industrial settings and in other environments. Sensors bridge the gap between the physical world and logical world, acting as the eyes and ears for a computing infrastructure that analyzes and acts upon the data collected from the sensors.

<u>What are the types of sensors?</u>

Sensors can be categorized in multiple ways. One common approach is to classify them as either active or passive. An active sensor is one that requires an external power source to be able to respond to environmental input and generate output. For example, sensors used in weather satellites often require some source of energy to provide meteorological data about the Earth's atmosphere.

A passive sensor, on the other hand, doesn't require an external power source to detect environmental input. It relies on the environment itself for its power, using sources such as light or thermal energy. A good example is the mercury-based glass thermometer. The mercury expands and contracts in response to fluctuating temperatures, causing the level to be higher or lower in the glass tube. External markings provide a human-readable gauge for viewing the temperature.

Some types of sensors, such as seismic and infrared light sensors, are available in both active and passive forms. The environment in which the sensor is deployed typically determines which type is best suited for the application.

Another way in which sensors can be classified is by whether they're analog or digital, based on the type of output the sensors produce. Analog sensors convert the environmental input into output analog signals, which are continuous and varying. Thermocouples that are used in gas hot water heaters offer a good example of analog sensors. The water heater's pilot light continuously heats the thermocouple. If the pilot light goes out, the thermocouple cools, sending a different analog signal that indicates the gas should be shut off.

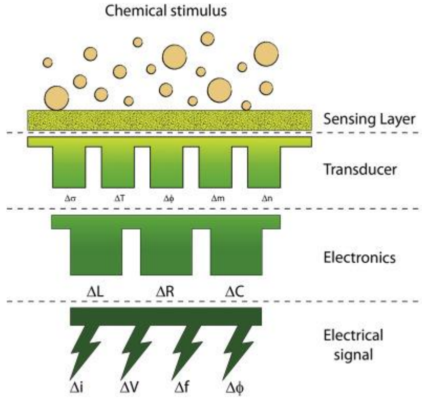
In contrast to analog sensors, digital sensors convert the environmental input into discrete digital signals that are transmitted in a binary format (1s and 0s). Digital sensors have become quite common across all industries, replacing analog sensors in many situations. For example, digital sensors are now used to measure humidity, temperature, atmospheric pressure, air quality and many other types of environmental phenomena.

As with active and passive sensors, some types of sensors -- such as thermal or pressure sensors -- are available in both analog and digital forms. In this case, too, the environment in which the sensor will operate typically determines which is the best option.

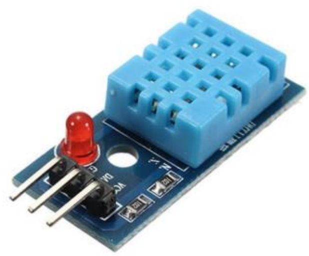
Sensors are also commonly categorized by the type of environmental factors they monitor. Here are some common examples:

i. **Accelerometer:** This type of sensor detects changes in gravitational acceleration, making it possible to measure tilt, vibration and, of course, acceleration. Accelerometer sensors are used in a wide range of industries, from consumer electronics to professional sports to aerospace and aviation.

ii. **Chemical:** Chemical sensors detect a specific chemical substance within a medium (gas, liquid or solid). A chemical sensor can be used to detect soil nutrient levels in a crop field, smoke or carbon monoxide in a room, pH levels in a body of water, the amount of alcohol on someone's breath or in any number of other scenarios. For example, an oxygen sensor in a car's emission control system will monitor the gasoline-to-oxygen ratio, usually through a chemical reaction that generates voltage. A computer in the engine compartment reads the voltage and, if the mixture is not optimal, readjusts the ratio.



iii. **Humidity:** These sensors can detect the level of water vapors in the air to determine the relative humidity. Humidity sensors often include temperature readings because relative humidity is dependent on the air temperature. The sensors are used in a wide range of industries and settings, including agriculture, manufacturing, data centers, meteorology, and heating, ventilation and air conditioning (HVAC).



iv. **Level:** A level sensor can determine the level of a physical substance such as water, fuel, coolant, grain, fertilizer or waste. Motorists, for example, rely on their gas level sensors to ensure they don't end up stranded on the side of the road. Level sensors are also used in tsunami warning systems.

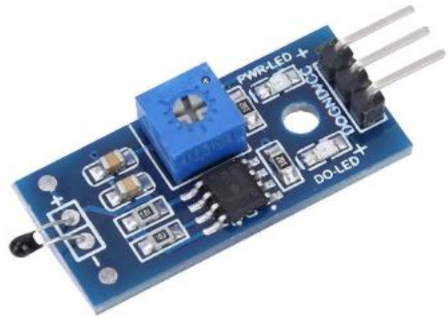
v. **Motion:** Motion detectors can sense physical movement in a defined space (the field of detection) and can be used to control lights, cameras, parking gates, water faucets, security systems, automatic door openers and numerous other systems. The sensors typically send out some type of energy -- such as microwaves, ultrasonic waves or light beams -- and can detect when the flow of energy is interrupted by something entering its path.

vi. **Optical:** Optical sensors, also called photosensors, can detect light waves at different points in the light spectrum, including ultraviolet light, visible light and infrared light. Optical sensors are used extensively in smartphones, robotics, Blu-ray players, home security systems, medical devices and a wide range of other systems.

vii. **Pressure:** These sensors detect the pressure of a liquid or gas, and are used extensively in machinery, automobiles, aircraft, HVAC systems and other environments. They also play an important role in meteorology by measuring the atmospheric pressure. In addition, pressure sensors can be used to monitor the flow of gases or liquids, often so that the flow can be regulated.

viii. **Proximity:** Proximity sensors detect the presence of an object or determine the distance between objects. Proximity monitors are used in elevators, assembly lines, parking lots, retail stores, automobiles, robotics and numerous other environments.

ix. **Temperature:** These sensors can identify the temperature of a target medium, whether gas, liquid or air. Temperature sensors are used across a wide range of devices and environments, such as appliances, machinery, aircraft, automobiles, computers, greenhouses, farms, thermostats and many other devices.



x. **Touch:** Touch sensing devices detect physical contact on a monitored surface. Touch sensors are used extensively in electronic devices to support trackpad and touchscreen technologies. They're also used in many other systems, such as elevators, robotics and soap dispensers.

The above are only some of the various types of sensors being used across environments and within devices. However, none of these categories are strictly black and white; for example, a level sensor that tracks a material's level might also be considered an optic or pressure sensor. There are also plenty of other types of sensors, such as those that can detect load, strain, color, sound and a variety of other conditions. Sensors have become so commonplace, in fact, that often their use is barely noticed.

2. **Transducer:**

A transducer is a broader term that encompasses devices capable of converting one form of energy or physical quantity into another. In essence, a transducer can convert various types of physical signals, including mechanical, electrical, thermal, or optical, from one form to another. Sensors are a specific type of transducer, primarily focused on detecting physical phenomena and generating electrical signals in response. Transducers, however, can include devices like microphones (acoustic-to-electrical transducers), loudspeakers (electrical-to-acoustic transducers), and more. Transducers are essential components in many engineering and electronic systems where signal conversion is necessary.

Characteristic	Sensor	Transducer
Definition	A sensor is a specific type of transducer that detects and responds to a physical stimulus or environmental change, generating an electrical, optical, or mechanical signal as output.	A transducer is a broader term that refers to devices capable of converting one form of energy or physical quantity into another, encompassing sensors but also including other types of signal converters.

Characteristic	Sensor	Transducer
Functionality	Detects specific physical phenomena or inputs and converts them into measurable signals.	Converts one type of physical energy or quantity into another, which may or may not involve sensing a particular stimulus.
Examples	Temperature sensor, light sensor, motion sensor, pressure sensor, humidity sensor, etc.	Microphone (acoustic-to-electrical transducer), loudspeaker (electrical-to-acoustic transducer), piezoelectric sensor (mechanical-to-electrical transducer), etc.
Focus	Primarily focused on detecting and measuring specific physical quantities or environmental changes.	Encompasses a wider range of devices used for signal conversion, not limited to sensing applications.
Output Type	Typically produces electrical, optical, or mechanical signals as output, often in response to a detected stimulus.	May produce various types of outputs, including electrical, acoustic, thermal, or optical signals, depending on the specific transducer type.
Usage	Commonly used in data acquisition, monitoring, control systems, and automation where precise measurement and detection are required.	Used in diverse applications, including telecommunications, audio systems, signal processing, and instrumentation, where signal conversion is essential.

Analog Sensor (Transducer):

Thermocouples are often used as temperature sensors. When you expose a thermocouple to a change in temperature, it generates a small analog voltage signal that corresponds to the temperature change. The voltage change is continuous and proportional to the temperature difference. So, if the temperature increases, the voltage output of the thermocouple will increase, and if it decreases, the voltage output will decrease in a continuous manner.

Digital Sensor (Transducer):

Digital sensors, on the other hand, provide discrete, on/off signals that represent information. For example, a digital temperature sensor might output a series of binary signals (0s and 1s) that encode the temperature reading in a digital format. It might send a binary "10101010" to represent a specific temperature range.

Smart Sensor

A smart sensor is an advanced type of sensor that goes beyond basic sensing capabilities. It is designed to not only measure physical quantities but also perform various functions to enhance its performance and usability. Here are some key characteristics and capabilities of smart sensors:

1. **Integrated Sensor and Signal Conditioning:** Smart sensors typically combine the sensor element and signal conditioning circuitry into a single package. This integration simplifies the overall sensor system and reduces the need for external components.

2. **Microprocessor Integration:** In addition to sensor and signal conditioning, smart sensors often include a microprocessor or microcontroller. This microprocessor adds computational capabilities to the sensor, allowing it to process data and make intelligent decisions.

3. **Error Compensation:** Smart sensors can compensate for random errors in measurements. They have the ability to filter out noise and provide more accurate readings.

4. **Adaptability:** These sensors can adapt to changes in the environment. For example, they may adjust their measurement range or sensitivity based on the conditions they are exposed to.

5. **Measurement Accuracy Calculation:** Smart sensors can automatically calculate measurement accuracy and provide this information as part of their output. Users can rely on this information to assess the reliability of the sensor's measurements.

6. **Linearity Adjustment:** They can adjust for nonlinearities in the sensor's response to make the output more linear and predictable.

7. **Self-Calibration:** Smart sensors have the capability to perform self-calibration routines, ensuring that their measurements remain accurate over time.

8. **Self-Diagnosis:** They can diagnose and report faults or malfunctions, making maintenance and troubleshooting easier.

9. **Standardized Communication:** Many smart sensors adhere to standards like IEEE 1451. This standardization allows them to communicate with other devices in a plug-and-play manner. Each smart sensor has a Transducer Electronic Datasheet (TEDS) that stores information about the sensor's characteristics and calibration data.

10. **EEPROM Storage:** TEDS information is typically stored in non-volatile memory, such as EEPROM (Electrically Erasable Programmable Read-Only Memory), which retains data even when power is disconnected.

Smart sensors are valuable in various applications where accuracy, adaptability, and advanced features are required. They are commonly used in industrial automation, environmental monitoring, automotive systems, and many other fields where precise and intelligent sensing is essential.

Performance Terminology

1. **Range and Span:**

- **Range:** The limits within which the input can vary. For example, a temperature sensor might have a range of -10°C to 100°C, meaning it can measure temperatures within this range.

- **Span:** The maximum value of the input minus the minimum value. In the case of the temperature sensor, the span would be 100°C - (-10°C) = 110°C.

2. **Error:**

   - **Error:** The difference between the measured value and the true value of the quantity being measured. For instance, if a thermometer reads 25°C when the actual temperature is 24°C, the error is +1°C. If the actual temperature were 26°C, the error would be -1°C.

3. **Accuracy:**

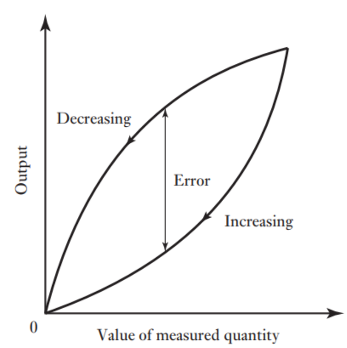
   - **Accuracy:** The extent to which the value indicated by a measurement system might be wrong. If a temperature-measuring instrument is specified as having an accuracy of ±2°C, it means the reading can deviate by up to 2°C from the true value. This is often expressed as a percentage of full range, like ±5% of full range output.

4. **Sensitivity:**

   - **Sensitivity:** The relationship indicating how much output there is per unit input. For example, a strain gauge might have a sensitivity of 2 mV/V, meaning it produces a 2-millivolt change in output voltage per volt change in input.

5. **Hysteresis Error:**

   - **Hysteresis Error:** Transducers can produce different outputs for the same input value depending on whether the input has been reached through an increasing or decreasing change. This effect is called hysteresis. For example, a pressure transducer might have a hysteresis error of 1% of the full scale, indicating that the output can differ by up to 1% when approached from different directions.



6. **Non-linearity Error:**

   - **Non-linearity Error:** It occurs when a transducer's output doesn't have a perfect linear relationship with the input over its working range. For instance, a position sensor might assume a linear relationship, but due to non-linearity, there are deviations from a straight line. This error is usually expressed as a percentage of the full range output, like ±0.5% of the full range.

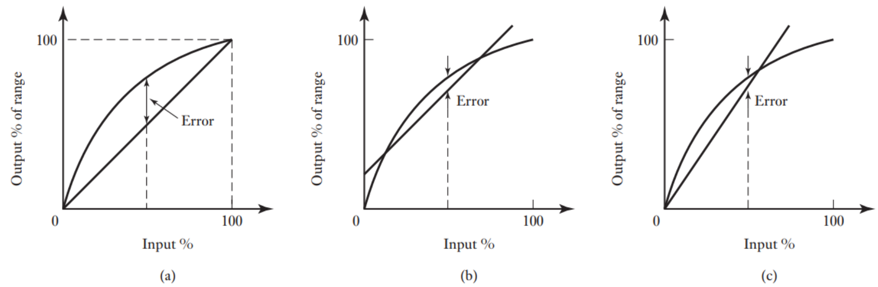


Fig: Non-linearity error using: (a) end-range values, (b) best straight line for all values, (c) best straight line through the zero point.

7. **Repeatability/Reproducibility:**

- **Repeatability:** It assesses the ability of a transducer to give the same output for repeated applications of the same input. For example, if a pressure transducer consistently provides the same output when the same pressure is applied multiple times, its repeatability might be specified as ±0.01% of the full range.

$$\text{repeatability} = \frac{\text{max.} - \text{min. values given}}{\text{full range}} \times 100$$

8. **Stability:**

- **Stability:** It measures a transducer's ability to provide a consistent output when measuring a constant input over time. Stability is related to drift, which is the change in output over time. The drift may be expressed as a percentage of the full range output. Zero drift refers to changes when there's no input.

9. **Dead Band/Time:**

- **Dead Band:** The range of input values for which a transducer provides no output. For instance, in a flowmeter using a rotor, there might be a velocity threshold below which no output is observed due to bearing friction.

- **Dead Time:** The time it takes from the application of an input until the output begins to respond and change. It indicates the delay in the transducer's response.

10. **Resolution:**

- **Resolution:** It's the smallest change in the input value that produces an observable change in the output. For example, a digital sensor may have a resolution of 1 bit. In this context, for a data word of N bits, the resolution is generally expressed as 1/2^N.

11. **Output Impedance:**

- **Output Impedance:** When an electrical sensor is connected to an electronic circuit, its output impedance becomes crucial. It affects how the sensor behaves when connected to the circuit. For example, if a sensor has a high output impedance and is connected in series with a circuit, it can significantly affect the circuit's behavior, causing loading effects.

Example: Consider the significance of the terms in the following specification of a strain gauge pressure transducer:

Ranges: 70 to 1000 kPa, 2000 to 70 000 kPa

Supply voltage: 10 V d.c. or a.c. r.m.s.

Full range output: 40 mV

Non-linearity and hysteresis: ±0.5% of full range output

Temperature range: -54°C to +120°C when operating

Thermal zero shift: 0.030% of full range output/°C

Interpret the following specifications.

1. **Ranges:** The transducer can measure pressures within two different ranges:
    - 70 to 1000 kPa
    - 2000 to 70,000 kPa

This means it can be used for a wide range of pressure measurements, from relatively low to high pressures.

2. **Supply Voltage:** The transducer requires a supply voltage of 10 V DC or AC root mean square (RMS) for its operation. This indicates the voltage level needed to power the transducer.
3. **Full Range Output:** When the pressure is at its maximum within the specified range, the transducer will produce a 40 mV output. This is the signal strength the transducer generates for a maximum pressure input.
4. **Non-linearity and Hysteresis:** These terms indicate potential errors in the transducer's output. The specification mentions an error of ±0.5% of the full range output for both non-linearity and hysteresis. This means that, due to these factors, the transducer's output may deviate by up to 0.5% of the maximum output for a given pressure range. For the lower range (1000 kPa), this represents ±5 kPa, and for the upper range (70,000 kPa), it represents ±350 kPa.
5. **Temperature Range:** The transducer can operate within a wide temperature range, from -54°C to +120°C. This indicates the environmental conditions under which it can provide accurate measurements.
6. **Thermal Zero Shift:** This term specifies how much the transducer's output will change when the temperature changes by 1°C. For the lower range (1000 kPa), the output changes by 0.030% of

the full range output per degree Celsius, which is equivalent to 0.3 kPa. For the upper range (70,000 kPa), the change is 21 kPa per degree Celsius.