# Sensor and Actuators

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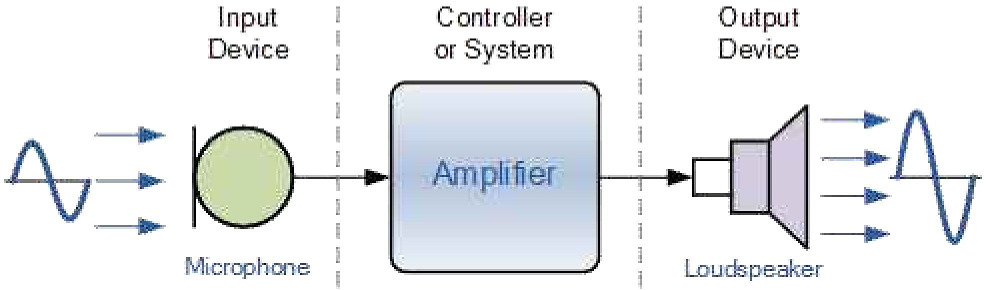
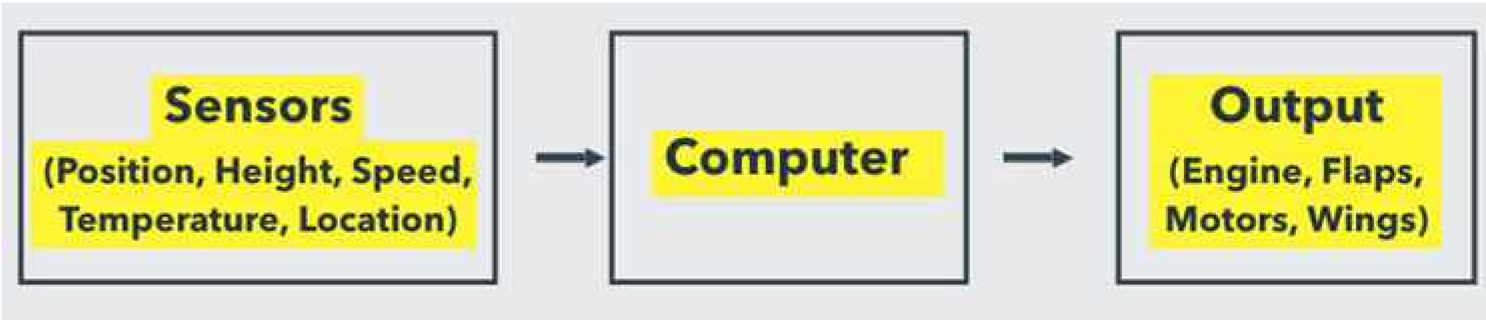

Input
Device
Controller
or System
Output
Device
Amplifier
Microphone
Loudspeaker


Sensors
(Position, Height, Speed,
Temperature, Location)
Computer
Output
(Engine, Flaps,
Motors, Wings)

# Sensors

- Sensor is a device that when exposed to a physical phenomenon (temperature, displacement, force, etc.) produces a proportional output signal (electrical, mechanical, magnetic, etc.).
- The term transducer is often used synonymously with sensors.
- However, ideally, a sensor is a device that responds to a change in the physical phenomenon.
- On the other hand, a transducer is a device that converts one form of energy into another form of energy.
- Sensors are transducers when they sense one form of energy input and output in a different form of energy.
- For example, a thermocouple responds to a temperature change (thermal energy) and outputs a proportional change in electromotive force (electrical energy). Therefore, a thermocouple can be called a sensor and or transducer.

**Sensors**

According to the Instrument Society of America, sensor can be defined as

"A device which provides an usable output in response to a specified measurand."

A device that detects and responds to some type of input from the physical environment.

Here, the output is usually an 'electrical quantity' and measurand is a 'physical quantity, property or condition which is to be measured'.

**Transducer**

It is defined as an element when subjected to some physical change experiences a related change or an element which converts a specified measurand into a usable output by using a transduction principle.

An electronic device that converts energy from one form to another

A wire of Constantan alloy (copper-nickel 55-45% alloy) can be called as a sensor because variation in mechanical displacement (tension or compression) can be sensed as change in electric resistance.

This wire becomes a transducer with appropriate electrodes and input-output mechanism attached to it. Thus we can say that 'sensors are transducers'.

# Sensors and Transducer Specification

| | |
|---|---|
| Range | Hysteresis |
| Span | Resolution |
| Error | Stability |
| Accuracy | Dead band/time |
| Sensitivity | Repeatability |
| Nonlinearity | Response time |

**Range**

The range of a sensor indicates the limits between which the input can vary. For example, a thermocouple for the measurement of temperature might have a range of 25-225 °C.

**Span**

The span is difference between the maximum and minimum values of the input. Thus, the above-mentioned thermocouple will have a span of 200 °C.

**Error**

Error is the difference between the result of the measurement and the true value of the quantity being measured. A sensor might give a displacement reading of 29.8 mm, when the actual displacement had been 30 mm, then the error is –0.2 mm.

**Sensitivity**

Sensitivity of a sensor is defined as the ratio of change in output value of a sensor to the per unit change in input value that causes the output change. For example, a general purpose thermocouple may have a ensitivity of 41 μV/°C.

**Accuracy**

The accuracy defines the closeness of the agreement between the actual measurement result and a true value of the measurand. It is often expressed as a percentage of the full range output or full–scale deflection.

**Resolution**

Resolution is the smallest detectable incremental change of input parameter that can be detected in the output signal. Resolution can be expressed either as a proportion of the full-scale reading or in absolute Terms. Example: if a LVDT sensor measures a displacement up to 20 mm and it provides an output as a number between 1 and 100 then the resolution of the sensor device is 0.2 mm.

**Stability**

Stability is the ability of a sensor device to give same output when used to measure a constant input over a period of time. The term ‘drift’ is used to indicate the change in output that occurs over a period of time. It is expressed as the percentage of full range output.

**Dead band/time**

The dead band or dead space of a transducer is the range of input values for which there is no output. The dead time of a sensor device is the time duration from the application of an input until the output begins to respond or change.

**Repeatability**

It specifies the ability of a sensor to give same output for repeated applications of same input value. It is usually expressed as a percentage of the full range output:

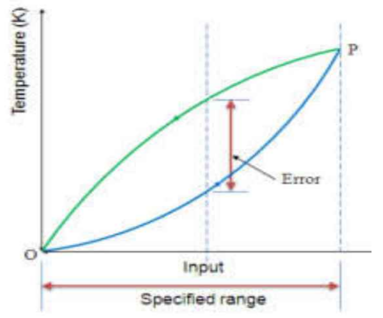
$$\text{Repeatability} = \frac{(\text{Maximum} - \text{Minimum})}{\text{Full Range}} \times 100$$

**Response time**

Response time describes the speed of change in the output on a step-wise change of the measurand. It is always specified with an indication of input step and the output range for which the response time is defined.

## Hysteresis

The hysteresis is an error of a sensor, which is defined as the maximum difference in output at any measurement value within the sensor's specified range when approaching the point first with increasing and then with decreasing the input parameter.

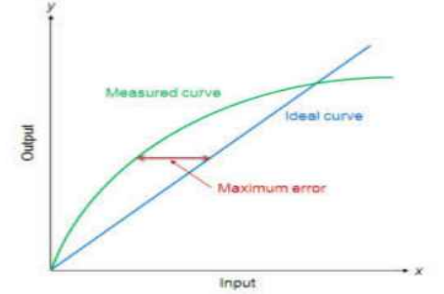



## Nonlinearity

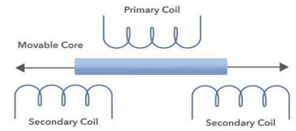
The nonlinearity indicates the maximum deviation of the actual measured curve of a sensor from the ideal curve.

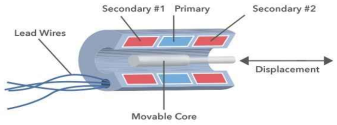
Linearity is often specified in terms of percentage of nonlinearity, which is defined as:

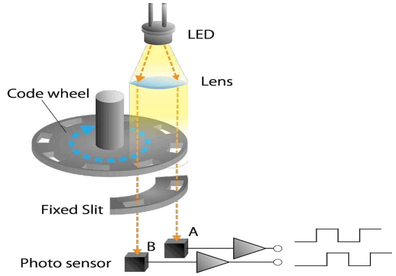
$$\text{Nonlinearity (\%)} = \frac{\text{Maximum deviation in input}}{\text{Maximum full scale input}}$$



| Linear/Rotational sensors | |
|---|---|
| Linear/Rotational variable differential transducer (LVDT/RVDT) | High resolution with wide range capability<br>Very stable in static and quasi-static applications |
| Optical encoder | Simple, reliable, and low-cost solution<br>Good for both absolute and incremental measurements |
| Electrical tachometer | Resolution depends on type such as generator or magnetic pickups |
| Hall effect sensor | High accuracy over a small to medium range |
| Capacitive transducer | Very high resolution with high sensitivity<br>Low power requirements<br>Good for high frequency dynamic measurements |
| Strain gauge elements | Very high accuracy in small ranges<br>Provides high resolution at low noise levels |



| Sensors | Features |
| --- | --- |
| Interferometer | Laser systems provide extremely high resolution in large ranges<br>Very reliable and expensive |
| Magnetic pickup<br>Gyroscope | Output is sinusoidal |
| Inductosyn | Very high resolution over small ranges |
| **Acceleration sensors** | |
| Seismic accelerometer | Good for measuring frequencies up to 40% of its natural frequency |
| Piezoelectric accelerometer | High sensitivity, compact, and rugged<br>Very high natural frequency (100 kHz typical) |
| | |

| Sensors | Features |
| --- | --- |
| **Force, torque, and pressure sensor** | |
| Strain gauge | Good for both static and dynamic measurements |
| Dynamometers/load cells | They are also available as micro- and nano-sensors |
| Piezoelectric load cells | Good for high precision dynamic force measurements |
| Tactile sensor | Compact, has wide dynamic range, and high |
| Ultrasonic stress sensor | Good for small force measurements |
| | |

| Sensors | Features |
|---|---|
| **Flow sensors** | |
| Pitot tube | Widely used as a flow rate sensor to determine speed in aircrafts |
| Orifice plate | Least expensive with limited range |
| Flow nozzle, venturi tubes | Accurate on wide range of flow<br>More complex and expensive |
| Rotameter | Good for upstream flow measurements<br>Used in conjunction with variable inductance sensor |
| Ultrasonic type | Good for very high flow rates<br>Can be used for both upstream and downstream flow measurements |
| Turbine flow meter | Not suited for fluids containing abrasive particles<br>Relationship between flow rate and angular velocity is linear |

| Sensors | Features |
| --- | --- |
| **Flow sensors continue..** | |
| Electromagnetic flow meter | Least intrusive as it is noncontact type<br>Can be used with fluids that are corrosive, contaminated, etc.<br>The fluid has to be electrically conductive |
| Temperature sensors | |
| Thermocouples | This is the cheapest and the most versatile sensor<br>Applicable over wide temperature ranges (-200°C to 1200°C typical) |
| Thermistors | Very high sensitivity in medium ranges (up to 100°C typical)<br>Compact but nonlinear in nature |
| Thermodiodes, thermo transistors | Ideally suited for chip temperature measurements<br>Minimized self heating |
| RTD—resistance temperature detector | More stable over a long period of time compared to thermocouple<br>Linear over a wide range |

| Sensors | Features |
|---|---|
| | **Temperature sensors continue..** |
| Infrared type | Noncontact point sensor with resolution limited by wavelength |
| Infrared thermography | Measures whole-field temperature distribution |
| | **Proximity sensors** |
| Inductance, eddy current, hall effect, photoelectric, capacitance, etc. | Robust noncontact switching action<br>The digital outputs are often directly fed to the digital controller |

| Sensors | Features |
|---|---|
| **Light sensors** | |
| Photoresistors, photodiodes, photo | Measure light intensity with high sensitivity |
| transistors, photo conductors, etc. | Inexpensive, reliable, and noncontact sensor |
| Charge-coupled diode | Captures digital image of a field of vision |
| **Smart material sensors** | |
| **Optical fiber**<br>As strain sensor | Alternate to strain gages with very high accuracy and bandwidth<br>Sensitive to the reflecting surface's orientation and status |
| As level sensor | Reliable and accurate |
| As force sensor | High resolution in wide ranges |
| As temperature sensor | High resolution and range (up to 2000 $^{o}$C) |

| Sensors | Features |
|---|---|
| **Smart material sensors continue…** | |
| **Piezoelectric** | |
| As strain sensor | Distributed sensing with high resolution and bandwidth |
| As force sensor | Most suitable for dynamic applications |
| As accelerometer | Least hysteresis and good set point accuracy |
| **Magnetostrictive** | Compact force sensor with high resolution and bandwidth |
| As force sensors | Good for distributed and noncontact sensing applications |
| As torque sensor | Accurate, high bandwidth, and noncontact sensor |

| Sensors | Features |
| --- | --- |
| **Micro- and nano-sensors** | |
| Micro CCD image sensor | Small size, full field image sensor |
| Fiberscope | Small (0.2 mm diameter) field vision scope using SMA coil actuators |
| Micro-ultrasonic sensor | Detects flaws in small pipes |
| Micro-tactile sensor | Detects proximity between the end of catheter and blood vessels |
| | |

# Types

- Sensors can also be classified as passive or active.
- In passive sensors, the power required to produce the output is provided by the sensed physical phenomenon itself (such as a thermometer) whereas
- The active sensors require external power source (such as a strain gauge)
- Sensors are classified as analog or digital based on the type of output signal.
- Analogue sensors produce continuous signals that are proportional to the sensed parameter and typically require analogue-to-digital conversion before feeding to the digital controller.
- Digital sensors on the other hand produce digital outputs that can be directly interfaced with the digital controller.
- Often, the digital outputs are produced by adding an analog-to-digital converter to the sensing unit. If many sensors are required, it is more economical to choose simple analog sensors and interface them to the digital controller equipped with a multi-channel analog-to-digital converter.

# Types

There are contact type sensors:

- Strain Gauge,
- LVDT (Linear Variable Differential Transformer),
- RVDT (Rotary Variable Differential Transformer),
- Tachometer

There are non contact type sensors:

- Encoders,
- Hall effect,
- Capacitance,
- Inductance, and
- Interferometer

# Requirements

(a) the field of view and range;

(b) accuracy;

(c) repeatability and resolution;

(d) responsiveness in the target-domain;

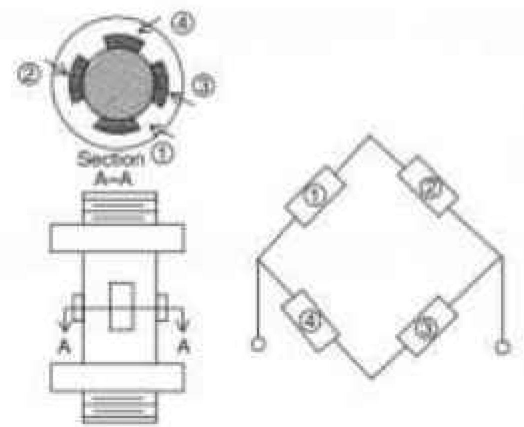
(e) power consumption;

(f) hardware reliability;

(g) size; and

(h) interpretation reliability.


Transducer Techniques


Section A-A
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# Force Measurement

- A load cell is a sensor used to measure force.
- It contains an internal flexural element, usually with several strain gauges mounted on its surface.
- A load cell is a transducer that is used to create an electrical signal whose magnitude is directly proportional to the force being measured. The various types of load cells include hydraulic load cells, pneumatic load cells and strain gauge load cells.
- The flexural element's shape is designed so that the strain gauge outputs can be easily related to the applied force.
- The load cell is usually connected to a bridge circuit to yield a voltage proportional to the load.

# Tasks

Case study of different types of sensors

Create a table having sensor characteristics, features, applications, availability (online link), price range etc.