UNIT 3

Sensors & Transducers

By:
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Chandwad.
- All sensors reporting position
- All connected to the web
- All with metadata registered
- All readable remotely
- Some controllable remotely
Sensors?

- American National Standards Institute
  - A device which provides a usable output in response to a specified measurand

- A sensor acquires a physical quantity and converts it into a signal suitable for processing (e.g. optical, electrical, mechanical)

- Nowadays common sensors convert measurement of physical phenomena into an electrical signal

- Active element of a sensor is called a transducer
Transducer?

A device which converts one form of energy to another

When input is a physical quantity and output electrical → Sensor

When input is electrical and output a physical quantity → Actuator

e.g. Piezoelectric:
Force -> voltage
Voltage-> Force

=> Ultrasound!

Microphone, Loud Speaker
Commonly Detectable Phenomena

• Biological
• Chemical
• Electric
• Electromagnetic
• Heat/Temperature
• Magnetic
• Mechanical motion (displacement, velocity, acceleration, etc.)
• Optical
• Radioactivity
Common Conversion Methods

• Physical
  – thermo-electric, thermo-elastic, thermo-magnetic, thermo-optic
  – photo-electric, photo-elastic, photo-magnetic,
  – electro-elastic, electro-magnetic
  – magneto-electric

• Chemical
  – chemical transport, physical transformation, electro-chemical

• Biological
  – biological transformation, physical transformation
**Commonly Measured Quantities**

<table>
<thead>
<tr>
<th>Stimulus</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustic</td>
<td>Wave (amplitude, phase, polarization), Spectrum, Wave Velocity</td>
</tr>
<tr>
<td>Biological &amp; Chemical</td>
<td>Fluid Concentrations (Gas or Liquid)</td>
</tr>
<tr>
<td>Electric</td>
<td>Charge, Voltage, Current, Electric Field (amplitude, phase, polarization), Conductivity, Permittivity</td>
</tr>
<tr>
<td>Magnetic</td>
<td>Magnetic Field (amplitude, phase, polarization), Flux, Permeability</td>
</tr>
<tr>
<td>Optical</td>
<td>Refractive Index, Reflectivity, Absorption</td>
</tr>
<tr>
<td>Thermal</td>
<td>Temperature, Flux, Specific Heat, Thermal Conductivity</td>
</tr>
<tr>
<td>Mechanical</td>
<td>Position, Velocity, Acceleration, Force, Strain, Stress, Pressure, Torque</td>
</tr>
</tbody>
</table>
## Choosing a Sensor

<table>
<thead>
<tr>
<th>Environmental Factors</th>
<th>Economic Factors</th>
<th>Sensor Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature range</td>
<td>Cost</td>
<td>Sensitivity</td>
</tr>
<tr>
<td>Humidity effects</td>
<td>Availability</td>
<td>Range</td>
</tr>
<tr>
<td>Corrosion</td>
<td>Lifetime</td>
<td>Stability</td>
</tr>
<tr>
<td>Size</td>
<td></td>
<td>Repeatability</td>
</tr>
<tr>
<td>Overrange protection</td>
<td></td>
<td>Linearity</td>
</tr>
<tr>
<td>Susceptibility to EM interferences</td>
<td></td>
<td>Error</td>
</tr>
<tr>
<td>Ruggedness</td>
<td></td>
<td>Response time</td>
</tr>
<tr>
<td>Power consumption</td>
<td></td>
<td>Frequency response</td>
</tr>
<tr>
<td>Self-test capability</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Need for Sensors

• Sensors are pervasive. They are embedded in our bodies, automobiles, airplanes, cellular telephones, radios, chemical plants, industrial plants and countless other applications.

• Without the use of sensors, there would be no automation!!
  – Imagine having to manually fill Poland Spring bottles
Motion Sensors

- Monitor location of various parts in a system
  - absolute/relative position
  - angular/relative displacement
  - proximity
  - acceleration

- Principle of operation
  - Magnetic, resistive, capacitance, inductive, eddy current, etc.

Lvdt Displacement Sensor

Optoisolator

Potentiometer
What is an LVDT?

An LVDT is a Linear Position Sensor With a Proportional Analog Output

An LVDT has 2 Elements, a Moving Core and a Stationary Coil Assembly
L V D Ts

**Linear Variable Differential Transformer**

- **Transformer**: AC Input / AC Output
- **Differential**: Natural Null Point in Middle
- **Variable**: Movable Core, Fixed Coil
- **Linear**: Measures Linear Position
How LVDT's Work
Working Principle of LVDT
Applications

• High Accuracy
• Very Good Stability
• Ability to Operate at High Temperature.
• High Sensitivity.
Photograph of LVDT
Strain Gauge

– If a strip of conductive metal is placed under compressive force (without buckle), it will broaden and shorten.

– If these stresses are kept within the elastic limit of the metal strip (so that the strip does not permanently deform), the strip can be used as a measuring element for physical force, the amount of applied force inferred from measuring its resistance.

– This is the principle of a Strain Gauge.
Strain Gauge

With no force applied to the test specimen, both strain gauges have equal resistance and the bridge circuit is balanced. However, when a downward force is applied to the free end of the specimen, it will bend downward, stretching gauge #1 and compressing gauge #2 at the same time:
Applications : Strain Gauge

• Strain gauges are used to measure force and small displacements. They are used for analyzing the dynamic strain of complex structures. They are used to measure tension, torque etc.

• Types of strain gauges are:
  (a) Wire strain gauges
  (b) Foil strain gauges
  (c) Thin film
  (d) Semiconductor
Load Cell

Sketch 1: Typical Electronic Weigh System

- Load
- Load Receiving
- (2) or More Electronic Load Cells
- Summing Network
- Electronic Signal
- Digital Indicator
- Printer

Outdoor/Hostile Environment vs. Indoor/Controlled Environment
A flow sensor is a device for sensing the rate of fluid flow. Typically a flow sensor is the sensing element used in a flow meter, or flow logger, to record the flow of fluids.
Differential Pressure Transducer

Resistance
What is Data Acquisition System?

- DAQ systems capture, measure, and analyze physical phenomena from the real world.

- Light, temperature and pressure are examples of the different types of signals that a DAQ system can measure.

- Data acquisition is the process of collecting and measuring electrical signals and sending them to a computer for processing.

- Electrical signals come from Transducers.
The building blocks of a DAQ system includes:

**Transducer or Sensors:** A device that converts a physical phenomenon such as light, temperature, pressure, or sound into a measurable electrical signal such as voltage or current.

**Signal:** The output of the transducer.

**Signal conditioning:** Hardware that you can connect to the DAQ device to make the signal suitable for measurement or to improve accuracy or reduce noise.

**DAQ hardware:** Hardware you use to acquire, measure, and analyze data.

**Software:** Application software is designed to help you easily design and program your measurement and control application.
Block Diagram of DAS

Data Acquisition System

Sensor → Signal conditioning → Acquisition hardware → Computer → Software

Physical phenomena

Actuator

Data analysis

Physical phenomena
### Common Analog Sensors

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Physical Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerometer</td>
<td>Acceleration</td>
</tr>
<tr>
<td>Microphone</td>
<td>Pressure</td>
</tr>
<tr>
<td>Pressure gauge</td>
<td>Pressure</td>
</tr>
<tr>
<td><strong>Resistive temperature device</strong></td>
<td><strong>Temperature</strong></td>
</tr>
<tr>
<td>(RTD)</td>
<td></td>
</tr>
<tr>
<td>Strain gauge</td>
<td>Force</td>
</tr>
<tr>
<td>Thermocouple</td>
<td>Temperature</td>
</tr>
</tbody>
</table>
Basic Data Acquisition System

1. Physical Parameter
2. Transducer
3. Amplifier
4. Active Filter
5. Analog Multiplexer
6. Sample Hold
7. A/D Converter
8. Data Bus
9. Computer
Data Loggers

- A **data logger** is an electronic device that records data over time or in relation to location either with a built-in **instrument** or **sensor** or via external instruments and sensors.

- They generally are small, battery powered, portable, and equipped with a microprocessor, internal memory for data storage, and sensors.

- **Data Logger Cube Storing technical & sensor data.**
• Different types of data loggers and their operation

• The differences between various data loggers are based on the way that data is recorded and stored. The basic difference between the two data logger types is that one type allows the data to be stored in a memory, to be retrieved at a later time, while the other type automatically records the data on paper, for immediate viewing and analysis. Many data loggers combine these two functions, usually unequally, with the emphasis oneither the ability to transfer the data or to provide a printout of it.
Applications

- Environmental monitoring
- Road traffic counting.
- Unattended soil moisture level recording.
- Motor Racing
- Temperature, Humidity and Power use for Heating and Air conditioning efficiency studies.
- Unattended weather station recording
- Measure temperatures (humidity, etc) of perishables during shipments
- Tank level monitoring.
• Temperature is an important parameter in many control systems
• Several distinctly different transduction mechanisms are employed
• These include non electrical as well as electrical methods
• A thermometer is the most common non electrical sensor
• Common electrical sensors include thermocouples, thermistors and resistance thermometers
Temperature Sensor Types

• Thermocouple
• Thermistor
• Resistance Temperature Detectors (RTD)
Thermocouples

- Based on the Seebeck effect
- When any conductor is subjected to a thermal gradient, it will generate a voltage
- The magnitude of the effect depends on the metal in use.
- A small difference voltage can be made available by use of dissimilar metals
- Difference increases with temperature, and can typically be between 1 and 70 µV/°C
• Thermocouples measure the temperature difference between two points and not the absolute temperature

• The relationship between the temperature difference and the output voltage of a thermocouple is nonlinear and is approximated by polynomial:

\[ \Delta T = \sum_{n=0}^{N} a_n v^n. \]
Advantages and Disadvantages

• They are simple, rugged, need no batteries, measure over very wide temperature ranges.

• The main limitation is accuracy System errors of less than 1°C can be difficult to achieve
Applications

• Thermocouples are most suitable for measuring over a large temperature range, up to 1800 °C

• These are widely used in the steel industry, heating appliances, manufacturing of electrical equipments like switch gears etc
**Thermistor**

- A thermistor is a type of resistor with resistance varying according to its temperature. The resistance is measured by passing a small, measured direct current through it and measuring the voltage drop produced.

- There are basically two broad types
  - *NTC-Negative Temperature Coefficient:* used mostly in temperature sensing
  - *PTC-Positive Temperature Coefficient:* used mostly in electric current control.
• A **NTC thermistor** is one in which the resistance decreases with an increase in temperature

• A **PTC thermistor** is one in which the resistance increases with an increase in temperature
Advantages and Disadvantages

• Thermistors, since they can be very small, are used inside many other devices as temperature sensing and correction devices.

• Thermistors typically work over a relatively small temperature range, compared to other temperature sensors, and can be very accurate and precise within that range.
Applications

• High Resolution
• Small Size
RTD

• Resistance Temperature Detectors (RTD), as the name implies, are sensors used to measure temperature by correlating the resistance of the RTD element with temperature.

• As they are almost invariably made of platinum, they are often called platinum resistance thermometers (PRTs).
Construction

Common Resistance Materials for RTDs:
- Platinum (most popular and accurate)
- Nickel
- Copper
- Tungsten (rare)

Image obtained from www.omega.com
Construction

• RTD elements consist of a length of fine coiled wire wrapped around a ceramic or glass core.

• The element is usually quite fragile, so it is often placed inside a sheathed probe to protect it.

• The RTD element is made from a pure material whose resistance at various temperatures has been documented. The material has a predictable change in resistance as the temperature changes; it is this predictable change that is used to determine temperature.
Advantages

• High accuracy
• Low drift
• Wide operating range
• Suitability for precision applications
Limitations

- RTDs in industrial applications are rarely used above 660 °C. Difficult to maintain the purity of Platinum at high temperatures.
- At low temperatures the resistance is independent of temperature as there are a very few phonons and resistance is determined by impurities.
- Compared to thermistors, platinum RTDs are less sensitive to small temperature changes and have a slower response time. However, thermistors have a smaller temperature range and stability.