Sensors and Transducers: Selection Criteria

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2013
Outline

- Sensor characteristics
- Sensor selection
- Sensor comparison
Sensor Characteristics

- **Range**
  - Difference between the maximum and minimum value of the sensed parameter

- **Resolution**
  - The smallest change the sensor can differentiate.
  - For digital sensors, it is related to number of bits used
  - For analog sensors, it is limited by low-level electrical noise

- **Sensitivity**
  - Ratio of change in output to a unit change of the input
  - *For digital sensors, sensitivity is closely related to resolution*
  - *For analog sensors, sensitivity is the output slope vs. input line*
Sensor Sensitivity

![Graph showing different sensitivity regions](image-url)
Sensor Characteristics

- **Error**
  - Difference between the measured value and the true value.
  - Two classifications: bias and random

- **Accuracy**
  - *Inversely proportional to the error*
  - *Sometimes related to the sensor’s linearity*

- **Precision**
  - Ability to reproduce repeatedly with a given accuracy
  - Sometimes called repeatability
Accuracy and Precision

Set 1: Precise, but not Accurate
Set 2: Accurate, but not Precise
Set 3: Neither Accurate nor Precise
Set 4: Both Accurate and Precise

[Ref] Joey Parker
Sensor Characteristics

- **Linearity**
  - Percentage of deviation from the best-fit linear calibration curve
  - Linearity means superposition principle
  - Most systems have nonlinear behavior

- **Impedance**
  - Ratio of voltage to current
  - Two types: input and output impedance
  - **Input impedance**
    - Measure of how much current must be drawn to power the sensors
    - Modeled as resistor in parallel
    - High input impedance is desirable
  - **Output impedance**
    - Sensors ability to provide current to next stage
    - Modeled as resistor is series with the sensor output
    - Low output impedance is desirable
Linearity

[Ref] Joey Parker
Sensor Characteristics

- **Saturation**
  - Maximum output capability, regardless of input

- **Deadband**
  - The range of input for which there is no output

- **Zero offset**
  - A nonzero value output for no input

- **Zero Drift**
  - The departure of output from zero value over a period of time for no input
Saturation and Deadband

[Ref] Joey Parker
Sensor Characteristics

- **Response time**
  - The time lag between the input and output

- **Bandwidth**
  - Frequency at which the output magnitude drops by 3 dB

- **Resonance**
  - The frequency at which the output magnitude peak occurs

- **Operating temperature**
  - The range in which the sensor performs as specified

- **Signal-to-noise ratio**
  - Ratio between the magnitudes of the signal and the noise at the output
Sensor Selection Criteria

- Variables measured and application
- Dynamic range
- Required resolution and sensitivity
- Required accuracy and precision
- Environmental conditions
- Power available for sensing
Sensor Selection Criteria

- Availability
- Cost
- Size and available space
- Ease of use
- Ease of maintenance
- Required signal processing
Sensor Comparisons

- Linear and rotational
- Acceleration
- Force and Torque
- Flow
- Temperature
- Proximity
- Light
- Smart material
## Linear and Rotational Sensors

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear/Rotational variable differential transducer (LVDT/RVDT)</td>
<td>High resolution with wide range capability</td>
</tr>
<tr>
<td>Optical encoder</td>
<td>Very stable in static and quasi-static applications</td>
</tr>
<tr>
<td>Electrical tachometer</td>
<td>Simple, reliable, and low-cost solution</td>
</tr>
<tr>
<td>Hall effect sensor</td>
<td>Good for both absolute and incremental measurements</td>
</tr>
<tr>
<td>Capacitive transducer</td>
<td>Resolution depends on type such as generator or magnetic pickups</td>
</tr>
<tr>
<td>Strain gauge elements</td>
<td>High accuracy over a small to medium range</td>
</tr>
<tr>
<td>Interferometer</td>
<td>Very high resolution with high sensitivity</td>
</tr>
<tr>
<td>Magnetic pickup</td>
<td>Low power requirements</td>
</tr>
<tr>
<td>Gyroscope</td>
<td>Good for high frequency dynamic measurements</td>
</tr>
<tr>
<td>Inductosyn</td>
<td>Very high accuracy in small ranges</td>
</tr>
<tr>
<td></td>
<td>Provides high resolution at low noise levels</td>
</tr>
<tr>
<td></td>
<td>Laser systems provide extremely high resolution in large ranges</td>
</tr>
<tr>
<td></td>
<td>Very reliable and expensive</td>
</tr>
<tr>
<td></td>
<td>Output is sinusoidal</td>
</tr>
<tr>
<td></td>
<td>Very high resolution over small ranges</td>
</tr>
</tbody>
</table>

[Ref.] Anjanappa, Datta, and Song
Acceleration Sensors

Seismic accelerometer
Good for measuring frequencies up to 40% of its natural frequency
High sensitivity, compact, and rugged
Very high natural frequency (100 kHz typical)

Piezoelectric accelerometer
Force, Torque, and Pressure Sensors

Force, torque, and pressure sensor

- Strain gauge
- Dynamometers/load cells
- Piezoelectric load cells
- Tactile sensor
- Ultrasonic stress sensor

- Good for both static and dynamic measurements
- They are also available as micro- and nanosensors
- Good for high precision dynamic force measurements
- Compact, has wide dynamic range, and high
- Good for small force measurements
## Flow Sensors

<table>
<thead>
<tr>
<th>Sensor Type</th>
<th>Description</th>
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<tbody>
<tr>
<td>Pitot tube</td>
<td>Widely used as a flow rate sensor to determine speed in aircrafts.</td>
</tr>
<tr>
<td>Orifice plate</td>
<td>Least expensive with limited range.</td>
</tr>
<tr>
<td>Flow nozzle, venturi tubes</td>
<td>Accurate on wide range of flow.</td>
</tr>
<tr>
<td>Rotameter</td>
<td>More complex and expensive.</td>
</tr>
<tr>
<td>Ultrasonic type</td>
<td>Good for upstream flow measurements. Used in conjunction with variable inductance sensor.</td>
</tr>
<tr>
<td>Turbine flow meter</td>
<td>Good for very high flow rates. Can be used for both upstream and downstream flow measurements.</td>
</tr>
<tr>
<td>Electromagnetic flow meter</td>
<td>Not suited for fluids containing abrasive particles. Relationship between flow rate and angular velocity is linear. Least intrusive as it is noncontact type. Can be used with fluids that are corrosive, contaminated, etc. The fluid has to be electrically conductive.</td>
</tr>
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## Temperature Sensors

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<th>Sensor Type</th>
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<tr>
<td>Thermocouples</td>
<td>This is the cheapest and the most versatile sensor</td>
</tr>
<tr>
<td></td>
<td>Applicable over wide temperature ranges (~200°C to 1200°C typical)</td>
</tr>
<tr>
<td>Thermistors</td>
<td>Very high sensitivity in medium ranges (up to 100°C typical)</td>
</tr>
<tr>
<td></td>
<td>Compact but nonlinear in nature</td>
</tr>
<tr>
<td>Thermodiodes, thermo transistors</td>
<td>Ideally suited for chip temperature measurements</td>
</tr>
<tr>
<td></td>
<td>Minimized self heating</td>
</tr>
<tr>
<td>RTD—resistance temperature detector</td>
<td>More stable over a long period of time compared to thermocouple</td>
</tr>
<tr>
<td></td>
<td>Linear over a wide range</td>
</tr>
<tr>
<td>Infrared type</td>
<td>Noncontact point sensor with resolution limited by wavelength</td>
</tr>
<tr>
<td>Infrared thermography</td>
<td>Measures whole-field temperature distribution</td>
</tr>
</tbody>
</table>
Proximity Sensors

Proximity sensors

Inductance, eddy current, hall effect, photoelectric, capacitance, etc.

Robust noncontact switching action
The digital outputs are often directly fed to the digital controller
Light Sensors

Light sensors

- Photoresistors, photodiodes, photo transistors, photo conductors, etc.
- Charge-coupled diode

Measure light intensity with high sensitivity
Inexpensive, reliable, and noncontact sensor
Captures digital image of a field of vision
### Smart Material Sensors

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<th>Optical fiber</th>
<th>Piezoelectric</th>
<th>Magnetostrictive</th>
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<tr>
<td>As strain sensor</td>
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<td>As force sensors</td>
</tr>
<tr>
<td>As level sensor</td>
<td>As force sensor</td>
<td>As torque sensor</td>
</tr>
<tr>
<td>As force sensor</td>
<td>As accelerometer</td>
<td></td>
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<tr>
<td>As temperature sensor</td>
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</table>

- Optical fiber:
  - Alternate to strain gages with very high accuracy and bandwidth
  - Sensitive to the reflecting surface’s orientation and status
  - Reliable and accurate
  - High resolution in wide ranges
  - High resolution and range (up to 2000°C)

- Piezoelectric:
  - Distributed sensing with high resolution and bandwidth
  - Most suitable for dynamic applications
  - Least hysteresis and good setpoint accuracy

- Magnetostrictive:
  - Compact force sensor with high resolution and bandwidth
  - Good for distributed and noncontact sensing applications
  - Accurate, high bandwidth, and noncontact sensor
# Macro and Nano Sensors

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<tr>
<td>Micro CCD image sensor</td>
<td>Small size, full field image sensor</td>
</tr>
<tr>
<td>Fiberscope</td>
<td>Small (0.2 mm diameter) field vision scope using SMA coil actuators</td>
</tr>
<tr>
<td>Micro-ultrasonic sensor</td>
<td>Detects flaws in small pipes</td>
</tr>
<tr>
<td>Micro-tactile sensor</td>
<td>Detects proximity between the end of catheter and blood vessels</td>
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</table>