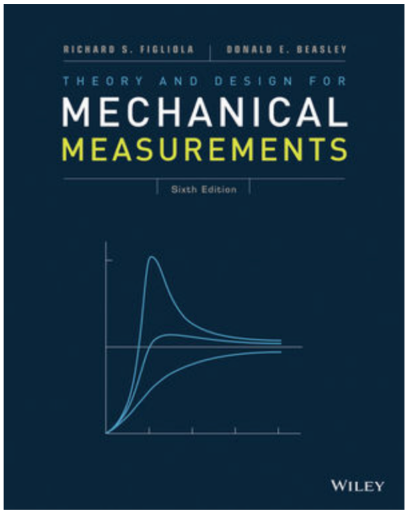


Measurement Characteristics

Engr325

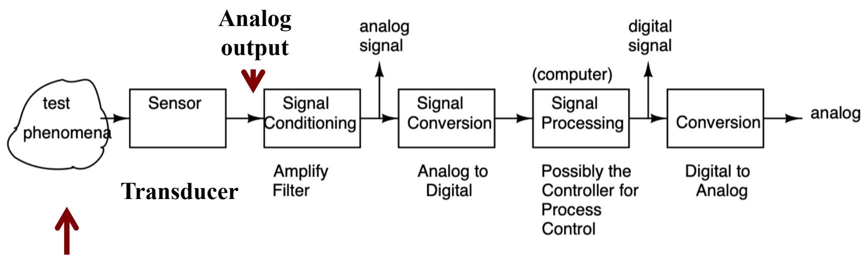
Instrumentation

Dr Curtis Nelson

Lecture Outline

- Instrumentation systems.
- Terminology.
- Error sources.

Typical Instrumentation System



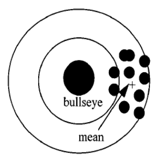
Temperature, Light, Displacement, Position, Vibration, Strain, Angle, Velocity, Acceleration, Flow rate, Pressure, Viscosity, Heart Rate, Etc.

Definition of Measurement

- ***Measurement*** is the experimental process of acquiring any quantitative information.
- Can be divided into *direct* or *indirect* measurements
  - *Direct* measurement – measured quantity is registered directly from the instrument display
    - Measuring voltage with a voltmeter.
    - Measuring length with a ruler.
  - *Indirect* measurement – result is calculated from the values obtained from direct measurements
    - Calculating energy
      - Measure voltage, current, and time
      - Energy = (voltage)(current)(time)

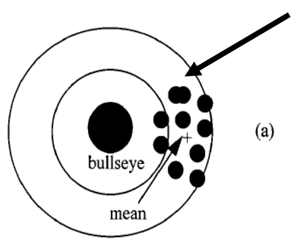
Correct Terms

- Measurement is described by its *resolution*, its *precision*, and its *accuracy.* These terms are often used interchangeably, but they cover different concepts:
  - *Resolution* – the smallest increment that can be discerned.
  - *Precision* – the spread of values obtained during the measurements. Two terms that should be used here are:
    - *Repeatability* – variation for a set of measurements made in a very short period.
    - *Reproducibility* – same concept, but for measurements made over a long period.
  - *Accuracy* – is the closeness of a measurement to the value defined to be the true value.



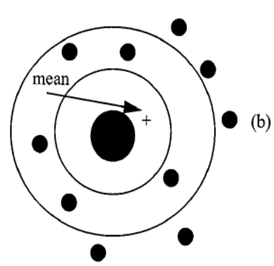
Resolution, Precision, and Accuracy

Two sets of arrows fired into a target to understand the measurement concepts of *resolution, precision, and accuracy*



Thickness of the hole determines the resolution.

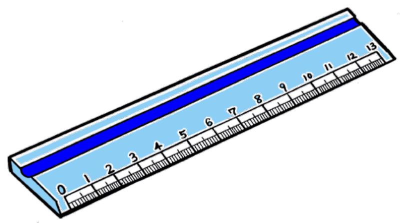
Better *precision* means better *repeatability*



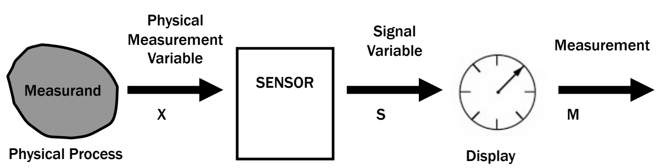
Better *accuracy* – Mean value closer to the bullseye.

What is an Instrument?

- An *Instrument* is a device that transforms a *physical variable* of interest (the *measurand*) into a form that is suitable for recording (the *measurement*).
- An example is a ruler:
  - The measurand is the length of some object.
  - The measurement is the number of units (meters, inches, etc.) that represent the length.



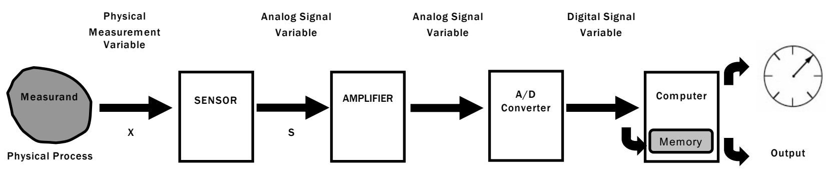
Simple Instrument Model



- The key functional element of the instrument model is the *sensor,* which has the function of converting the *physical variable input* into a *signal variable output*.
- For many sensors, voltage is a common signal variable.
- Other signal variables may be current, resistance, displacement, light, etc.

Simple Instrument Model

- If the signal from the sensor output is small, it needs to be amplified. In many cases, it is also necessary for the instrument to provide a digital signal output for connection to computer-based data acquisition systems.

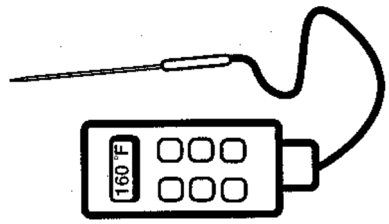


Sensors

- **Sensor** – the part of a measurement system that responds directly to the physical variable being measured.
- Sensors can be categorized into two broad classes:
  - Passive sensors.
  - Active sensors.

Passive Sensors

- *Passive sensors* do not add energy as part of the measurement process, but may remove energy in their operation, i.e. energy is converted to a measurable quantity.
- One example of a *passive sensor* is a thermocouple, which converts a physical temperature into a voltage signal.



Active Sensors

- *Active sensors* add energy to the measurement environment as part of the measurement process.
- An example of an active sensor is a radar or sonar where active radio or acoustic waves reflect off of some object and thus measures its range from the sensor.

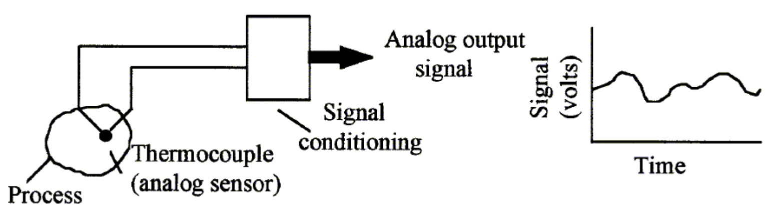
Arecibo Observatory in Puerto Rico
Besides being the most powerful radio telescope and the largest single unit telescope in the world, it is also a *radar*. Probably the worlds biggest active sensor.

Analog and Digital Sensors

- **Analog sensors** – provide a signal that is continuous in both its magnitude and its temporal (time) or spatial (space) content.
- **Digital sensors** – provide a signal that is a direct digital representation of the measurand. Digital sensors are basically binary ("on" or "off ") devices. Essentially, a digital signal exists at only discrete values of time or space.

Analog Sensor

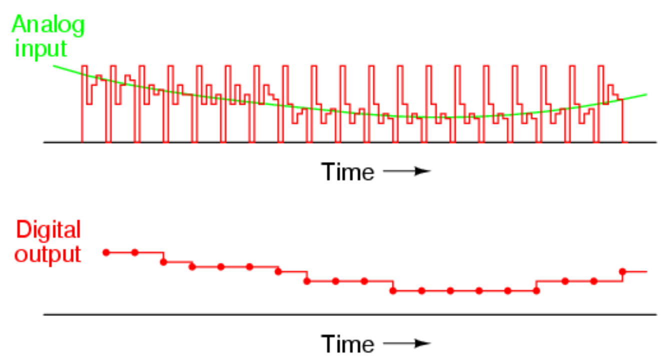
- The defining word for analog is "continuous" i.e. if a sensor provides a continuous output signal that is directly proportional to the input signal, then it is analog.



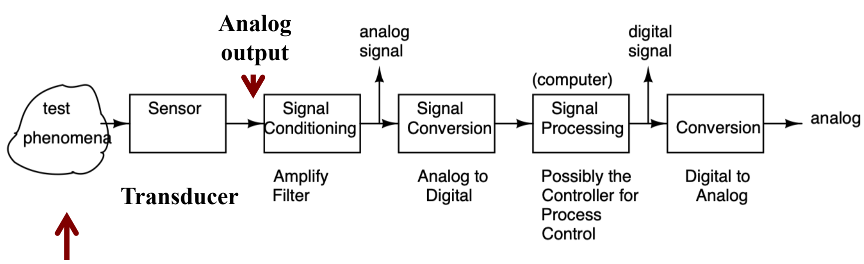
Thermocouple as an analog sensor

Digital Sensor

- A common representation of digital signal is the discrete sampled signal, which represents a sensor output in a form that is discrete both in *time* or *space* and in *magnitude*.



Why Go Digital if the World is Analog?



Temperature, Light, Displacement, Position, Vibration, Strain, Angle, Velocity, Acceleration, Flow rate, Pressure, Viscosity, Heart Rate, Etc.

Input Impedance - Recap

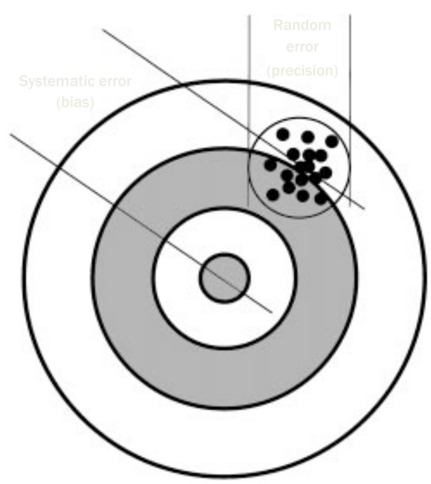
- In the ideal case, the act of measurement should not alter the value of the measured signal. Any such alteration is a **loading error.**
- Loading errors can be minimized by *impedance matching* of the source with the measuring instrument – reduce the power needed for measurement.
- To minimize the power loss, the **input impedance of the measuring device should be large.**
- A general rule is for the input impedance *of the measuring device* to be at least 100 times the source impedance to reduce the loading error to 1%.

Error Types and Sources

Systematic errors (bias) – measured values have similar deviation from the correct value.

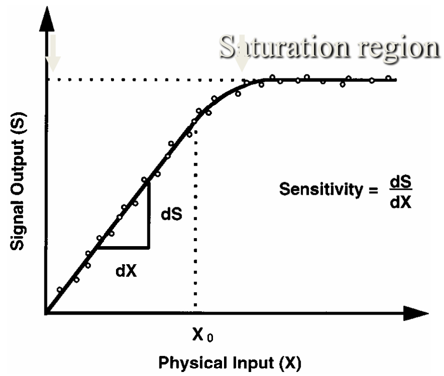
Random errors (noise) – measured values deviate randomly around the mean value.

Systematic errors can be reduced or eliminated through ***calibration***.



Calibration

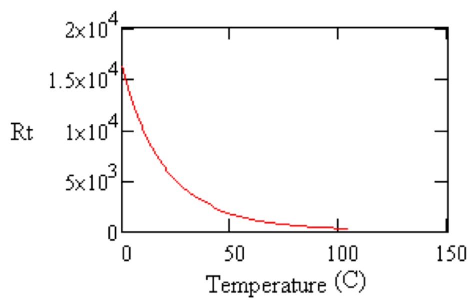
- *Calibration* is the relationship between the physical measurement variable (input) and the signal variable (output) for a specific sensor.
- *Calibration curve* – graph that characterizes sensor or instrument response to a physical input.



Calibration Curve Example.

Thermistor Calibration

- Shown below, the thermistor resistance changes from 15kΩ to 100Ω based on the temperature. The change is most rapid at low temperatures, giving better resolution for determining the corresponding temperature values. At the other end of the range, resistance levels change less with temperature, resulting in poorer resolution.

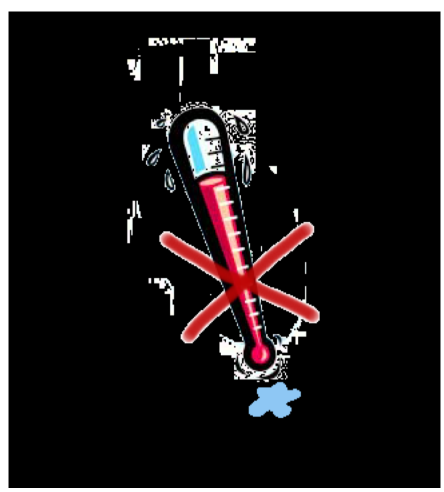


Systematic Error Sources

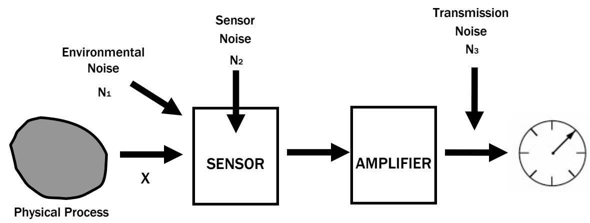
- If measurements are made at temperatures other than a sensor was calibrated for, it introduces *systematic error.* If the systematic error source is known, it can be corrected for by the use of *compensation methods,* like *calibration.*
- *Aging* of the components will change the sensor response and hence the calibration.
- *Damage* or *abuse* of the sensor can also change the accuracy.
- *Invasiveness* - the measurement process itself changes the intended measurand. This is a key concern in many measurement applications.

Invasivness Example

- Reducing *invasivness*
  - use high impedance electronic devices to measure voltage.
- Extreme *invasiveness*
  - large warm thermometer to measure the temperature of a small volume of cold fluid.



Random Error Sources



- An example for N_1 would be background noise received by a microphone.
- An example of N_2 would be thermal noise within a sensitive transducer, such as an infrared sensor.
- A common example of N_3 is 60 Hz interference from the electric power grid.

- **The noise will be amplified along with the signal as it passes through the amplifier**
- **Noise is represented as signal to noise ratio (SNR) and measured in decibels.**
- **SNR(dB)=10*log(Psignal/Pnoise)**

Random Noise

- What if the power of the signal of interest is less than the power of the noise component?
  - If some identifying characteristics of that signal are known and sufficient signal processing power is available, then the signal can likely be extracted.
  - An example of such signal processing is the human ability to hear a voice in a loud noise environment.

Lecture Summary

- Instrumentation systems.
- Terminology.
- Error sources.