ROHINI COLLEGE OF ENGINEERING AND TECHNOLOGY
AUTONOMOUS INSTITUTION
Approved by AICTE & Affiliated to Anna University
NBA Accredited for BE (ECE, EEE, MECH) | Accredited by NAAC with A+ Grade
Anjugramam - Kanyakumari Main Road, Palkulam, Variyoor P.O. - 629 401, Kanyakumari District.

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

VII Semester

AU3008 Sensors and Actuators

UNIT – I - *INTRODUCTION TO MEASUREMENTS AND SENSORS*

1.3 Units and standards-Calibration methods:

1.3.1 Units:

Units are defined quantities used as a standard for measurement. For instance, meters for length, kilograms for mass, and seconds for time.

Standards are physical representations or definitions of units, ensuring consistency and accuracy in measurements. These could be physical objects (like the international prototype kilogram) or natural phenomena (like the speed of light).

Why are They Important?

- **Communication:** Common units enable effective communication of measurements across different regions and fields.
- **Consistency:** Standardized units ensure that measurements are comparable and reproducible.
- **Accuracy:** Precise standards enhance the reliability of measurements.
- **Trade:** International trade relies on consistent units for fair transactions.
- **Science and Technology:** Accurate measurements are crucial for scientific research and technological advancement.

Systems of Units

(a) International System of Units (SI):

The International System of Units (SI) is based on seven fundamental units, known as base units. These units are the foundation for all other derived units in the SI system. Here are the seven fundamental SI units:

1. Meter (m)

- ✓ **Quantity**: Length
- ✓ **Definition**: The meter is defined as the distance that light travels in a vacuum in 1/299,792,458 of a second.

2. Kilogram (kg)

- ✓ **Quantity**: Mass
- ✓ **Definition**: The kilogram is defined by fixing the numerical value of the Planck constant (h) to be exactly $6.62607015 \times 10^{-34}$ joule-seconds (J·s), where the second and the meter are defined in terms of the cesium frequency and the speed of light, respectively.

3. Second (s)

- ✓ **Quantity**: Time
- ✓ **Definition**: The second is defined as the duration of 9,192,631,770 periods of the radiation corresponding to the transition between two hyperfine levels of the ground state of the cesium-133 atom.

4. Ampere (A)

- ✓ **Quantity**: Electric Current
- ✓ **Definition**: The ampere is defined by fixing the numerical value of the elementary charge (e) to be exactly $1.602176634 \times 10^{-19}$ coulombs, where the coulomb is defined as the charge transported by a constant current of one ampere in one second.

5. Kelvin (K)

- ✓ **Quantity**: Thermodynamic Temperature
- ✓ **Definition**: The kelvin is defined by fixing the numerical value of the Boltzmann constant (k) to be exactly 1.380649×10^{-23} joules per kelvin (J/K), which defines temperature in terms of energy.

6. Mole (mol)

- ✓ **Quantity**: Amount of Substance
- ✓ **Definition**: The mole is defined by fixing the numerical value of the Avogadro constant (N_a) to be exactly $6.02214076 \times 10^{23}$ per mole, which defines the amount of substance by the number of specified elementary entities (atoms, molecules, etc.).

7. Candela (cd)

- ✓ **Quantity**: Luminous Intensity
- ✓ **Definition**: The candela is defined by fixing the numerical value of the luminous efficacy of monochromatic radiation of frequency 540×10^{12} hertz to be exactly 683 lumens per watt (lm/W), which relates the power of visible light to its perceived brightness.

The latest standards for defining the units used for measuring a range of physical variables are given in Table 1.1.

Table 1.1 Definitions of Standard Units

Physical Quantity	Standard Unit	Definition
Length	Meter	Length of path traveled by light in an interval of 1/299,792,458 seconds
Mass	Kilogram	Mass of a platinum-iridium cylinder kept in the International Bureau of Weights and Measures, Sevres, Paris
Time	Second	9.192631770×10^9 cycles of radiation from vaporized cesium 133 (an accuracy of 1 in 10^{12} or one second in 36,000 years)
Temperature	Degrees	Temperature difference between absolute zero Kelvin and the triple point of water is defined as 273.16 K
Current	Amphere	One ampere is the current flowing through two infinitely long parallel conductors of negligible cross section placed 1 meter apart in vacuum and producing a force of 2×10^{-7} newtons per meter length of conductor
Luminous intensity	Candela	One candela is the luminous intensity in a given direction from a source emitting monochromatic radiation at a frequency of 540 terahertz (Hz $\times 10^{12}$) and with a radiant density in that direction of 1.4641 mW/steradian (1 steradian is the solid angle, which, having its vertex at the centre of a sphere, cuts off an area of the sphere surface equal to that of a square with sides of length equal to the sphere radius)
Matter	Mole	Number of atoms in a 0.012-kg mass of carbon 12

(b) Derived System of Units (SI):

Derived units are units that are formed by combining the seven fundamental SI base units. These combinations correspond to various physical quantities, such as velocity, acceleration, force, energy, and pressure. Each derived unit can be expressed as a product of powers of the base units. The full range of fundamental SI measuring units and the further set of units derived from them are given in Tables 1.2 and 1.3.

Table 1.2 Fundamental SI Units

(a) Fundamental Units		
Quantity	**Standard Unit**	**Symbol**
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Luminous	candela	cd
Matter	mole	mol
(b) Supplementary Fundamental Units		
Quantity	**Standard Unit**	**Symbol**
Plane angle	radian	rad
Solid angle	steradian	sr

Table 1.3 Derived SI Units

Quantity	Standard Unit	Symbol	Derivation Formula
Area	square meter	m^2	
Volume	cubic meter	m^3	
Velocity	metre per second	m/s	
Acceleration	metre per second squared	m/s^2	
Angular velocity	radian per second	rad/s	
Angular acceleration	radian per second squared	rad/s^2	
Density	kilogram per cubic meter	kg/m^3	
Specific volume	cubic meter per kilogram	m^3/kg	
Mass flow rate	kilogram per second	kg/s	
Volume flow rate	cubic meter per second	m^3/s	
Force	newton	N	$kg\text{-}m/s^2$
Pressure	pascal	Pa	N/m^2
Torque	newton meter	N-m	
Momentum	kilogram meter per second	kg-m/s	
Moment of inertia	kilogram meter squared	$kg\text{-}m^2$	
Kinematic viscosity	square meter per second	m^2/s	
Dynamic viscosity	newton second per sq metre	$N\text{-}s/m^2$	
Work, energy, heat	joule	J	N-m
Specific energy	joule per cubic meter	J/m^3	
Power	watt	W	J/s
Thermal conductivity	watt per meter Kelvin	W/m-K	
Electric charge	coulomb	C	A-s
Voltage, e.m.f., pot diff	volt	V	W/A
Electric field strength	volt per meter	V/m	
Electric resistance	ohm	Ω	V/A
Electric capacitance	farad	F	A-s/V
Electric inductance	henry	H	V-s/A
Electric conductance	siemen	S	A/V
Resistivity	ohm meter	Ω-m	
Permittivity	farad per meter	F/m	
Permeability	henry per meter	H/m	
Current density	ampere per square meter	A/m^2	
Magnetic flux	weber	Wb	V-s
Magnetic flux density	tesla	T	Wb/m^2
Magnetic field strength	ampere per meter	A/m	
Frequency	hertz	Hz	s^{-1}
Luminous flux	lumen	lm	cd-sr
Luminance	candela per square meter	cd/m^2	
Illumination	lux	lx	lm/m^2
Molar volume	cubic meter per mole	m^3/mol	
Molarity	mole per kilogram	mol/kg	
Molar energy	joule per mole	J/mol	

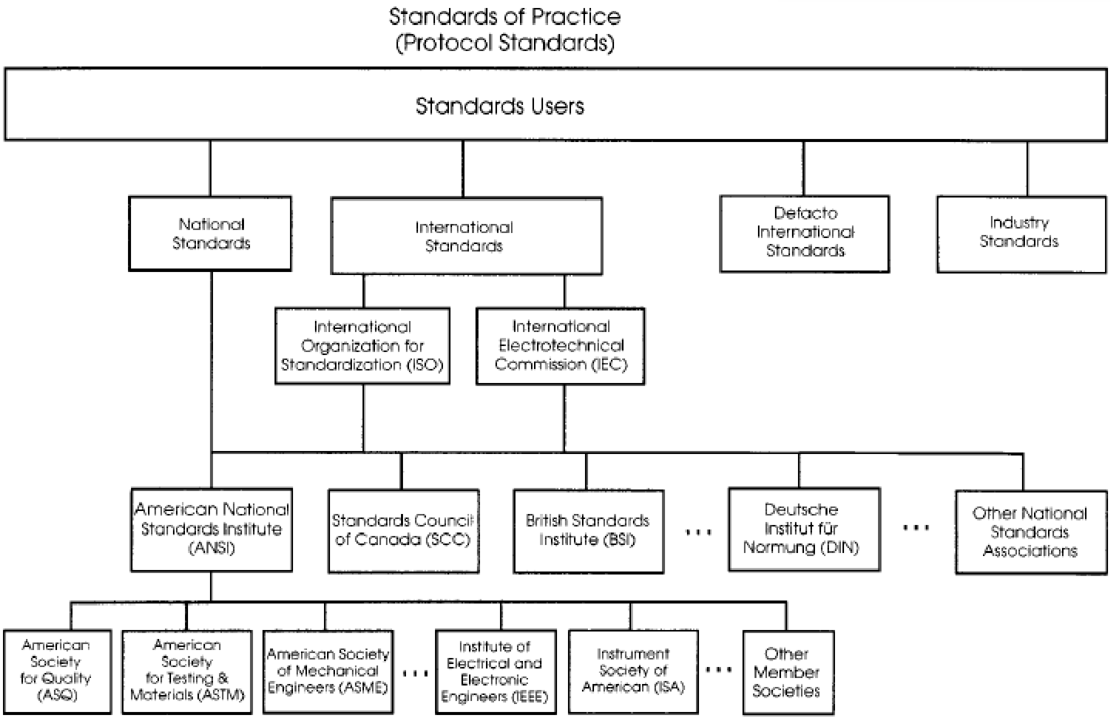
- **Imperial System:** Primarily used in the United States and a few other countries, with units like inches, feet, pounds, and gallons.
- **Other Systems:** There are various other systems, such as the CGS (centimeter-gram-second) system, used in specific scientific fields.

1.3.2 Measurement Standards:

The Need for Standards

Standards define the units and scales in use, and allow comparison of measurements made in different times and places. For example, buyers of fuel oil are charged by a unit of liquid volume. In the U.S., this would be the gallon; but in most other parts of the world, it would be the liter. It is important for the buyer that the quantity ordered is actually received and the refiner expects to be paid for the quantity shipped. Both parties are interested in accurate measurements of the volume and, therefore, need to agree on the units, conditions, and method(s) of measurement to be used.

Persons needing to measure a mass cannot borrow the primary standard maintained in France or even the national standard from the National Institute of Standards and Technology (NIST) in the U.S. They must use lower-level standards that can be checked against those national or international standards. Everyday measuring devices, such as scales and balances, can be checked (calibrated) against working level mass standards from time to time to verify their accuracy. These working-level standards are, in turn, calibrated against higher-level mass standards. This chain of calibrations or checking is called "traceability." A proper chain of traceability must include a statement of uncertainty at every step.



National standards are sets of technical specifications, guidelines, or characteristics that provide a common reference point for consistency, interchangeability, and quality. They are developed and implemented by national standards bodies to ensure products, services, processes, and systems meet specific requirements.

National Standards Bodies

Each country has its own national standards body responsible for developing and promoting standards. Some well-known examples include:

- **Bureau of Indian Standards (BIS):** India
- **American National Standards Institute (ANSI):** United States
- **British Standards Institution (BSI):** United Kingdom
- **International Organization for Standardization (ISO):** Global

International Standards: A Global Framework:

International standards are technical specifications, guidelines, or characteristics that provide a common reference point for consistency, interchangeability, and quality on a global scale. They are developed through consensus by experts from various countries and approved by internationally recognized bodies.

Key International Standards Organizations

- **International Organization for Standardization (ISO):** Develops and publishes international standards on a wide range of topics, including quality management, environmental management, and technology.
- **International Electrotechnical Commission (IEC):** Focuses on standardization in the fields of electrical, electronic, and related technologies.
- **International Telecommunication Union (ITU):** Develops standards for information and communication technologies.

Benefits of Adopting International Standards

- **Improved Market Access:** Compliance with international standards can open up new markets.
- **Enhanced Reputation:** Demonstrates a commitment to quality, safety, and environmental responsibility.
- **Cost Reduction:** Streamlined processes and reduced risks can lead to cost savings.
- **Risk Management:** Mitigates potential risks associated with product or service failures.

De Facto International Standards

A de facto international standard is a standard that has gained widespread acceptance and use through market dominance or public preference, rather than through formal standardization processes. Unlike formal standards developed by organizations like ISO or IEC, de facto standards emerge organically and are often associated with a specific company or product.

Examples of De Facto Standards

- **Operating Systems:** Windows and macOS are de facto standards in personal computing.
- **Internet Protocols:** TCP/IP is a de facto standard for internet communication.

- **File Formats:** PDF, JPEG, and MP3 are de facto standards for document, image, and audio formats.
- **Programming Languages:** Python, Java, and JavaScript have become de facto standards in software development.

Advantages and Disadvantages of De Facto Standards

Advantages:

- Rapid adoption and widespread use
- Often innovative and efficient
- Can drive market growth and competition

Disadvantages:

- Lack of formal oversight and governance
- Potential for vendor lock-in
- May not be interoperable with other standards

1.3.3 Calibration Methods:

❒ **Calibration** is the process of configuring a sensor or instrument to provide accurate and reliable measurements by comparing its output against a known reference or standard. This ensures the device performs within the desired accuracy limits.

❒ **Purpose of Calibration:**

- ❖ Ensure measurement accuracy.
- ❖ Minimize errors in the sensor or instrument's readings.
- ❖ Verify compliance with standards and regulatory requirements.
- ❖ Enhance consistency and repeatability of measurements.

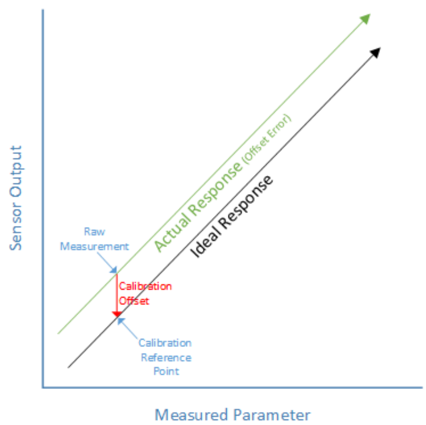
❒ **Steps in Calibration**

1. **Define the Calibration Standard:**
   - ❖ Use a standard reference device with known, certified accuracy.
   - ❖ The standard must be traceable to an international or national standard (e.g., NIST, ISO).

2. **Set the Calibration Environment:**
   - Ensure stable environmental conditions to avoid introducing errors.
3. **Compare Readings:**
   - Place the sensor or instrument in the same conditions as the standard.
   - Measure the same input (e.g., temperature, pressure, force) and record readings from both.
4. **Adjust the Sensor or Instrument:**
   - If discrepancies exist, adjust the device to match the standard reference.
   - Some devices allow manual adjustments, while others require software-based tuning.
5. **Document the Results:**
   - Record pre- and post-calibration readings for traceability.
   - Generate a calibration certificate, if required, for regulatory or quality assurance purposes.

Types of Calibration:

1. **Single-point Calibration:**
   - Adjusts the sensor to match the standard at one reference point.
   - Useful for simple devices or applications.
   - Single point calibration is a calibration method that involves adjusting the measurement system at a single known point within the measurement range. It's a simpler and faster method compared to multi-point calibration, which involves checking multiple points.

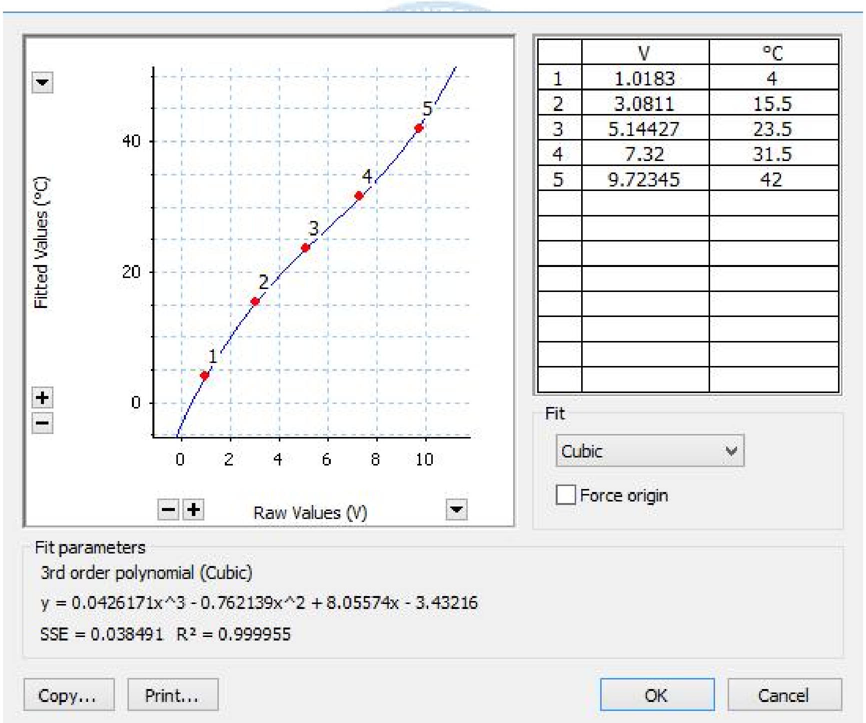


   - Take a measurement with your sensor.
   - Compare that measurement with your reference standard.

- Subtract the sensor reading from the reference reading to get the offset.
- In your code, add the offset to every sensor reading to obtain the calibrated value.

2. Multi-point Calibration:

- Compares readings across multiple input values within the sensor's range.
- Ensures accuracy across the entire operating range.
- Multi-point calibration is a calibration method that involves adjusting the measurement system at multiple known points within the measurement range. It's a more accurate and comprehensive method compared to single-point calibration, which only checks one point.

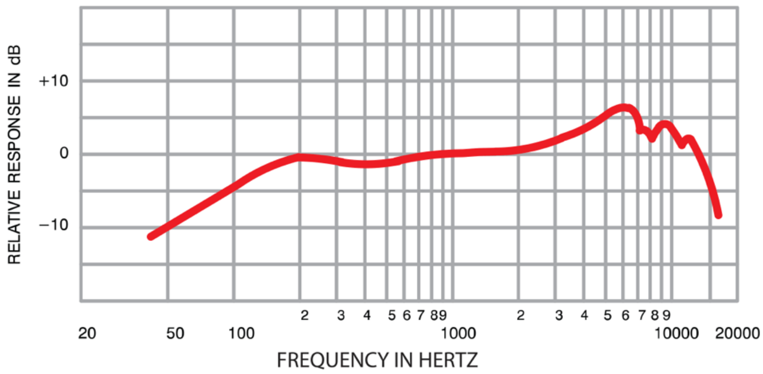


1. **Choose calibration points:** Multiple points are selected across the entire measurement range of the sensor.
2. **Apply known inputs:** The input signals corresponding to the chosen calibration points are applied to the sensor.

3. **Adjust the measurement system:** The output of the sensor is compared to the known inputs at each point, and the measurement system is adjusted to match the expected outputs.
4. **Verify calibration:** The adjusted measurement system is tested with other inputs within the measurement range to ensure accuracy.

3. <u>Dynamic Calibration</u>:

- Tests and calibrates the sensor under varying or dynamic conditions (e.g., vibration, fluctuating temperatures).
- **Dynamic calibration** is the process of calibrating a sensor or instrument under conditions that involve changing or time-varying inputs, rather than static or steady-state conditions. It is particularly important for sensors used in applications where measurements are taken in rapidly changing environments, such as vibrations, shock, or fluctuating temperatures.



<u>Frequency Response Graph</u>:

- **X-axis:** Frequency of the input signal
- **Y-axis:** Magnitude or amplitude of the output signal (often in decibels)
- **Interpretation:** This graph shows how the system's gain (amplification or attenuation) varies with the frequency of the input signal. Ideally, the gain should remain constant across the desired frequency range. Deviations from a flat line indicate frequency-dependent distortions.

4. **Factory Calibration:**
   - ❖ Performed by the manufacturer before shipment.
   - ❖ May not account for user-specific operating conditions.
5. **Field Calibration:**
   - ❖ Conducted on-site where the sensor is used.
   - ❖ Often necessary for large or permanently installed systems.

****