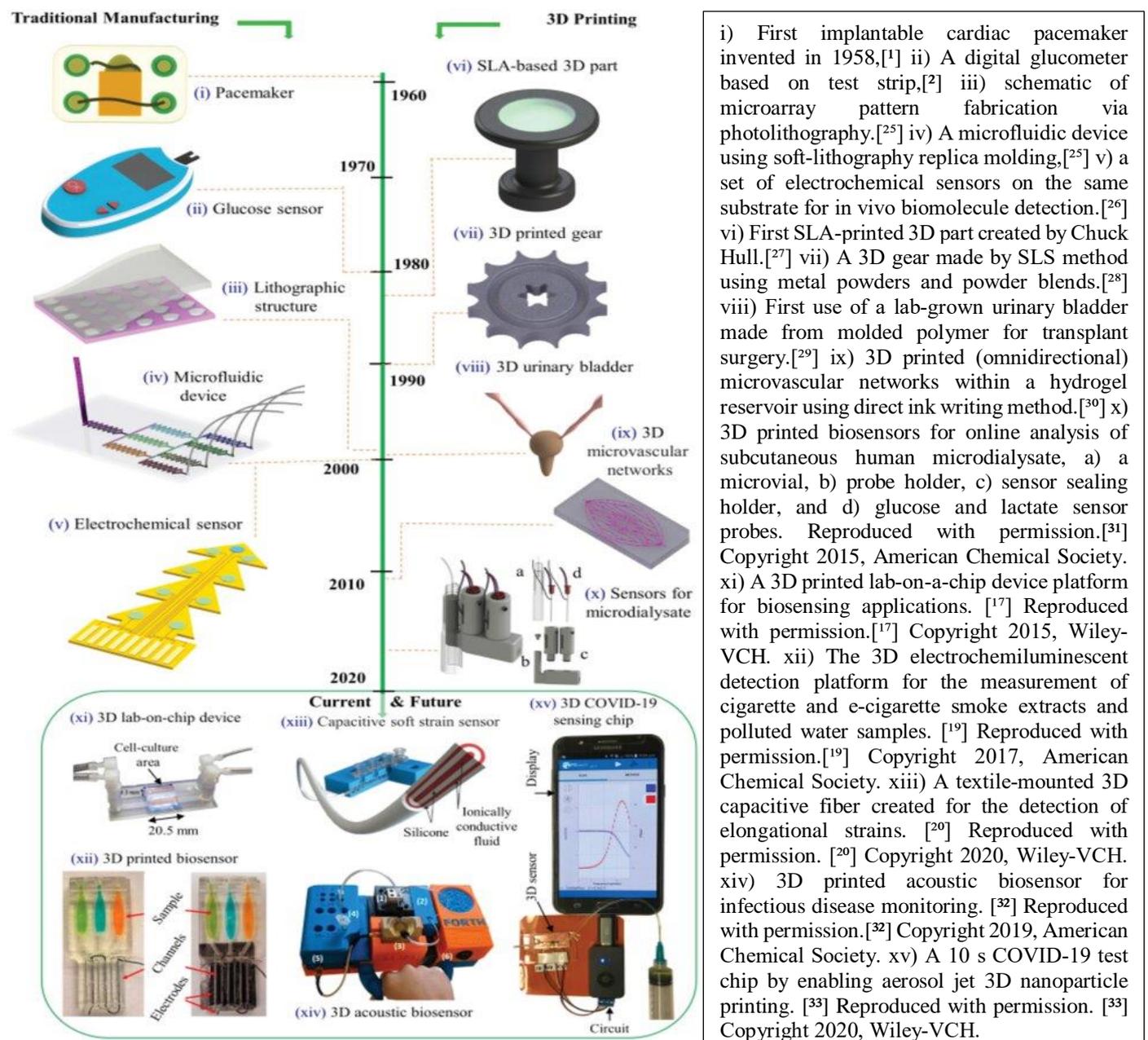


# Chapter 1: Introduction to the Principles of Instrumentation and Measurements

## 1.1 Introduction

Instrumentation is the science of measuring and controlling physical phenomena through automated systems. It has evolved from simple mechanical devices, such as water clocks and mercury thermometers, to highly advanced electronic and digital systems that drive modern industry, research, and technology. The historical growth of instrumentation parallels human technological progress. Each new era of discovery demanded more precise measurement, from navigation during the Age of Exploration to space missions and nanotechnology today.



**Figure 1.1:** A timeline diagram showing progression of biomedical devices fabricated using traditional manufacturing and 3D printing.

## 1.2 Instrumentation: Definitions and Functions

Instrumentation, in technology, the development and use of precise measuring equipment. Although the sensory organs of the human body can be extremely sensitive and responsive, modern science and technology rely on the development of much more precise measuring and analytical tools for studying, monitoring, or controlling all kinds of phenomena.

- **Definition:** Refers to devices or systems used to measure, display, control, and record physical quantities such as temperature, pressure, flow, and liquid levels.
- **Functions:** The functions of instrumentation are primarily directed toward the precise detection, conversion, and presentation of physical quantities to support observation, analysis, and control. Instrumentation extends human faculties by enabling accurate sensing and monitoring of variables such as temperature, pressure, and flow, and by converting these into signals that can be displayed, recorded, or transmitted. Within industrial settings, instrumentation provides real-time data that allows operators to make informed decisions and supports automation by integrating with control systems. It also contributes to safety through the provision of alarms and protective responses when parameters exceed prescribed limits. Beyond production, instrumentation ensures consistency, reliability, and efficiency in technical processes, forming the essential link between the physical world and human or machine interpretation.

### 1.2.1 Basic Components of an instrumentation system

An Instrumentation System is a combination of input devices (sensors), signal conditioners, processing units, and output devices (display, recorder, or actuator) that work together to measure and sometimes control a physical quantity. At its core, a basic instrumentation system consists of four main elements:

#### 1. **Sensor/Transducer :**

- Converts a physical quantity (temperature, pressure, displacement, etc.) into an electrical signal.
- Example: Thermocouple (temperature → voltage).

#### 2. **Signal Conditioning Unit**

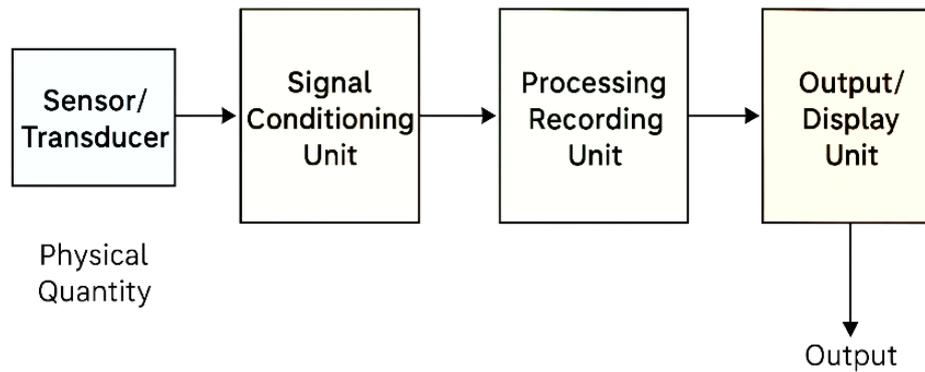
- Processes the raw signal (amplification, filtering, modulation, conversion).
- Ensures the signal is strong and clean for further processing.

#### 3. **Processing/Recording Unit**

- Can be a microcontroller, computer, or data acquisition system.
- Stores, analyzes, and interprets the signal.

#### 4. **Output/Display Unit**

- Converts processed information into a readable or actionable form.
- Example: Digital display, recorder, or actuator (motor, valve).



**Figure 1.2:** Instrumentation system.

## 1.3 Types of Instrumentation Systems

### 1.3.1 Measurement Systems

- **Definition:** A measurement system is designed only to sense, detect, and display a physical quantity.
- **Function:** It does not alter or control the measured variable; it simply reports it.
- **Typical Components:**
  - **Sensor/Transducer** – Converts the physical parameter (e.g., temperature, pressure, displacement) into an electrical signal.
  - **Signal Conditioning Unit** – Amplifies, filters, or converts the signal for processing.
  - **Display/Recording Device** – Shows the measured value in a readable form (dial, digital display, graph, or computer interface).
- ◆ **Examples:**
  - A digital thermometer that only displays body temperature.
  - A voltmeter showing electrical voltage across a circuit.
  - A pressure gauge used in pipelines.

### 1.3.2 Control Systems

- **Definition:** A control system both measures and regulates a physical variable to maintain it at a desired setpoint.
- **Function:** It continuously compares the measured output with a reference input (set value) and makes adjustments if needed.
- **Types of Control Systems:**
  - 1) **Open-Loop Control Systems:** In open-loop systems, the control action is independent of the actual output. The system acts purely based on input instructions, without verifying if the desired result is achieved.

- 2) **Closed-Loop (Feedback) Control Systems:** In closed-loop systems, the control action depends on the output. The system compares the measured output with the reference value and automatically adjusts to minimize the error.

## 1.4 Classification of Measuring Instruments

Instruments can be subdivided into separate classes according to several criteria. These sub-classifications are useful in broadly establishing several attributes of particular instruments such as accuracy, cost, and general applicability to different applications.

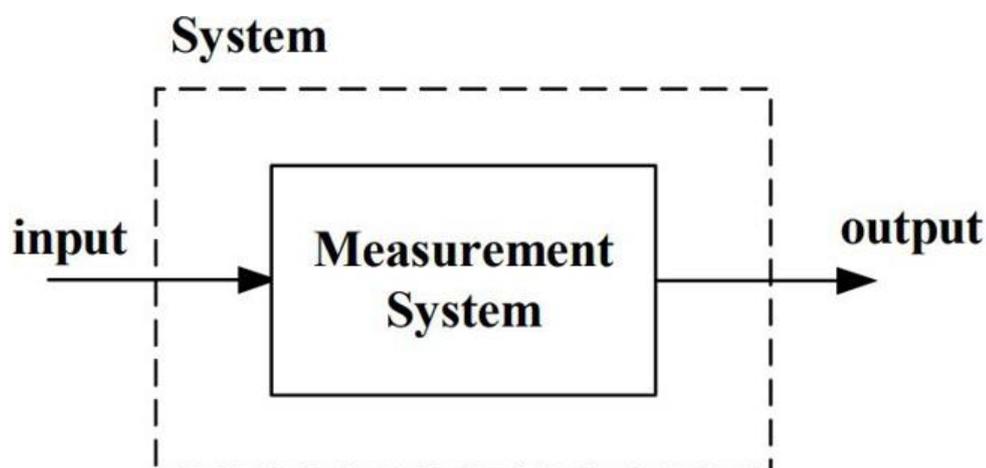
### 1.4.1 Active and passive instruments

Instruments are divided into active or passive ones according to whether the instrument output is entirely produced by the quantity being measured or whether the quantity being measured simply modulates the magnitude of some external power source.

In active instruments, the external power source is usually in electrical form, but in some cases, it can be other forms of energy such as a pneumatic or hydraulic one. One very important difference between active and passive instruments is the level of measurement resolution that can be obtained.

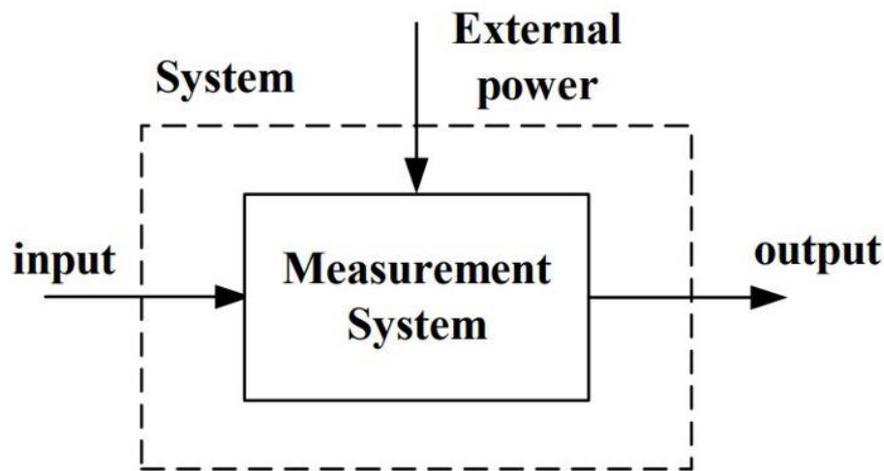
In an active instrument, however, adjustment of the magnitude of the external energy input allows much greater control over measurement resolution. Whilst the scope for improving measurement resolution is much greater incidentally, it is not infinite because of limitations placed on the magnitude of the external energy input, in consideration of heating effects and for safety reasons.

- ❖ **Example 01:** for active instruments- Piezo-electric Crystal, Thermocouple etc.



**Figure 1.3:** Active instruments – self generating.

- ❖ **Example 02:** for passive instruments- Potentiometer, Strain Gauge, RTD etc.



**Figure 1.4:** Passive instruments.

### 1.5.2 Null-type and deflection-type instruments

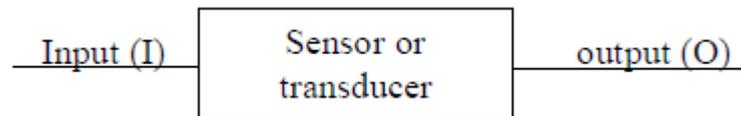
Null type instruments are those in which or null indication determines the magnitude of measured quantity. A null type instrument indicates a zero condition when the measured quantity and the opposite quantity are same. Null type instrument requires many controls before null condition are obtained and hence it is not suitable for dynamic measurement because in dynamic measurement the quantity changes rapidly with the time. The measured quantity produced some physical effects that cause a similar but opposing effect in some part of the instrument. The opposing affect increases until a balance is achieved, at which point the “deflection” is measured. Such instruments are called deflection type instruments.

### 1.4.3 Analog and digital instruments

An analog instrument gives an output that varies continuously as the quantity being measured changes. The output can have an infinite number of values within the range that the instrument is designed to measure. A digital instrument has an output that varies in discrete steps and so can only have a finite number of values. The distinction between analog and digital instruments has become particularly important with the rapid growth in the application of microcomputers to automatic control systems. Any digital computer system, of which the microcomputer is but one example, performs its computations in digital form. An instrument whose output is in digital form is therefore particularly advantageous in such applications, as it can be interfaced directly to the control computer. Analog instruments must be interfaced to the microcomputer by an analog-to-digital (A/D) converter, which converts the analog output signal from the instrument into an equivalent digital quantity that can be read into the computer. This conversion has several disadvantages. Firstly, the A/D converter adds a significant cost to the system. Secondly, a finite time is involved in the process of converting an analog signal to a digital quantity, and this time can be critical in the control of fast processes where the accuracy of control depends on the speed of the controlling computer. Degrading the speed of operation of the control computer by imposing a requirement for A/D conversion thus impairs the accuracy by which the process is controlled.

## 1.5 Performance characteristics

The first and for most important step in designing instrumentation system is the selection of sensor or transducer. Thus knowledge of the performance characteristic of the sensor or transducer is essential for the proper choice of the transducer. Based on the responses of sensor or transducer to inputs which are either constant or varying with time rapidly, the Performance characteristic of sensor or transducer is broadly classified in to static and dynamic characteristic.



**Figure 1.5:** Performance characteristic.

- 1) Static characteristics: are a set of performance criteria that give a meaningful description of the quality of measurement while the measured quantity is either constant or varying slowly.
- 2) Dynamic characteristics: describe the quality of measurement when the measured quantities vary rapidly with time.

A conventional approaches is to treat these two characteristics separately because the first one is expressed in terms of linear equations and the second one in terms of differential equations.

## 1.6 Summary

Instrumentation bridges theory and practice, making invisible phenomena measurable and controllable. With evolving digital, smart, and networked technologies, it remains at the heart of industrial automation, scientific progress, and innovation.