Chapter-1
Introduction

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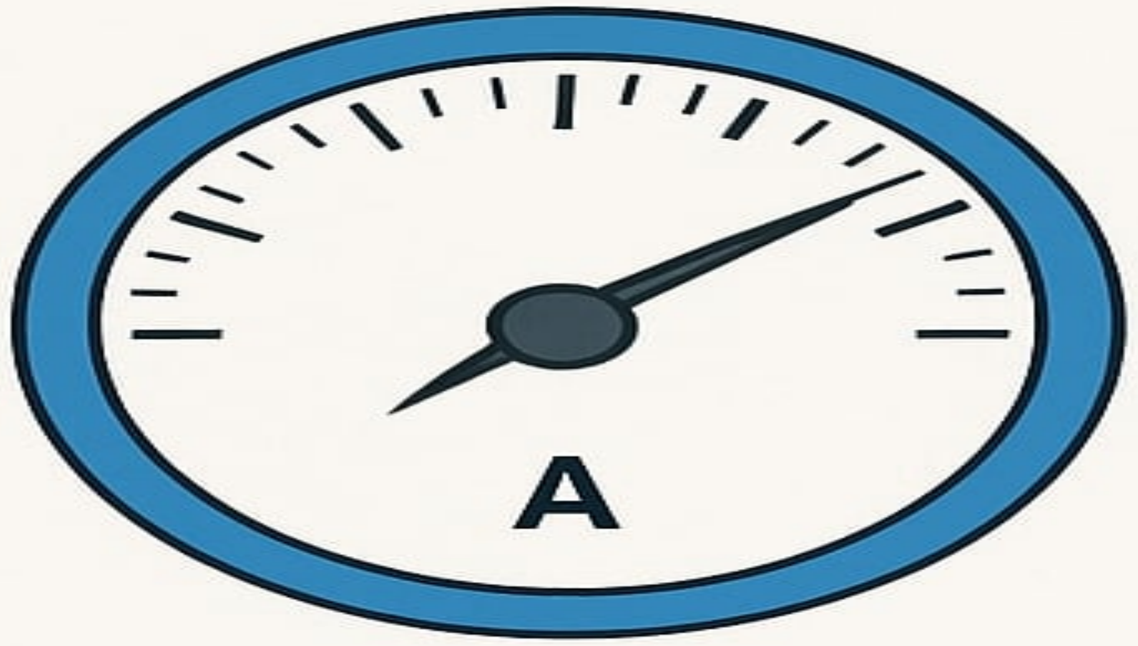
Analog Instruments

Definition

An analog instrument measures and displays a physical quantity as a continuous signal. Its display typically includes a needle or pointer that moves across a *dial* to indicate the measured value.



Block Diagram

Sensor Detects the physical quantity to be measured and converts it to an analog signal.

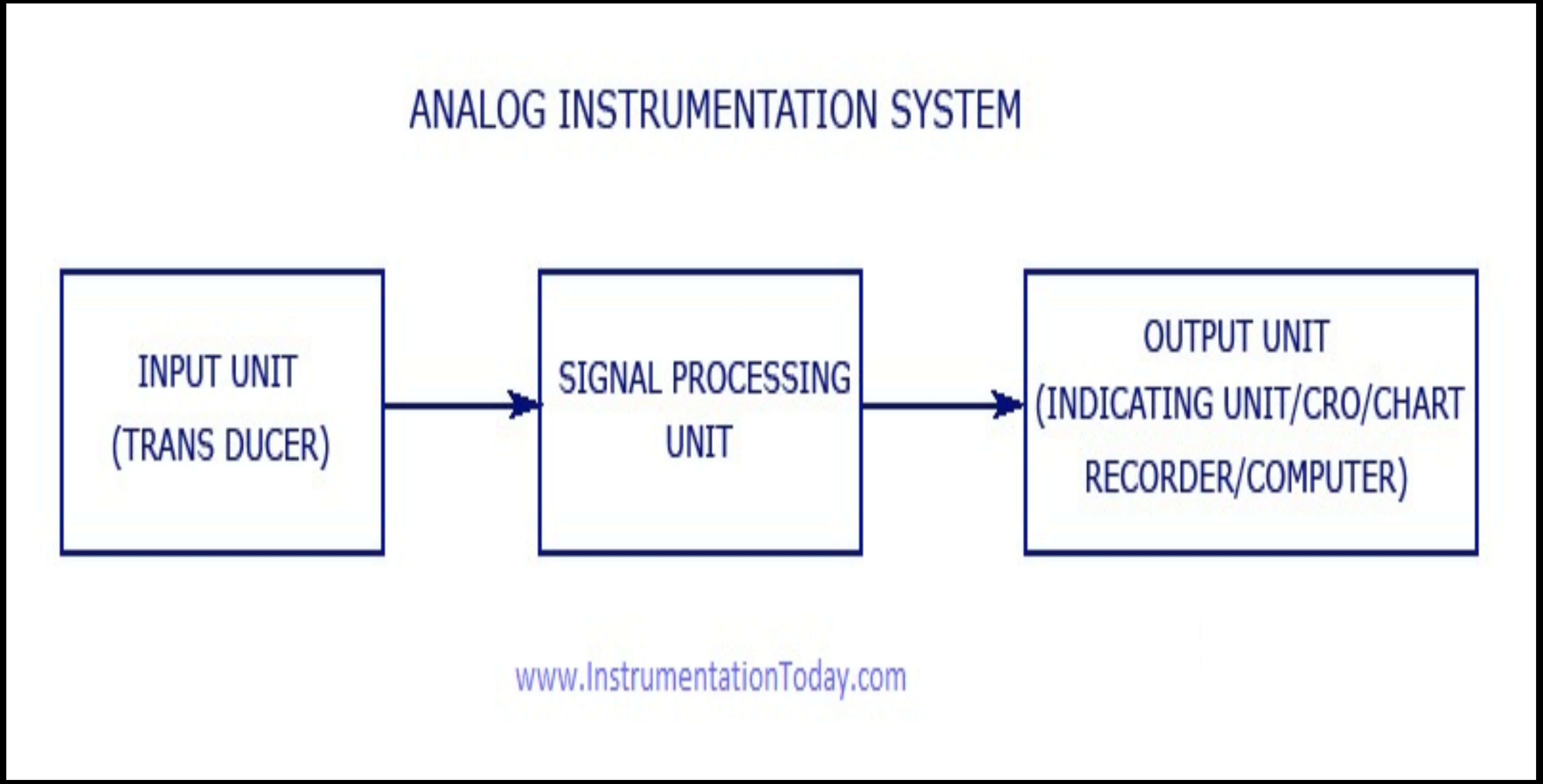
Signal Conditioning Amplifies, filters, or otherwise modifies the analog signal to make it suitable for display.

Analog Display The processed analog signal drives a dial with a needle or pointer that indicates the measured value

Analog Instruments

1. Input Unit (Transducer)

- Function: Converts a physical quantity (e.g., temperature, pressure, light) into an electrical signal (e.g., voltage or current).
- Example: A thermocouple (converts temperature to voltage) or a strain gauge (converts mechanical stress to resistance changes).
- Purpose: Acts as the sensor that "senses" the real-world parameter to be measured.



2. Signal Processing Unit

- Function: Modifies the transducer's output signal to make it suitable for the output unit. This may include:
  - Amplification: Boosts weak signals (e.g., using an operational amplifier).
  - Filtering: Removes noise or unwanted frequencies (e.g., with a low-pass filter).
  - Modification: Converts resistance to voltage (e.g., Wheatstone bridge) or adjusts signal levels.
- Purpose: Ensures the signal is accurate, noise-free, and compatible with the output device.

3. Output Unit

- Function: Displays or records the processed signal. Common output devices include:
  - Indicating Unit: Analog meters (e.g., a needle-based voltmeter).
  - CRO (Cathode Ray Oscilloscope): Visualizes time-varying signals as waveforms.
  - Chart Recorder: Plots signals on paper over time (e.g., for temperature trends).
  - Computer: Digitizes the analog signal for further analysis/storage (requires an ADC).
- Purpose: Provides a human-readable or storable representation of the measured data.

Digital Instruments

Definition

A digital instrument measures and displays a physical quantity as a discrete value. Its display typically shows the measured value as a numeric readout.

Block Diagram

Sensor Detects the physical quantity to be measured and converts it to an analog signal.

Signal Conditioning Amplifies, filters, or otherwise modifies the analog signal to make it sultable for conversion

Analog-to-Digital Converter Converts the conditioned analog signal into a digital signal

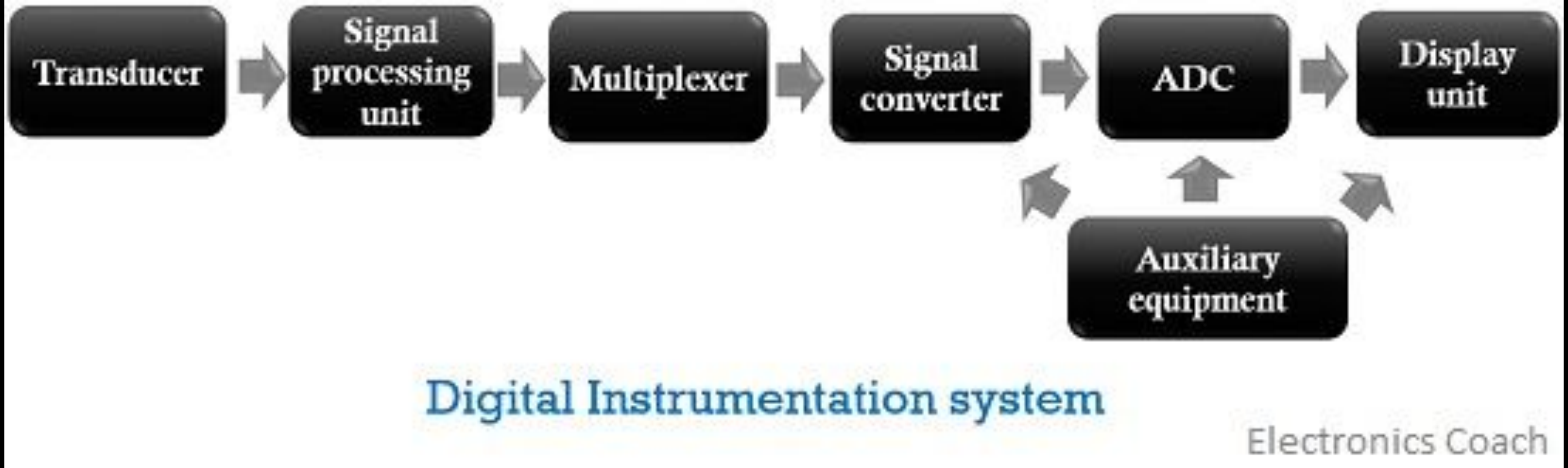
Digital Display The digital signal is presented as a numeric readout indicating the measured value

Digital Instruments

1. Transducer
- Function: Converts a physical quantity (e.g., temperature, pressure) into an electrical signal (e.g., voltage, current).
- Example: Thermocouple (temperature to voltage), LVDT-Linear Variable Differential Transformer (displacement to voltage).

2. Signal Processing Unit
- Function: Conditions the transducer's output for further processing.
- Tasks include:
  - Amplification: Boosts weak signals (e.g., using an op-amp). Filtering: Removes noise (e.g., with a low-pass filter).
  - Linearization: Adjusts non-linear signals to a linear range.

3. Multiplexer (MUX)
- Function: Selects one of multiple input signals and routes it to the next stage.
- Purpose: Enables a single ADC to process data from multiple transducers sequentially, reducing cost/complexity.



4. Signal Converter

- Function: Prepares the signal for digitization (e.g., sample-and-hold circuit to "freeze" analog values during ADC conversion).

5. ADC (Analog-to-Digital Converter)

- Function: Converts the conditioned analog signal into a digital format (binary code).
- Key Parameters: Resolution (e.g., 12-bit), sampling rate.
- Example: Successive Approximation ADC, Delta-Sigma ADC.

6. Display Unit

- Function: Shows the digital output in human-readable form.
- Examples: LCD screens, digital meters, or computer monitors (for graphical representation).

7. Auxiliary Equipment

- Additional Components: May include:
  - Microcontroller/Processor: For advanced data processing (e.g., calibration, algorithms).
  - Memory: Stores historical data.
  - Communication Modules: Transmits data to networks (e.g., IoT systems).

Microprocessor-Based Instrumentation Systems

1. Definition of a Microprocessor

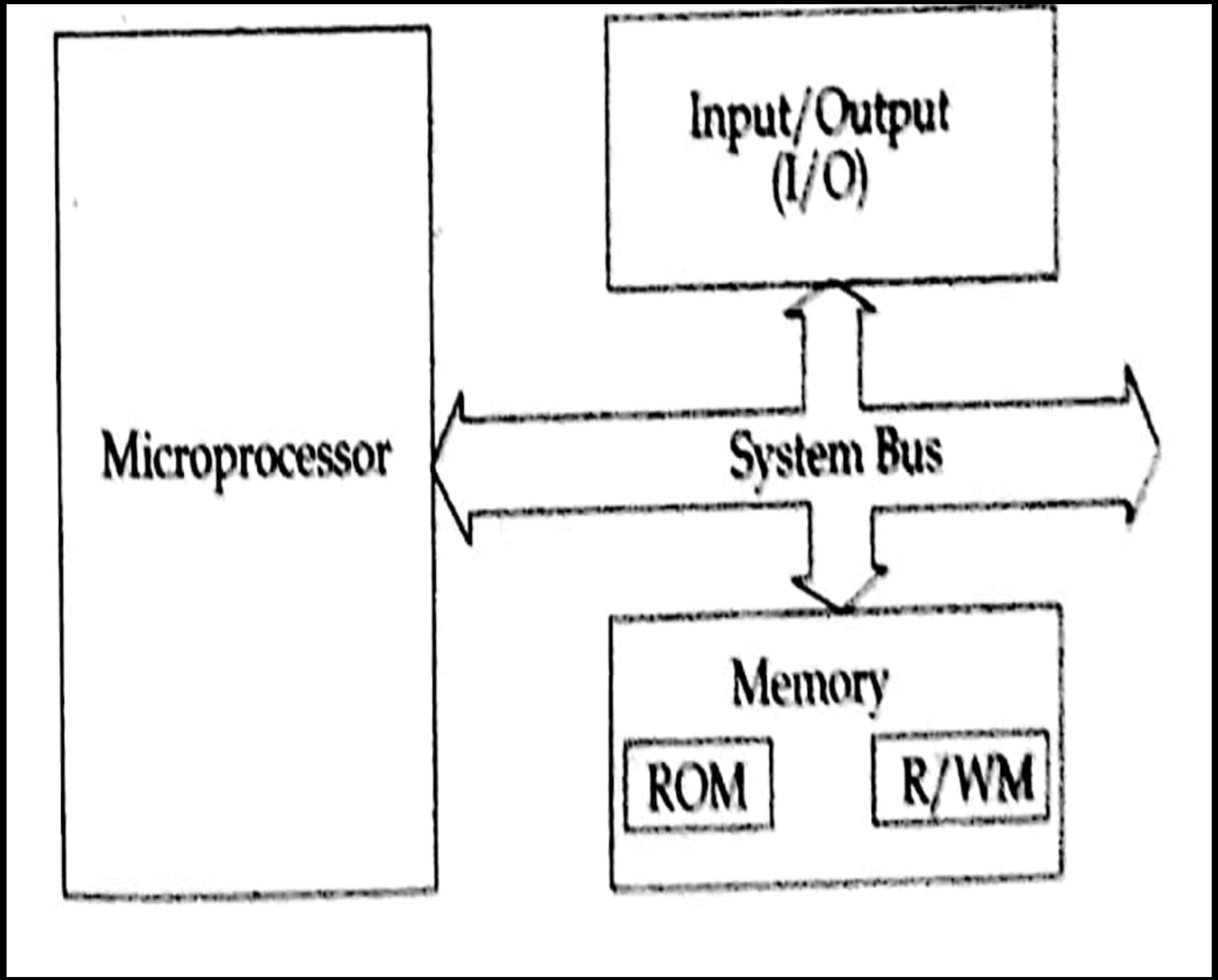
- A multipurpose, programmable, clock-driven, and register-based electronic device.
- Fabricated using scale integration (from SSI to VLSI).
- Reads binary instructions from memory.
- Accepts binary data as input, processes it, and provides results as output.

2. Definition of an Instrumentation System

- An assembly of instruments and components interconnected to:
  - Measure physical quantities (electrical, thermal, mechanical, etc.).
  - Analyze data.
  - Control processes.

3. Microprocessor-Based Instrumentation Systems

- Systems where a microprocessor is the central processing unit.
- Enhances functionality by enabling:
  - Programmable control (flexible operation).
  - High-speed data processing.
  - Automation and digital signal handling.
- Examples of microprocessor-based instrumentation systems are ATM, automatic washing machine, fuel control, oven, etc



4. Advantages Over Analog Systems

- Higher accuracy & precision (digital processing reduces errors).
- Noise immunity (digital signals are less prone to interference).
- Data storage & communication (integration with computers/networks).
- Real-time processing & programmability (adaptive control).

5. Key Components

- Microprocessor (CPU for decision-making).
- Memory (stores instructions & data).
- ADC/DAC (bridges analog sensors & digital processing).
- I/O Interfaces (connects sensors, displays, and control units).

6. Example Applications

- Digital Multimeters (DMMs) – Measure voltage, current, resistance.
- Smart Thermostats – Process temperature data and control HVAC systems.
- Automotive ECUs – Monitor engine parameters for optimal performance.

Basic Features of a Microprocessor-based System

The basic features of a microprocessor-based system are:

- It comprises of three main components: microprocessor, I/O, and memory.
- It has decision making power based on previous entered values.
- Repeatability of readings.
- User friendly (Signal readout).
- Parallel processing.
- Timesharing and multiprocessing.
- Data storage, retrieval, and transmission.
- Effective control of multiple equipments on time sharing basis.
- A lot of processing capability.

Open Loop Microprocessor-Based System

1. Definition

- A control system where the microprocessor provides output (e.g., display) to a human operator, who then manually adjusts control inputs.
- No automatic feedback is used to correct errors in real-time.

2. How It Works

- Microprocessor processes input data (e.g., from sensors).
- Output is displayed (e.g., temperature reading on a screen).
- Human operator interprets the data and manually adjusts control inputs (e.g., turning a knob to increase pressure).

3. Characteristics

- Simple & Low Cost – No feedback sensors or complex algorithms required.
- No Automatic Correction – Errors due to disturbances are not self-corrected.
- Reliant on Human Judgment – Accuracy depends on operator response.

4. Applications

- Basic temperature control systems (e.g., manual thermostat adjustment).
- Pressure monitoring in non-critical environments (e.g., industrial tanks with operator oversight).
- Simple process control where precision is not vital.

5. Example

- A microprocessor-based pressure display system:
    - Sensor measures pressure → Microprocessor shows value on a screen.
    - Operator checks reading and manually adjusts a valve if needed.

6. Limitations

- Prone to human error (delays or incorrect adjustments).
- Not suitable for critical systems (e.g., medical devices, aviation).

Conclusion

Open-loop systems are cost-effective for non-critical applications where human oversight is acceptable. For precision-dependent tasks, closed-loop (feedback) systems are preferred.

- Upper and lower limits of desired pressure are set.
- Pressure is converted to digital form to be fed to the microprocessor.
- The microprocessor compares the sampled pressure measurement with the preset pressure limits.
- If the sampled pressure is beyond the limits, the microprocessor triggers an alarm or lamp as an indication.
- Based on the output signal, a human operator makes the necessary adjustments.

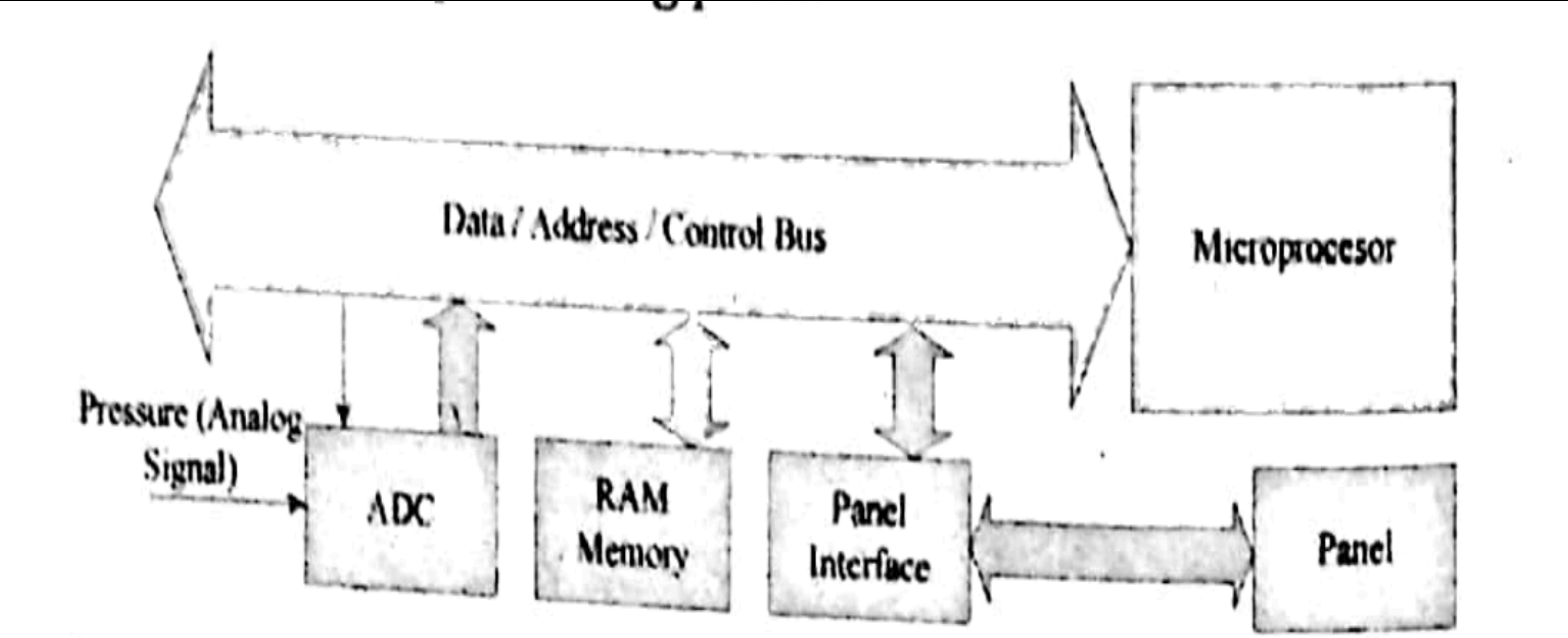


Figure 1.2: *Block diagram of an open loop microprocessor-based system (pressure monitoring system).*

Closed-Loop Microprocessor-Based Control System

1. System Overview

- The microprocessor continuously monitors process variables (e.g., temperature, pressure).
- It automatically adjusts the system using electromechanical devices (e.g., valves, heaters) to maintain desired set-points.
- No human intervention is required for corrections.

2. Key Components

- Sensors: Measure process variables (e.g., thermocouples for temperature).
- Microprocessor: Processes sensor data, compares it with setpoints, and computes control actions.
- Actuators: Execute control commands (e.g., relays, motors, solenoids).

3. How It Works

- Sensing: Real-time data is fed to the microprocessor.
- Comparison: Microprocessor checks if values are within desired limits.
- Control Action: If deviations occur, it sends signals to actuators for correction.
- Feedback Loop: Continuous monitoring ensures stability.

4. Advantages

- High Accuracy: Automatic adjustments minimize errors.
- Fast Response: Immediate corrections without human delay.
- Adaptive: Handles dynamic changes in process conditions.
- Reliable: Reduces dependency on operator judgment.

5. Example: Automatic Oven Temperature Control

- Sensor: Thermocouple measures oven temperature.
- Microprocessor: Compares temperature with the set value.
- Actuator: Adjusts heating element power to maintain exact temperature.

6. Applications

- Industrial automation (e.g., CNC- Computer Numerical Control machines).
- Climate control systems (e.g., smart thermostats).
- Automotive systems (e.g., engine control units).

7. Limitations

- Higher initial cost due to sensors and control hardware.
- More complex design and maintenance.

Conclusion

Closed-loop systems provide precise, autonomous control, making them ideal for critical applications where accuracy and reliability are essential.

- Upper and lower temperature limits are set in the microprocessor.
- Each temperature sample from the transducer is compared by the processor.
- If the temperature exceeds the preset upper limit:
  - The microprocessor sends an output signal to a system.
  - The system turns off the supply to some of the heater elements.
- If the temperature is below the preset lower limit:
  - The microprocessor sends a signal to the system.
  - The system turns on the supply to the heater element of the oven.

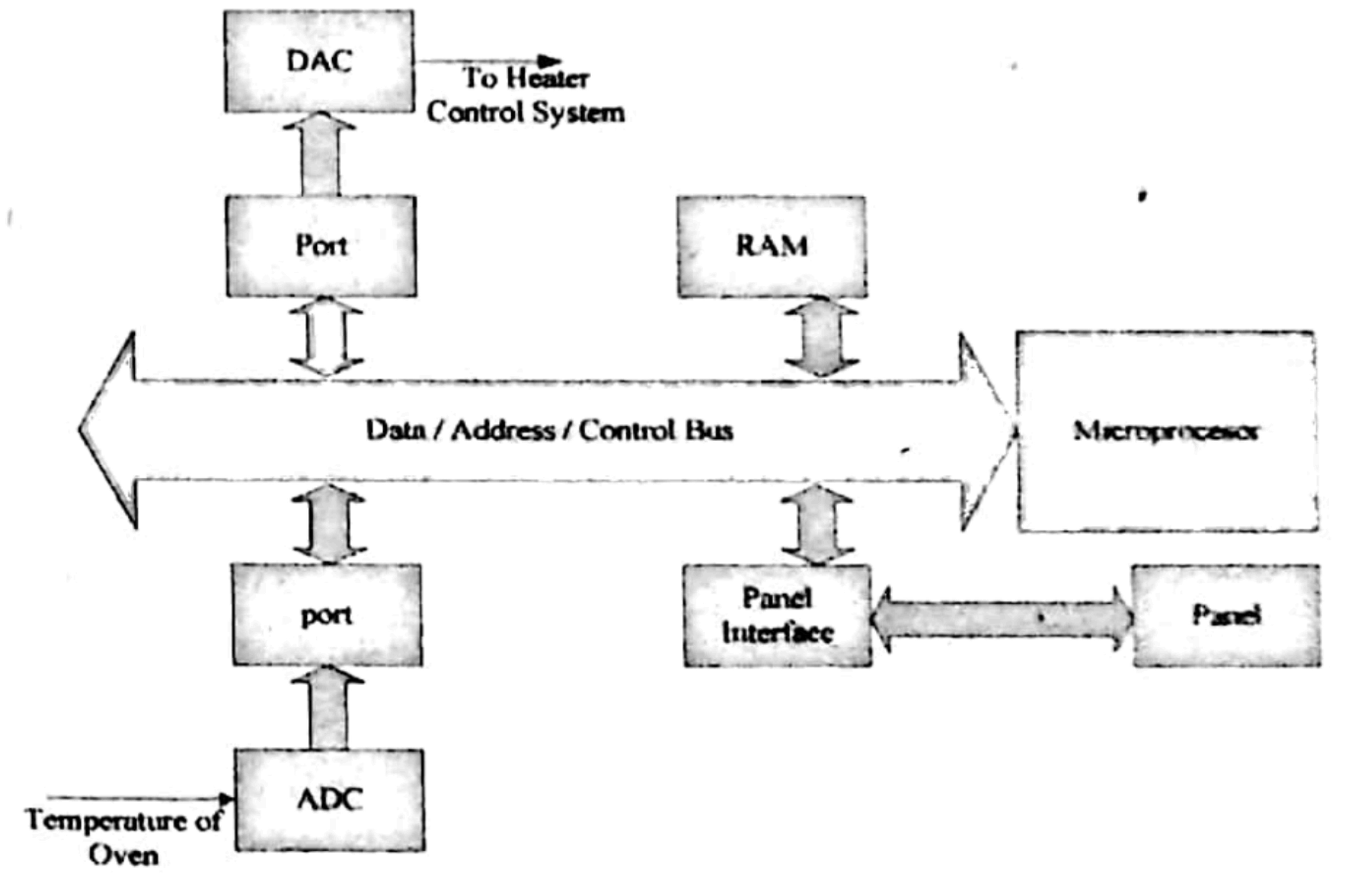


Figure 1.3: *Block diagram of a closed loop microprocessor-based system (automatic temperature control system).*

Open-Loop vs. Closed-Loop Control Systems

Feature	Open-Loop System	Closed-Loop System
Feedback	❌ No automatic feedback.	✔ Real-time feedback (self-correcting).
Human Role	Operator manually adjusts based on displayed output.	Fully automatic; no human intervention needed.
Accuracy	Lower (prone to human error/environmental changes).	High (continuously corrects deviations).
Complexity	Simple design, fewer components.	More complex (sensors, control algorithms, actuators).
Cost	Lower (no feedback sensors/actuators).	Higher (additional hardware/software).
Response Time	Slower (depends on operator).	Faster (instantaneous adjustments).
Reliability	Less reliable (human-dependent).	Highly reliable (automated corrections).
Applications	Non-critical systems (e.g., manual thermostat, basic pressure alarms).	Critical systems (e.g., oven temperature control, industrial automation).

Benefits of Microprocessor Based System

- **High speed processing** – Executes instructions rapidly, enabling quick decision-making.
- **Compact size** – Reduces the size of the overall system due to integration.
- **Low power consumption** – Efficient operation with minimal energy usage.
- **High reliability** – Fewer mechanical parts result in more reliable performance.
- **Automation** – Enables full or partial automation of processes, reducing need for human intervention.
- **Flexibility** – Easy to reprogram or modify for different tasks or conditions.
- **Cost-effective** – Reduces overall system cost due to integration and reduced hardware needs.
- **Real-time control** – Capable of monitoring and responding to changes instantly.
- **Accuracy and precision** – Offers improved measurement and control accuracy.
- **Data handling** – Can store, analyze, and process large amounts of data for better control and monitoring.

Microcomputer on Instrumentation Design

1. Definition & Core Function

- A microcomputer is a compact computing system with a microprocessor, memory, and I/O interfaces.
- In instrumentation, it serves as the brain for data acquisition, processing, and control.

2. Advantages in Instrumentation

- Precision: Enables high-accuracy measurements via digital signal processing.
- Automation: Eliminates manual intervention (e.g., auto-calibration, closed-loop control).
- Flexibility: Programmable for diverse tasks (e.g., sensor fusion, adaptive algorithms).
- Data Handling: Stores, logs, and analyzes large datasets (e.g., trend analysis in industrial sensors).
- Real time measurement, processing, and display.

3. Disadvantages

- They cannot replace the program themselves.
- They require software update on regular basis.
- They are prone to virus problem, which may cause fault in operation.

4. Key Components

- Microprocessor/CPU: Executes control algorithms (e.g., PID- Proportional-Integral-Derivative for temperature control).
- ADC/DAC: Bridges analog sensors and digital processing.
- Memory: Stores firmware (ROM) and real-time data (RAM).
- I/O Ports: Connects sensors (input) and actuators (output).

5. Applications

- Smart Sensors: Microcomputer-integrated sensors (e.g., digital multimeters).
- Industrial Automation: PLCs (Programmable Logic Controllers) for process control.
- Medical Devices: ECG monitors, infusion pumps.
- Environmental Monitoring: Weather stations with real-time data logging.

6. Design Considerations

- Real-Time Operation: Requires fast response (e.g., interrupt handling for critical events).
- Power Efficiency: Crucial for battery-powered devices (e.g., IoT sensors).
- Robustness: EMI shielding and error-checking (e.g., CRC for data integrity).

Conclusion

Microcomputers revolutionize instrumentation by merging precision, programmability, and connectivity, making them indispensable in modern smart systems.

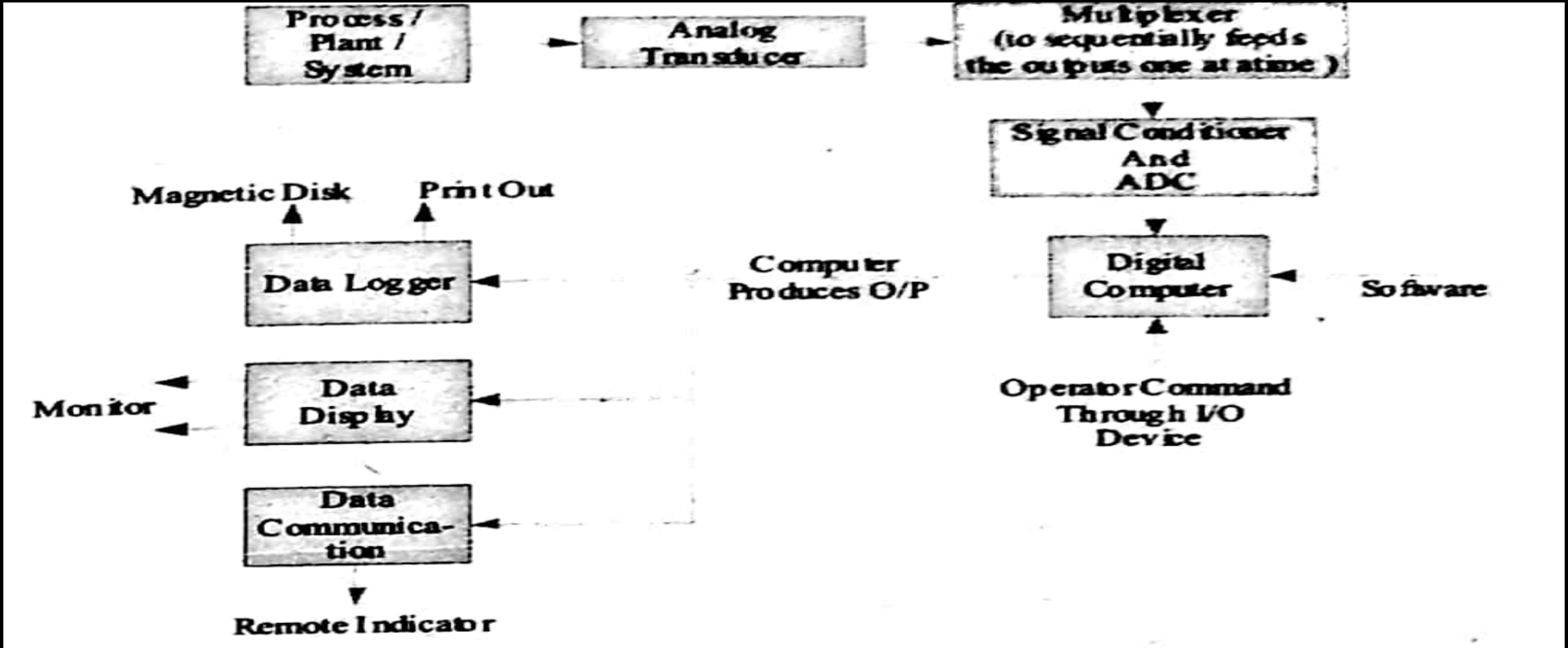


Fig: Block Diagram of typical digital computer-based instrumentation system.

Thank You