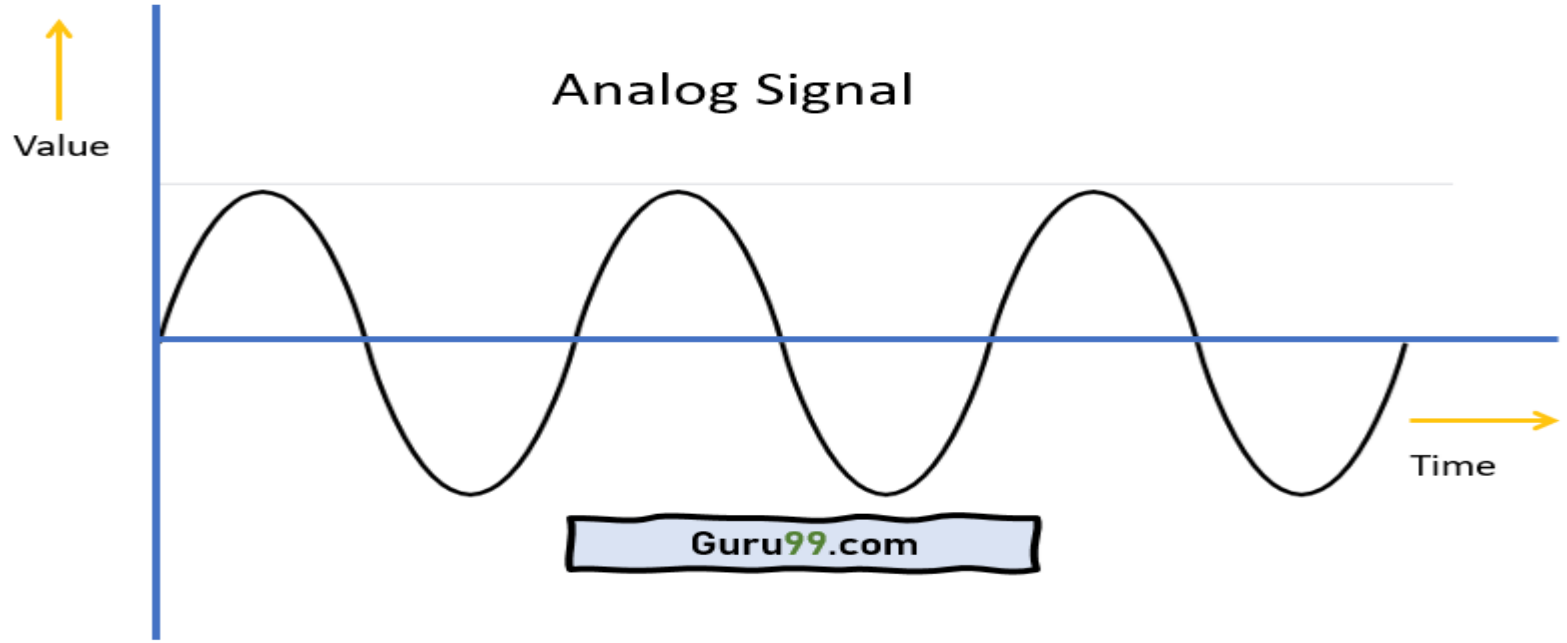
Chapter 1 on Instrumentation

Unit 1: Introduction to Instrumentation Systems (2 hours)

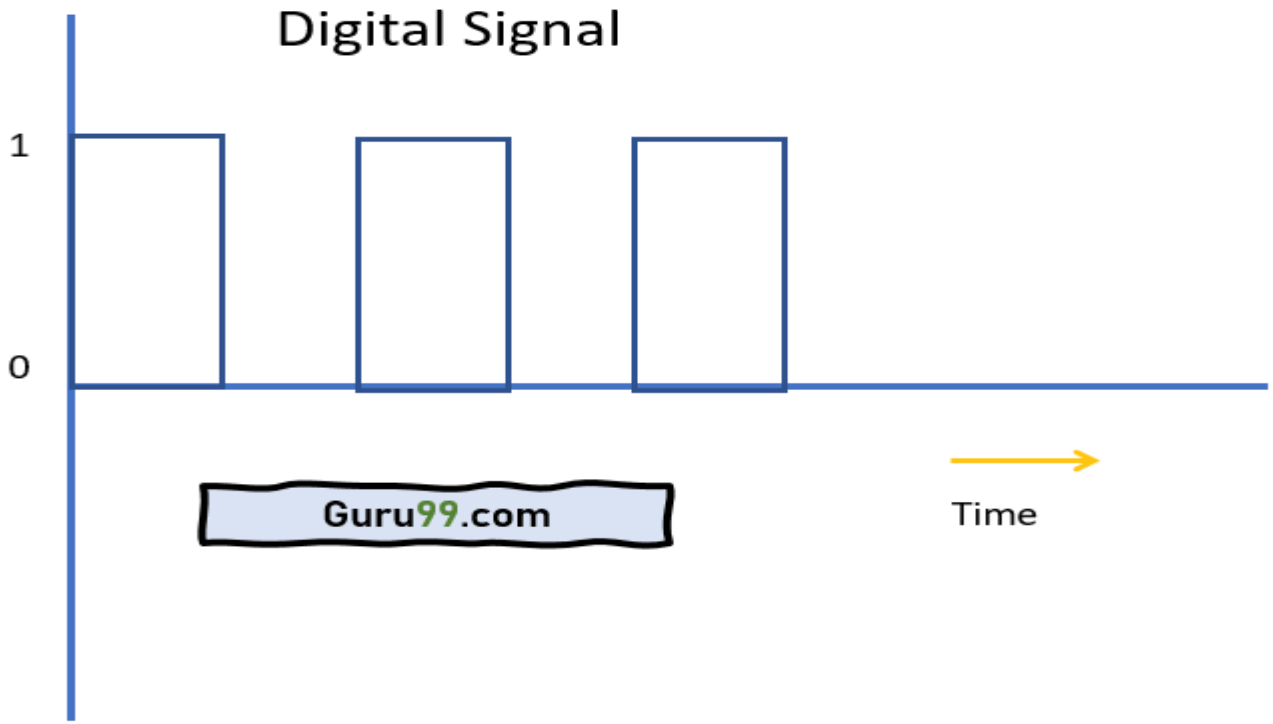
Analog and Digital Signals

- A **signal** is an electromagnetic or electrical current that is used for carrying data from one system or network to another.
- The signal is a function that conveys information about a phenomenon.
- In electronics and telecommunications, it refers to any time-varying voltage that is an electromagnetic wave which carries information.
- A signal can also be defined as an observable change in quality such as quantity
- A signal is function of one or more independent variables such as time, etc.

- **Analog signal** is a continuous signal in which one time-varying quantity represents another time-based variable.
- These kind of signals works with physical values and natural phenomena such as earthquake, frequency, volcano, speed of wind, weight, lighting, etc.



- A **digital signal** is a signal that is used to represent data as a sequence of separate values at any point in time.
- It can only take on one of a fixed number of values. This type of signal represents a real number within a constant range of values.



Analog and Digital Systems

- Digital as well as Analog System, both are used to transmit signals from one place to another like audio/video.
- Digital system uses binary format as **0** and **1** whereas analog system uses **electronic pulses** with **varying magnitude** to send data.
- Following are some of the important differences between Digital System and Analog System.

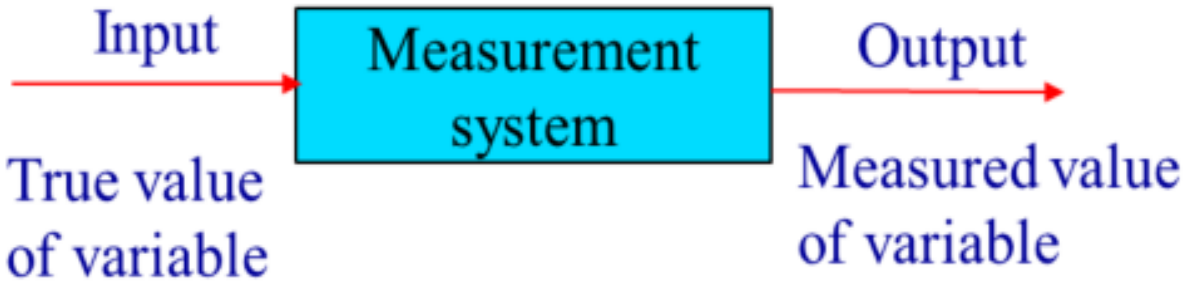
Sr. No.	Key	Digital System	Analog System
1	Signal Type	Digital System uses discrete signals as on/off representing binary format. Off is 0, On is 1.	Analog System uses continous signals with varying magnitude.
2	Wave Type	Digital System uses square waves.	Analog system uses sine waves.
3	Technology	Digital system first transform the analog waves to limited set of numbers and then record them as digital square waves.	Analog systems records the physical waveforms as they are originally generated.
4	Transmission	Digital transmission is easy and can be made noise proof with no loss at all.	Analog systems are affected badly by noise during transmission.
5	Flexibility	Digital system hardware can be easily modulated as per the requirements.	Analog system's hardwares are not flexible.
6	Bandwidth	Digital transmission needs more bandwidth to carry same information.	Analog tranmission requires less bandwidth.

Sr. No.	Key	Digital System	Analog System
7	Memory	Digital data is stored in form of bits.	Analog data is stored in form of waveform signals.
8	Power requirement	Digital system needs low power as compare to its analog counterpart.	Analog systems consume more power than digital systems.
9	Best suited for	Digital system are good for computing and digital electronics.	Analog systems are good for audio/video recordings.
10	Cost	Digital system are costly.	Analog systems are cheap.
11	Example	Digital system are: Computer, CD, DVD.	Analog systems are: Analog electronics, voice radio using AM frequency.

Instrumentation (Measurement) System

- It is an aggregation or assembly of device united by some form of regular interaction.
- It is the operation or process of determining the value of the variable or quantity under measurement.
- It is the means to carry out the measurement.
- It is a group of devices or diverse units of devices so combined by nature or by an art to form an integral whole and to function , operate or more in unisons, and often in obedience to some form of control.
- **Example**: **CT Scan Machine**, **MRI Machine**, **PID Controller Equipment**, etc.
- Its purpose is to give the users a numerical value corresponding to the variable being measured.

- The numerical value may not actually be the **true value** (**T.V.**)of the variable.
- There may be error due to the limited accuracy in the scale calibration or error due to miss – reading of scale by users.
- Thus a **measurement system** can be a system which has an input value as the **T.V.** of the variable being measured and output as the **measured value** (**M.V.**) of that variable.
- The relationship is shown below:



- Instrumentation system can be classified into following categories.

1. **On the basis of signal**
   - Analog Instrumentation System
   - Digital Instrumentation System
2. **On the basis of response**
   - Intelligent Instrumentation System
   - Dumb Instrumentation System

Analog Instruments

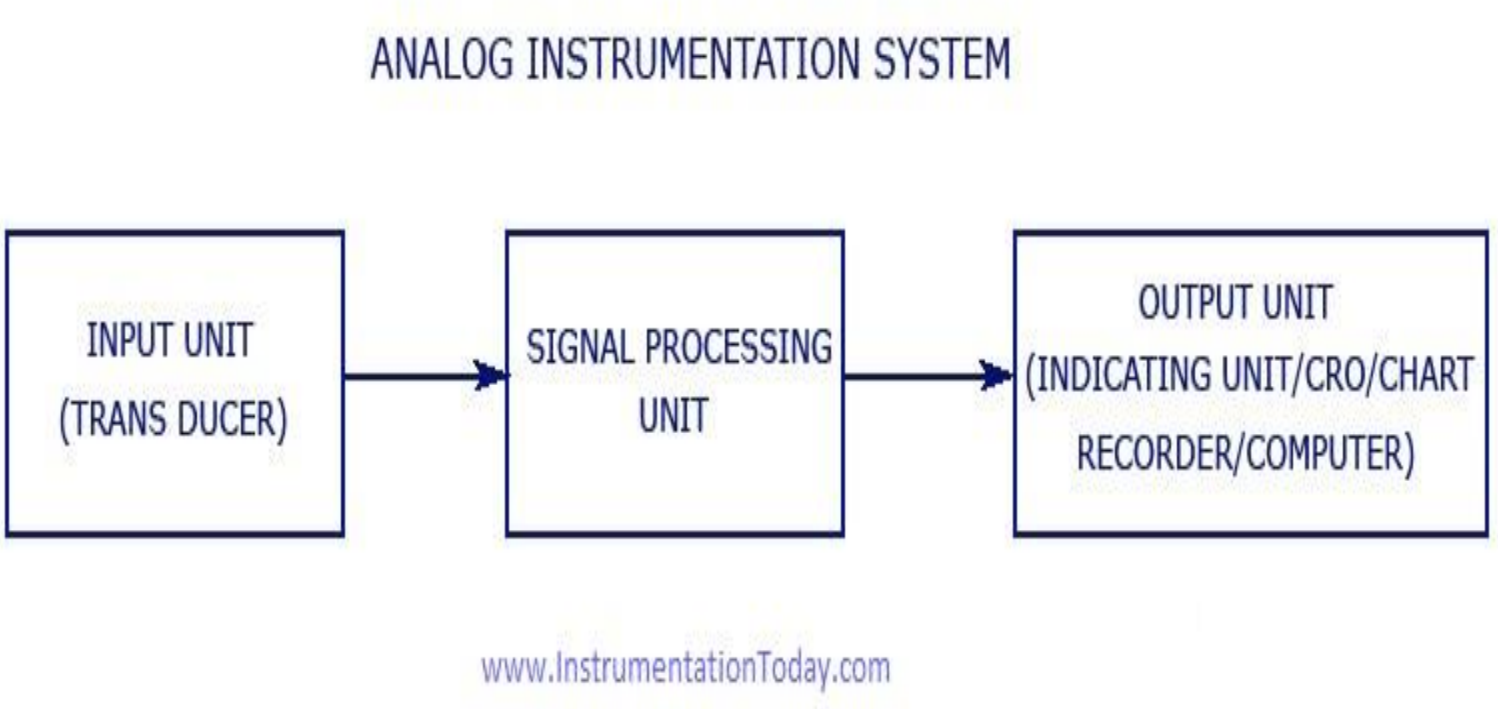
Definition

Analog instruments are those that **measure and display a continuous signal**, such as voltage, current, or temperature. The output varies smoothly over a range and is usually shown using a **pointer on a scale** (e.g., voltmeter, ammeter).

Characteristics

- Continuous signal representation
- Lower accuracy due to reading/parallax errors
- Prone to noise and signal degradation
- Simple construction and operation
- No need for analog-to-digital conversion

Analog Instrumentation System



Digital Instruments

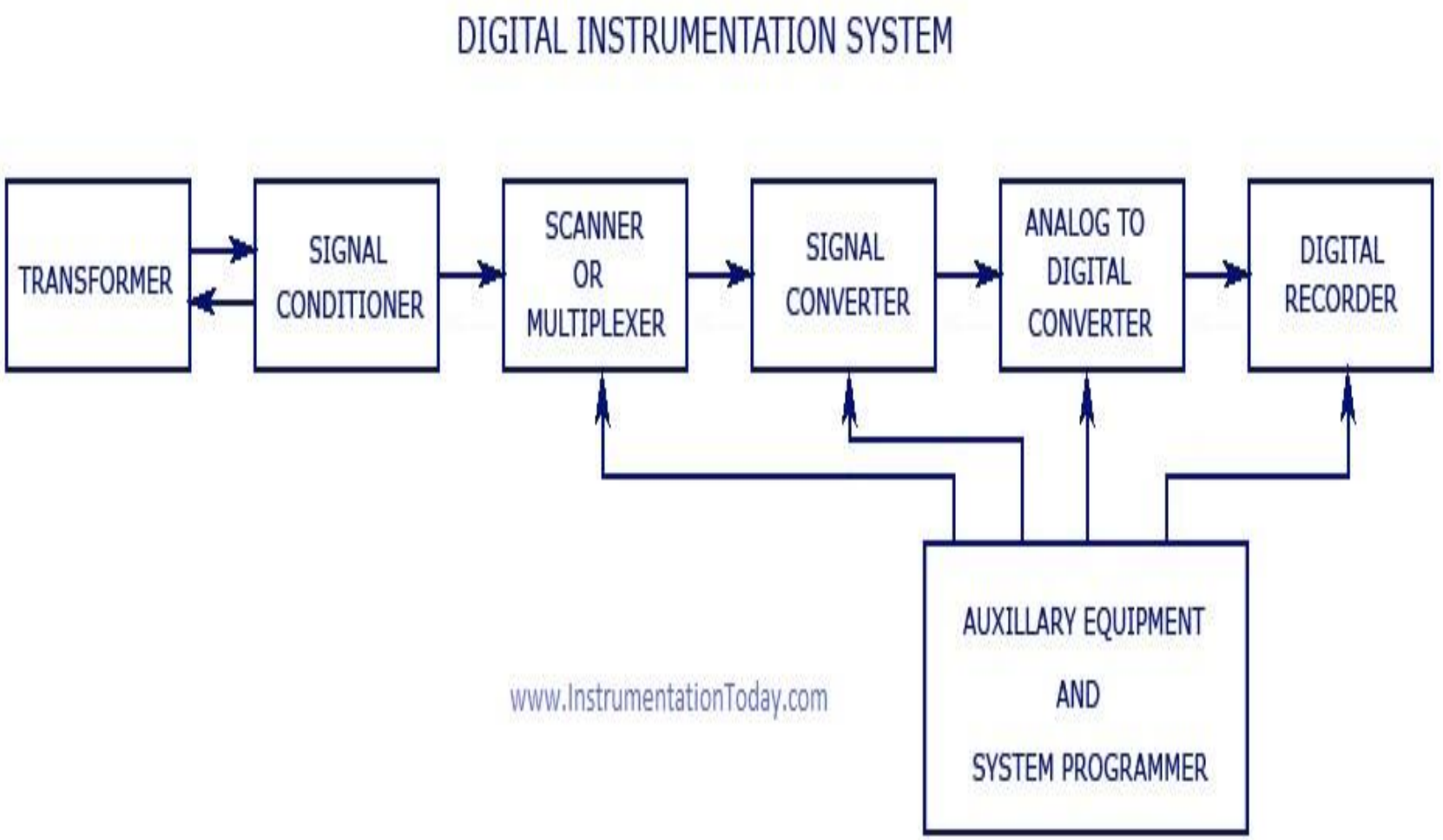
Definition

Digital instruments are those that **measure signals and convert them into digital form**, displaying the result in **numerical (digital) format**. They use microprocessors or microcontrollers to process data.

Characteristics

- Discrete (digital) signal representation
- High accuracy and precision
- Noise-resistant
- Uses analog-to-digital conversion
- Complex circuitry
- User-friendly digital display (LED/LCD)

Digital Instrumentation System



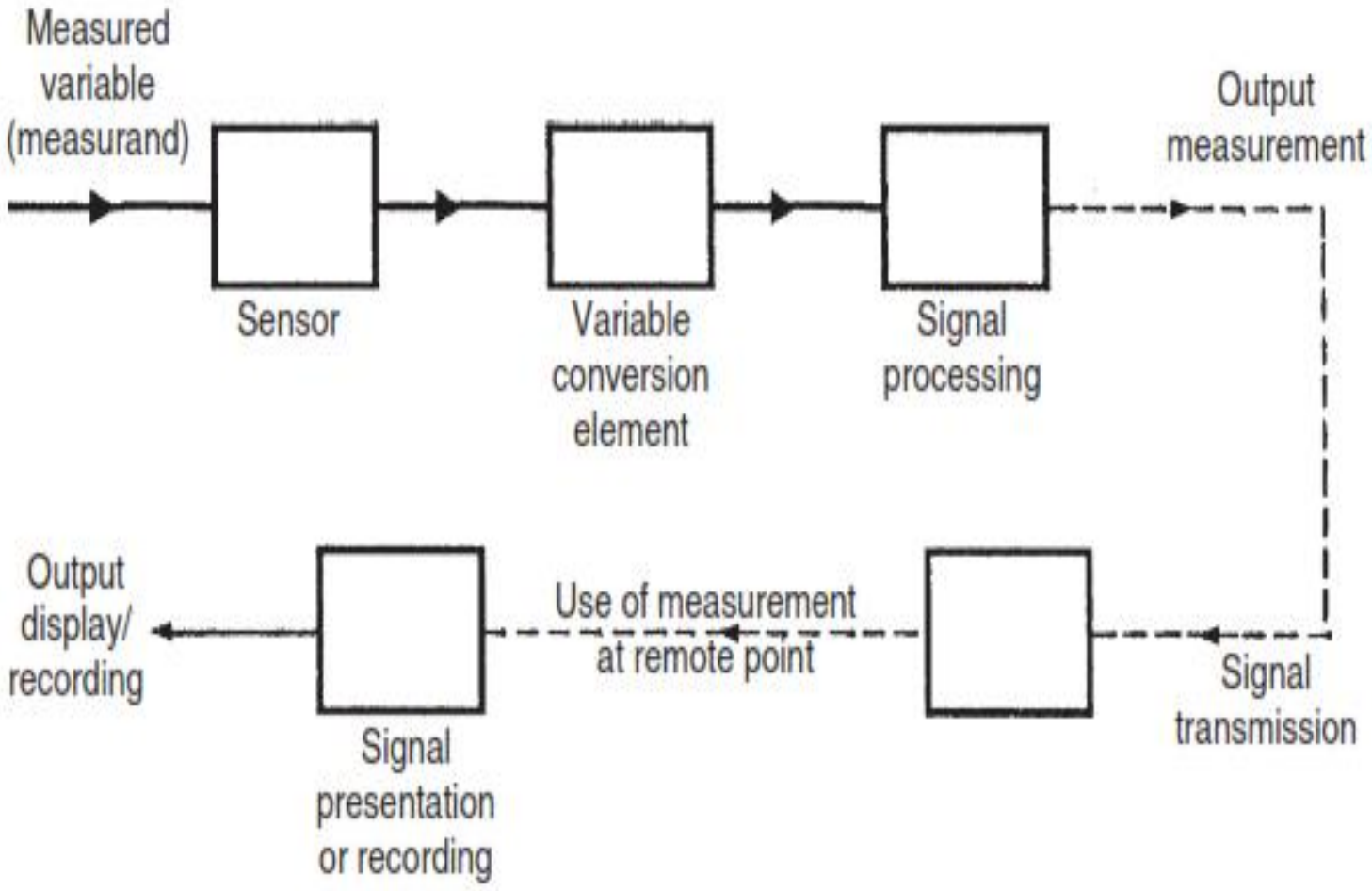
Difference: Analog and Digital Instruments

Feature	Analog Instruments	Digital Instruments
Signal Type	Continuous (Analog)	Discrete (Digital)
Display	Pointer/scale (dial type)	Numeric (LED/LCD display)
Accuracy	Lower (due to parallax and human error)	Higher (digital precision)
Sensitivity to Noise	More sensitive to electrical noise	Less sensitive due to digital processing
Response Time	Fast (in real-time)	Slightly delayed due to processing
Power Consumption	Generally low	Slightly higher due to internal circuits
Cost	Less expensive	More expensive
Size	Usually larger	Compact and portable
Maintenance	Easier to maintain	May require technical knowledge
Conversion Required	No conversion needed	Needs ADC (Analog to Digital Converter)

Advantages of Digital Instruments over Analog ones

- Detection of low-level signals
- High Input Impedance
- High Frequency Range
- Accuracy
- Better Resolution
- Storage capability

Functions / Elements / Components of Instrumentation / Measurement System



Primary Sensing Element (Sensor)

- The first element in any measuring system is the primary **sensor**: this gives an output that is a function of the **measurand** (the input applied to it).
- For most but not all **sensors**, this function is at least approximately linear.
- Some examples of primary sensors are a **liquid-in-glass thermometer**, a **thermocouple**, and a **strain gauge**.
- In the case of a **mercury-in-glass** thermometer, because the output reading is given in terms of the level of the mercury, this particular primary sensor is also a complete measurement system in itself.
- However, in general, the primary sensor is only part of a measurement system.
- The types of primary sensors available for measuring a wide range of physical quantities are presented later chapters.

Variable Conversion Elements

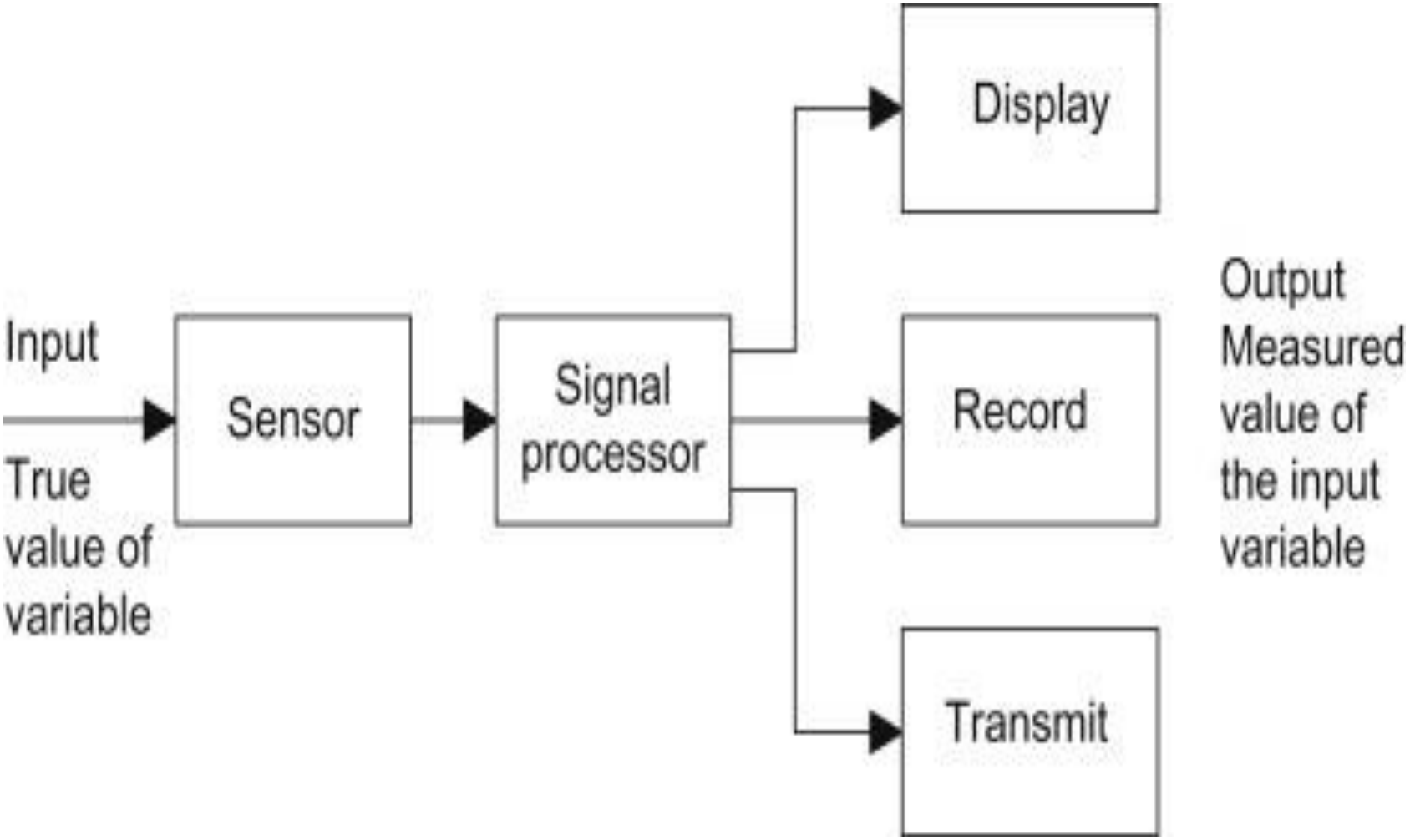
- Variable conversion elements are needed where the output variable of a primary **transducer** is in an inconvenient form and has to be converted to a more convenient form.
- For instance, the **displacement-measuring strain gauge** has an output in the form of a varying resistance.
- Because the resistance change cannot be measured easily, it is converted to a change in voltage by a bridge circuit, which is a typical example of a variable conversion element.
- In some cases, the primary sensor and variable conversion element are combined; this combination is known as a **transducer**.
- It may include **ADC**, **DAC**, **frequency to voltage conversion**, etc.

Signal Processing Elements

- Signal processing elements exist to improve the quality of the output of a measurement system in some way.
- A very common type of signal processing element is the **electronic amplifier**, which amplifies the output of the primary transducer or variable conversion element, thus improving the sensitivity and resolution of measurement.
- This element of a measuring system is particularly important where the primary transducer has a low output.
- For example, **thermocouples** have a typical output of only a few millivolts.
- Other types of signal processing elements are those that filter out induced noise and remove mean levels, etc.
- In some devices, signal processing is incorporated into a transducer, which is then known as a **transmitter**.

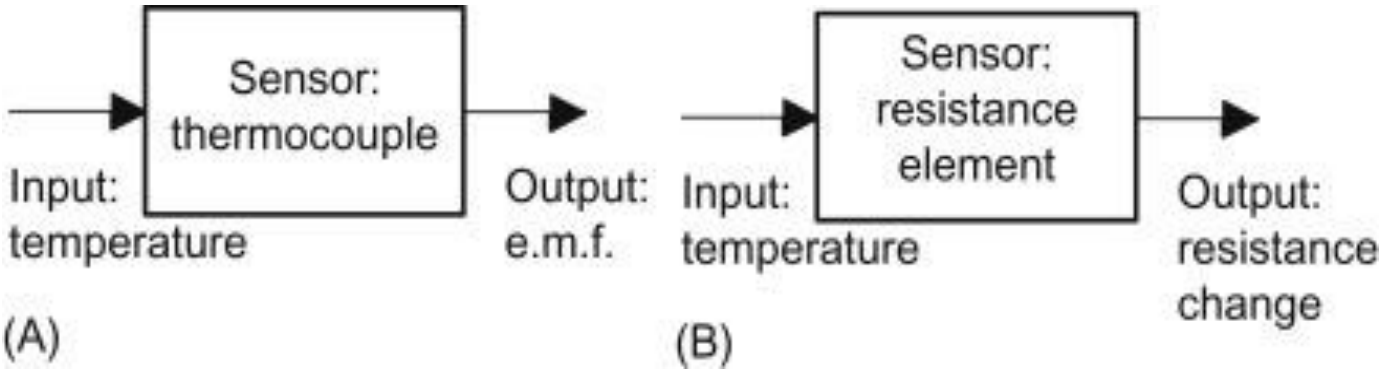
- In addition to these three components just mentioned, some measurement systems have one or two other components, first to **transmit** the signal to some remote point and second to **display** or **record** the signal if it is not fed automatically into a feedback control system.
- **Signal transmission** is needed when the observation or application point of the output of a measurement system is some distance away from the site of the primary transducer.
- Sometimes, this separation is made solely for purposes of convenience, but more often, it follows from the physical inaccessibility or environmental unsuitability of the site of the primary transducer for mounting the **signal presentation/recording unit**.
- The **signal transmission element** has traditionally consisted of single or multicored cable, which is often screened to minimize signal corruption by induced electrical noise.
- However, fiber-optic cables are being used in ever-increasing numbers in modern installations, in part because of their low transmission loss and imperviousness to the effects of electrical and magnetic fields.

The Constituent Elements of an Instrumentation System OR Measurement System Configuration



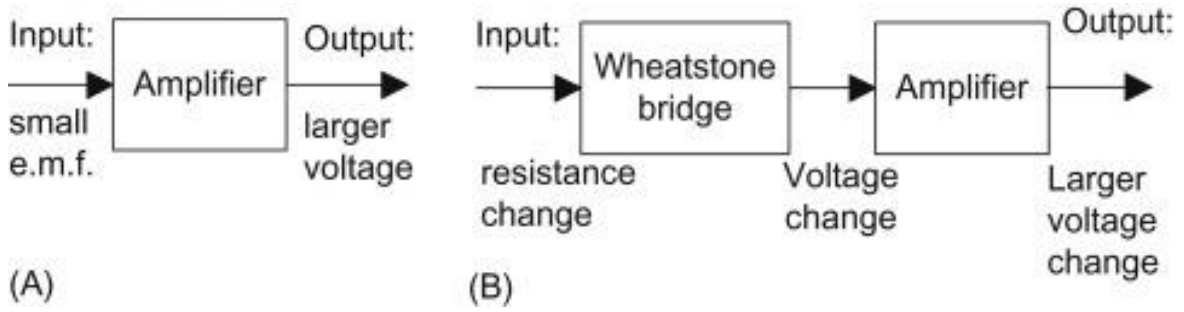
Sensor

- This is the element of the system which is effectively in contact with the process for which a variable is being measured and gives an output which depends in some way on the value of the variable and which can be used by the rest of the measurement system to give a value to it.
- For example, a **thermocouple** is a sensor which has an input of temperature and an output of a small e.m.f. which in the rest of the measurement system might be amplified to give a reading on a meter.
- Another example of a sensor is a **resistance thermometer element** which has an input of temperature and an output of a resistance change



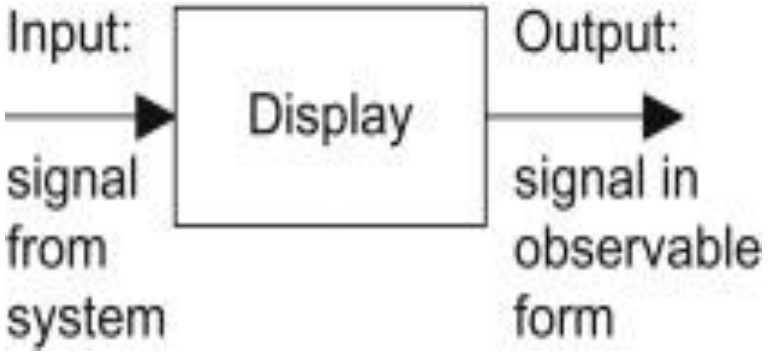
Signal Processor (and Signal Conditioner)

- This element takes the output from the sensor and converts it into a form which is suitable for display or onward transmission in some control system.
- In the case of the thermocouple this may be an amplifier to make the e.m.f. big enough to register on a meter.
- There often may be more than an item, perhaps an element which puts the output from the sensor into a suitable condition for further processing and then an element which processes the signal so that it can be displayed.
- The term ***signal conditioner*** is used for an element which converts the output of a sensor into a suitable form for further processing.
- Thus in the case of the resistance thermometer there might be a signal conditioner, such as a **Wheatstone bridge**, which transforms the resistance change into a voltage change, then an amplifier to make the voltage big enough for display or for use in a system used to control the temperature.



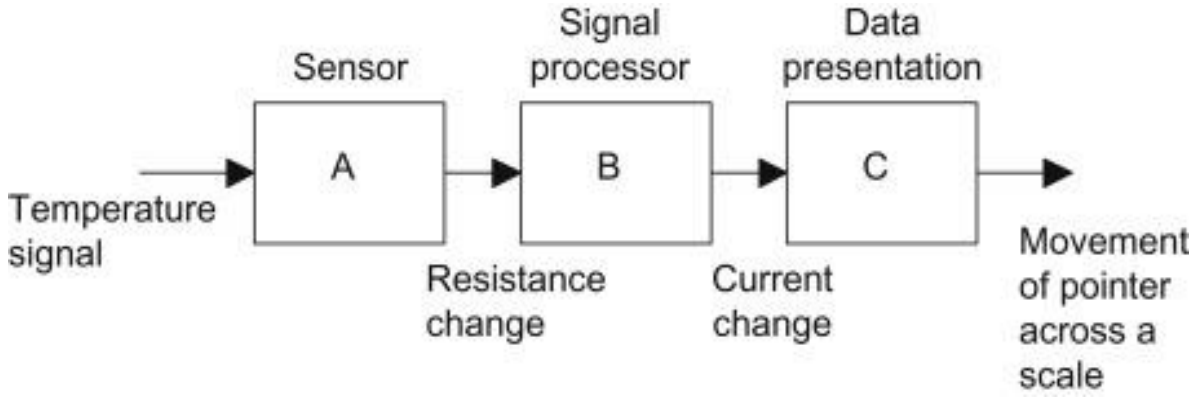
Data Presentation

- This presents the measured value in a form which enables an observer to recognise it.
- This may be via a display, e.g. a pointer moving across the scale of a meter or perhaps information on a **visual display unit** (**VDU**).
- Alternatively, or additionally, the signal may be recorded, e.g. in a computer memory, or transmitted to some other system such as a control system.

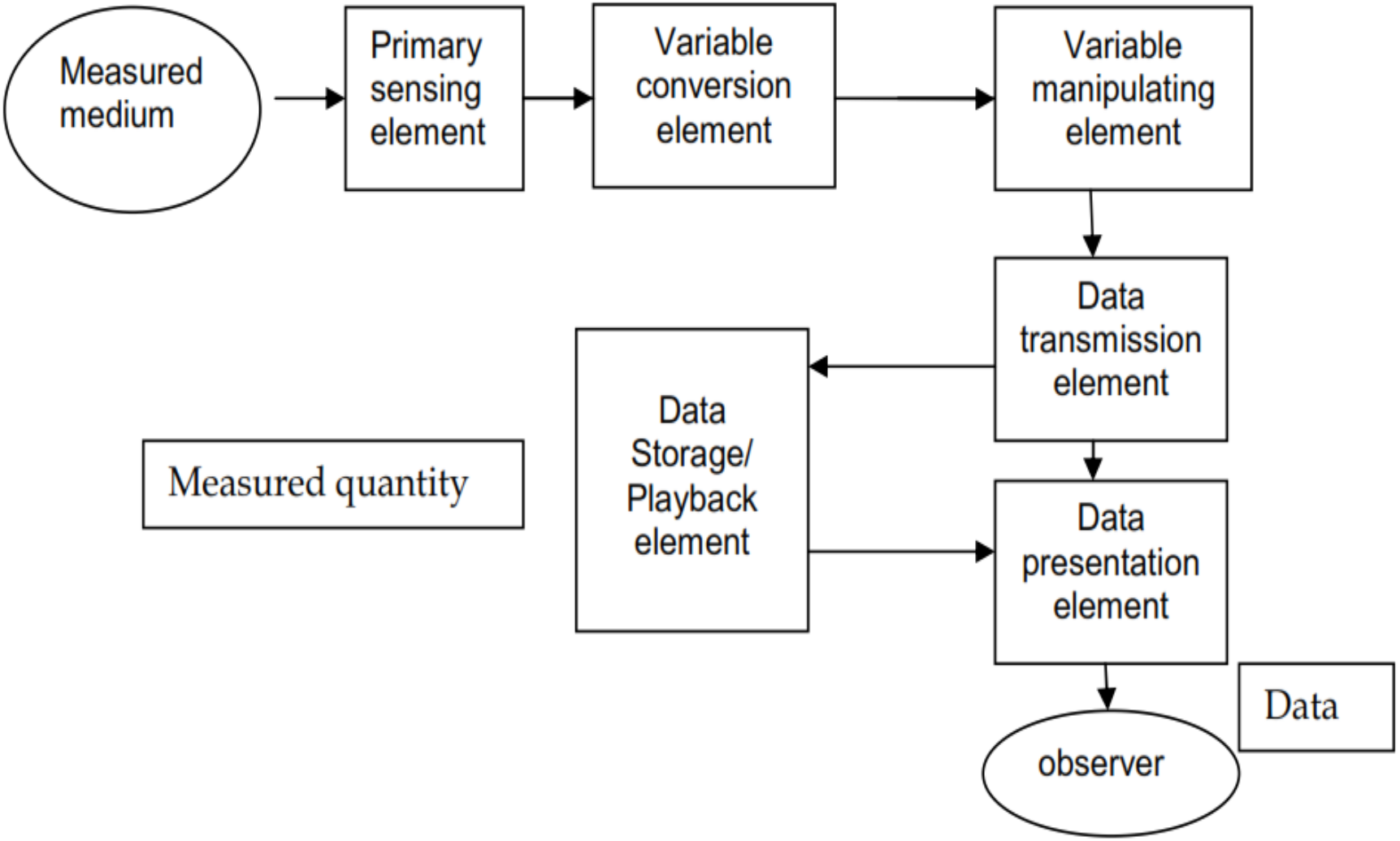


Example:

- With a resistance thermometer, element A takes the temperature signal and transforms it into resistance signal, element B transforms the resistance signal into a current signal, element C transforms the current signal into a display of a movement of a pointer across a scale.
- Which of these elements is (a) the **sensor**, (b) the **signal processor**, (c) the **data presentation**?
- The sensor is element **A**, the signal processor element **B**, and the data presentation element is **C**. The system can be represented by Figure.



Functions / Elements / Components of Instrumentation / Measurement System (Alternative)



Primary Sensing Element

- This is the element that first receives energy from the measured medium and procedures an output depending un some way on the measured quantity (measured).
- The output is some physical variable e.g displacement or voltage.
- An instrument always extract some energy from the measured medium.
- The measured quantity is always disturbed by the act of measurement, which makes a perfect theoritically impossible.
- Good instruments are designed to minimize this loading effect.

Variable Conversion Element

- If may be necessary to convert the output signal of the primary sensing element to another more suitable variable while preserving the information content of the original signal.
- This element performs this function.

Variable manipulation element

- An instrument may require that a signal represented by some physical variable be manipulated by some way.
- By manipulation we mean specifically a change in numerical value according to some definite rule but a preservation of the physical nature of the variable.
- This element performs such a functional signal.
- This element performs this function.

Data-Transmission Element

- When functional elements of an instrument are actually physically separated, it becomes necessary to transmit the data from one to another. This element performs this function.

Data presentation element

- If the information about the measured quantity is to be communicated to a human being for monitoring, control, or analysis purposes, it must be put into a form recognizable by one of the human senses. This element performs this ‘translation’ function.

Data Storage/Playback Element

- Some applications require a distinct data storage/playback which can easily recreate the stored data upon command.

Microprocessor

- A Microprocessor is a multipurpose programmable, clock driven, register based electronic device fabricated using signal integrations from SSI to VLSI that reads binary instructions from a storage device called memory, accepts binary data as input, processes data according to those instructions and provide result s as output.

Instrumentation System

- The system which is defined as the assembly of various instruments and other components interconnected to measure, analyze and control physical quantities such as electrical, thermal, mechanical etc.

Microprocessor based Instrumentation System

- Any instrumentation systems centered around a microprocessor are known as microprocessor based system. Logical and computing power of microprocessor has extended the capabilities of many basic instruments, improving accuracy and efficiency of use. Microprocessor is versatile device for use in any instrumentation system. Examples are ATM, automatic washing machine, fuel control, oven etc.

Why microprocessor?

- Can be used in any system.
- Can be used in specific applications and specific design.
- Logical and computational power of microprocessor has been used to develop more accurate and efficient system

Why not Microprocessor?

- Complexity in interfacing.
- Need to learn complex machine dependent language.
- Need of an expensive microprocessor development system.
- But all these problems are accepted if system designed sells a number of units so that the development cost spreads out.

Features for selecting microprocessor

- How fast the data has to be processed
- Cost-amount of memory intelligence
- Complexity of work
- Field for which system is designed

Basic Features of Microprocessor Based System

- Three components: Microprocessor, I/O, and memory
- Decision making power based on previous entered values
- Repeatability of readings
- User friendly (Signal readout)
- Parallel processing
- Timeshare and multiprocessing
- Data storage, retrieval and transmission
- Effective control of multiple equipments on time sharing basis
- A lot of processing capability

Open Loop and Closed Loop Microprocessor Based System

- Any instrumentation system can be controlled by microprocessor in two ways: open loop control system and closed loop control system.

Open loop control system

- Microprocessor gives output of control variable in the form of some display to human operator and then on the basis of displayed information, the human operator makes changes in the necessary control inputs.
- Example: pressure and temperature monitoring system in any chemical processing plant
- It is simple, low cost and used when feedback is not critical.

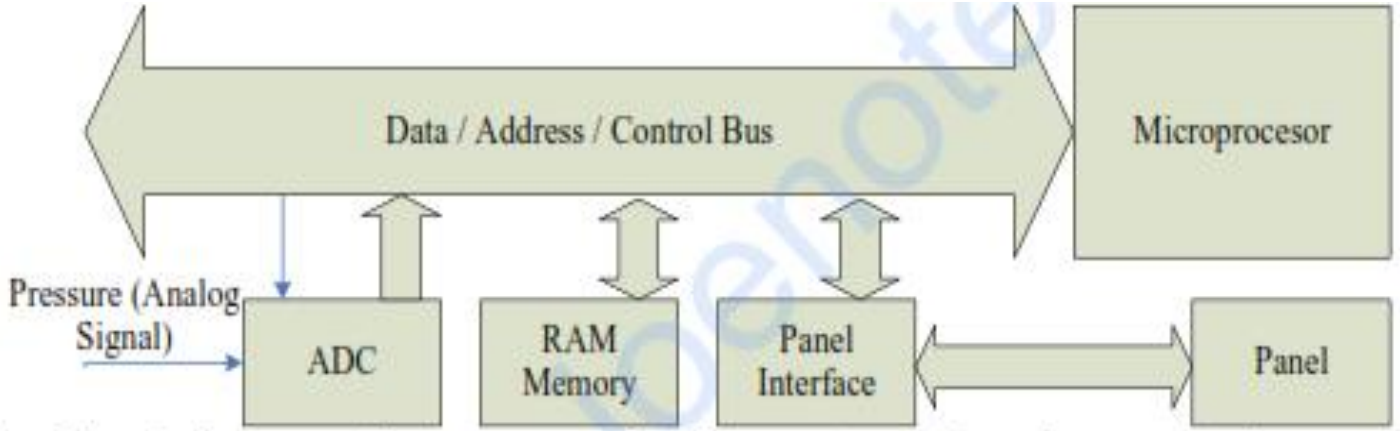


Fig: Block diagram of pressure monitoring system - Open loop control

- Upper and lower limit of desired pressure is set
- Pressure is converted to digital form to be fed to microprocessor
- The microprocessor compares a sample of pressure measurement with present pressure limits.
- If sample is beyond limits, the microprocessor indicates in form of come alarm or lamp.
- So, according to output signal, human operator makes necessary changes.

Closed loop control system

- Microprocessor monitors the process variables continuously and then supplies the output signal to the electromechanical devices, which in turn controls the values of process variables.
- Example: automatic temperature control system in an oven
- Accurate and Adaptive
- No human operator required

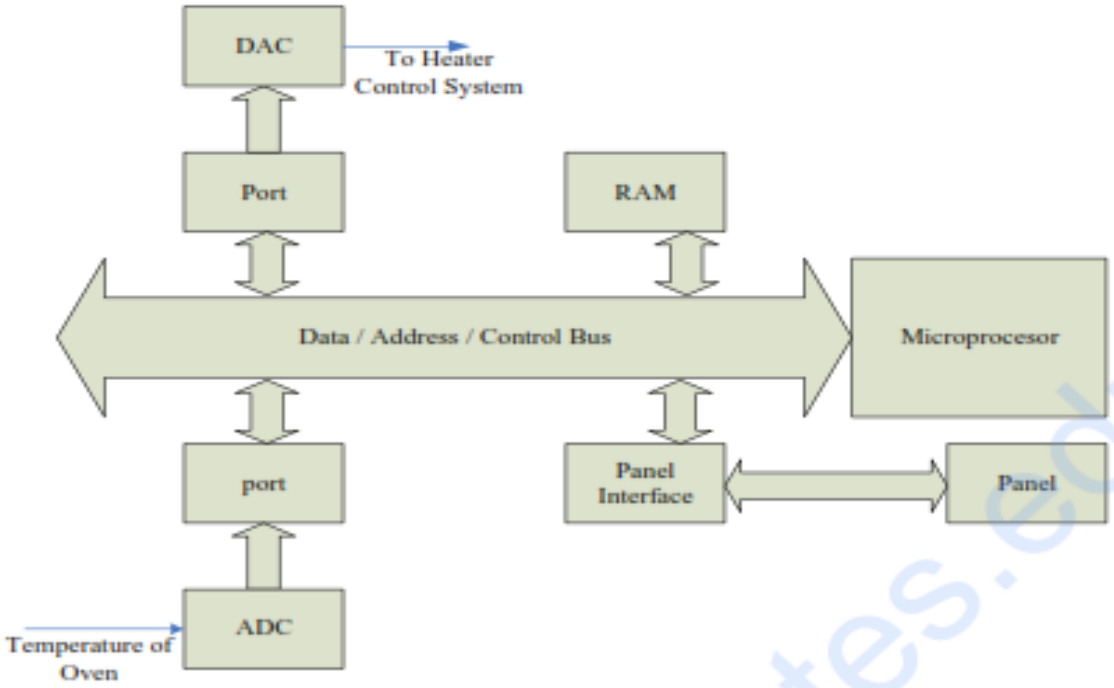


Fig: Block diagram of automatic temperature control system – Closed loop control

- In microprocessor, upper and lower limits of temperature are set.
- Every sample of temperature measurement from transducer is compared by the processor.
- If temperature exceeds the preset higher limit, the microprocessor transmits an output signal to a system which in turn turns off the supply to some of the heater elements.
- If temperature is less than the preset lower limit, the microprocessor transmits signal to system so that it turns on the supply to the heater element of the oven.

Microcomputer on Instrumentation Design

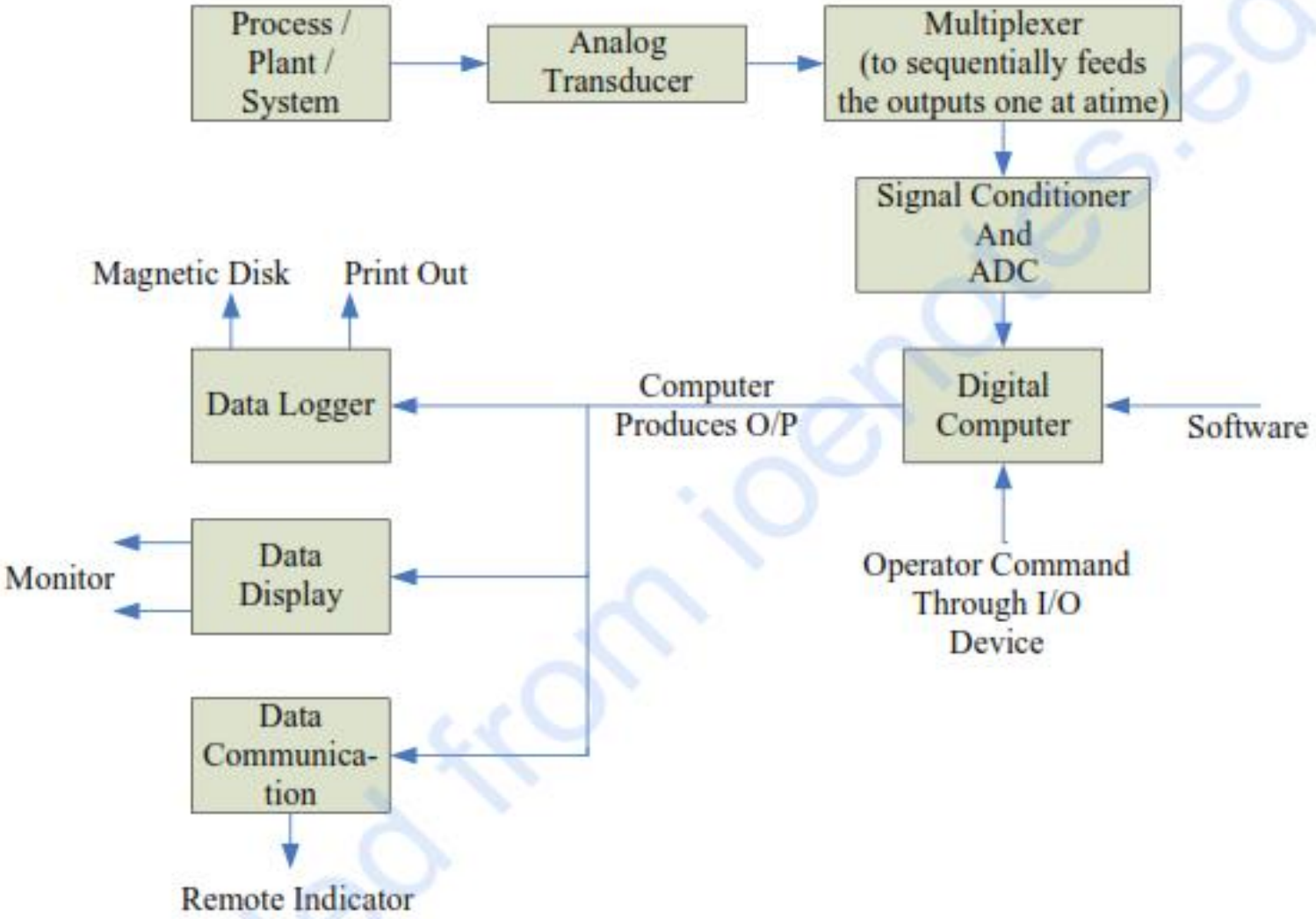


Fig: A typical digital computer based instrumentation system

- A process or plant or system may have to simultaneously measure multiple variables like pressure, temperature, velocity, viscosity, flow rate etc. A computer based measurement system has the capability of processing all inputs and present the data in real time. A digital computer is fed with a sequential list of instructions termed as computer program for suitable processing and manipulation of data.

Advantages:

- Suitably programmed to automatically carry out the mundane tasks of drift correction, noise reduction, gain adjustments, automatic calibration etc.
- These instruments have signal conditioning and display which are compact, rugged and reliable and are suited for performing in wide conditions like industrial, consumer, military, automobile etc.
- Built in diagnostic subroutines to detect only or detent and correct.
- Real time measurement, processing and display.
- Lower cost, higher accuracy, and more flexibility.

Disadvantages:

- They cannot replace the program themselves.
- Software update
- Prone to virus problem, so may become in-operational.