Instrumentation (ENEX 252)

(BCT – II/II)

Chapter 1
Introduction

Measurement

Measurement is a technique in which the properties of an object are determined by comparing them to a standard quantity. Also, measurement is the essential metric to express any quantity of objects, things and events. Measurement system or Instrumentation system is the means to carry out measurement.

Instruments

Some devices are used for measuring the physical quantities such as temperature, pressure, and so on, which are called as instruments. Instruments are basically classified into two types

- Analog Instruments
- Digital Instruments

Analog Instruments

The instrument which gives output that varies continuously as quantity to be measured is known as analog instrument. Analog voltmeter, Analog Ammeter, needle type speedometer etc. are the example of analog instruments.

Block diagram of Analog Instruments

The figure shows block diagram of an analog instrument that includes three functional units.

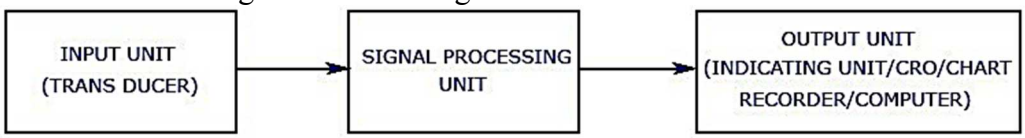


Figure: Block diagram of Analog Instrument

Input Unit/Transducer: The input receives the quantity whose value is to be measured and is converted into its proportional incremental electrical signal such as voltage, current, resistance change, inductance or even capacitance. Thus, the changed variable contains the information of the measured variable. Such a functional element or device is called a transducer.

Signal Processing Unit: The output of the transducer is provided to the input of the signal processing unit. This unit amplifies the weak transducer output and is filtered and modified to a form that is acceptable by the output unit. Thus this unit may have devices like: amplifiers, filters, analog to digital converters, and so on.

Output Unit: The output from the signal processing unit is fed to the input of the output unit. The output unit measures the signal and indicates the value to the reader. The indication may be either through: an indicating instrument, a CRO, digital computer, and so on.

Characteristics of Analog Instruments:

There are some characteristics of Analog instruments

- **Continuous Output:** Analog instruments provide continuous and real-time output, which allows for smooth and immediate observation of changes in the measured quantity.
- **Direct Reading:** They often feature direct reading scales, where the magnitude of the quantity being measured is directly indicated by the position of a pointer on a scale or the position of a graph.
- **Suitability for Analog Signals**: Analog instruments are well-suited for measuring and displaying analog signals directly, without the need for digitization or conversion.
- **Less Complex:** Analog instruments are generally simpler in design and operation, making them suitable for basic measurements and environments
- **Response Time:** They typically have fast response times, allowing them to show rapid changes in the measured quantity almost instantaneously.

Digital Instruments

The instrument which gives output that varies in discrete steps and only has finite number of values is known as digital instrument. Digital multimeter, digital ammeter and voltmeter, clamp-meter are the example of digital instruments.

Block diagram of Digital Instruments

The figure shows block diagram of digital instrument.

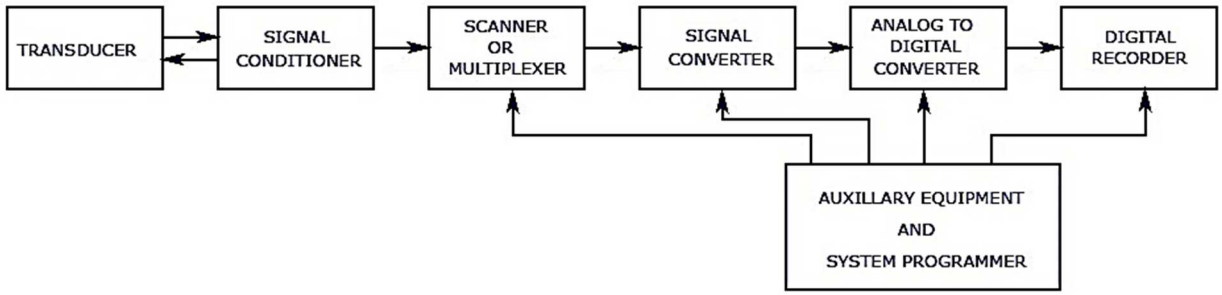


Figure: Block diagram of Digital Instrument

Transducer: All the physical input parameters like temperature, pressure, displacement, velocity, acceleration and so on will be converted into its proportionate electrical signal.

Signal Conditioning Unit: The working of this unit is exactly the same as that of a signal processing unit in an analog instrumentation system. It includes all the balancing circuits and calibrating elements along with it.

Scanner/Multiplexer: Multiple analog signals are received by this device and are sequentially provided on to a measuring instrument.

Signal Converter: It is used to convert an analog signal to a form that is acceptable by the analog to digital converter.

Analog to Digital Converter (ADC): The analog signal is converted into its proportional digital signal. The output of an ADC is given to a digital display.

Auxiliary Equipment: All the system programming and digital data processing functions are carried out by this unit. The auxiliary equipment may be a single computer or may be a collection of individual instruments. Some of its basic functions include linearizing and limit comparison.

Digital Recorder: It is mostly a CRO or a computer.

Characteristics of Digital Instruments:

- **Discrete Output:** Provides output in numerical form (e.g., 24.7°C), rather than on a scale.
- **Higher Accuracy:** More precise readings due to digital processing and reduced human error.
- **Memory and Storage:** Can store readings for later retrieval or analysis (e.g., data loggers).
- **Less Susceptible to Noise:** Better immunity to electrical noise compared to analog instruments.
- **Complex Design:** Involves microprocessors, software, and digital logic circuits.
- **Auto-ranging and Smart Features:** Many digital instruments can automatically adjust their range and provide features like max/min, average, hold, etc.

- **Low Power Consumption:** Often designed to consume less power, especially handheld devices.
- **Interface Capability:** Can be interfaced with computers or networks for data transmission.

Difference between Analog and digital instruments

There are some major differences between analog and digital instruments

Feature	Analog Instrument	Digital Instrument
Output Type	Continuous	Discrete (digital value)
Accuracy	Moderate	High
Readability	Subjective	Clear, numerical
Noise Sensitivity	High	Low
Complexity	Simple	More complex

Instrumentation System or Measurement system

It is branch of engineering which deals with various types of instrument to record, monitor, indicate and control various physical parameters such as pressure, temperature, etc. CT scan machine, MRI machine etc. are the example of Instrumentation system.

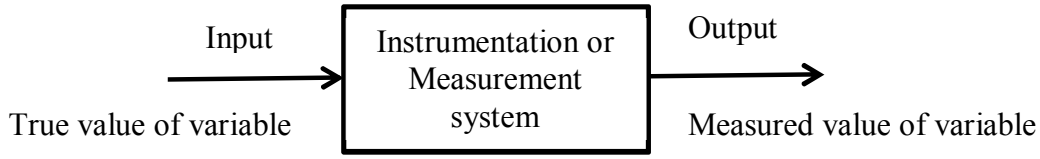


Figure: A simple block diagram of the instrumentation or measurement system.

Block diagram of Instrumentation system (Functional element or components of instrumentation/ measurement system)

It is branch of engineering which deals with various types of instrument to record, monitor, indicate and control various physical parameters such as pressure, temperature, etc. The figure shows the general block diagram of instrumentation system. It consists of primary sensing element, variable conversion element, variable manipulation element, data transmission element and data presentation element.

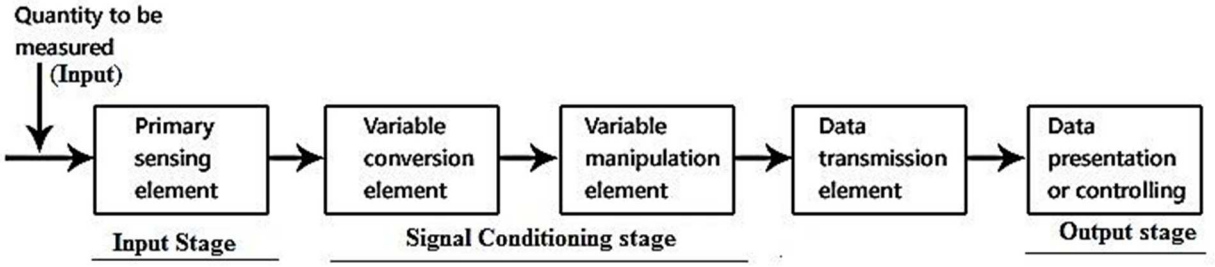
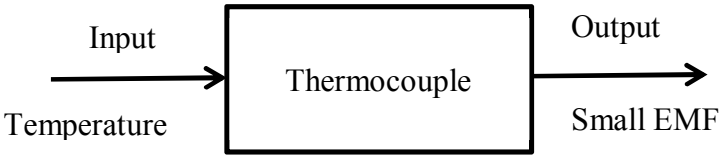


Figure: Block diagram or functional components of instrumentation system

Primary Sensing Element

The primary sensing element is also known as sensor. Basically transducers are used as a primary sensing element. Here, the physical quantity (such as temperature, pressure etc.) are sensed and then converted into analogues signal. Example:- Thermocouple, which has input as temperature and output as the small emf, Strain gauge, LVDT etc.



Variable Conversion Element

The output of the primary sensing element may be electrical signal of any form. It may be voltage or current or frequency or some other electrical parameter. Sometimes this output is not suited to the system so it converts the output of primary sensing element into suitable form without changing information. Basically these are secondary transducers.

Example:- Variable conversion involves, Analog to digital conversion, digital to analog conversion, AC to DC or DC to AC conversion, Frequency to voltage conversion etc.

Variable Manipulation Element

The function of this element is to manipulate the signal presented to it preserving the original nature of the signal. Here, manipulation means change in numerical value of signal. Signal amplification and attenuation task is performed in the variable manipulation element/unit of instrumentation system.

The combined form of variable conversion and variable manipulation is known as the signal conditioning element. The signal conditioning may be linear and nonlinear.

- **Linear:** Amplification, Attenuation, Integration, Differentiation, Addition, Subtraction etc.
- **Non-Linear:** Modulation, Demodulation/detection, Sampling, Filtering, Chopping and clipping etc.

Data Transmission Element

The element that transmit data from one unit to another is called a data transmission element. Data transmission is done either through a wire or wireless transmission media. The signal conditioning and transmission stage is commonly known as Intermediate stage of the instrumentation system and their position may be interchanged in the block diagram.

Data Presentation or Controlling Element

The information about the quantity under measurement has to be conveyed to the personnel handling the instrument or the system for monitoring, control, or analysis purposes. The information conveyed must be in a form intelligible to the personnel or to the intelligent instrumentation system. This function is done by data presentation element.

The data presentation element may be Video display unit (VDU) or the recorder (e.g. - X-Y plotter, Strip-chart recorder) or data may be transmitted to any control circuit so that it can be compared with required value.

Measurement system configuration

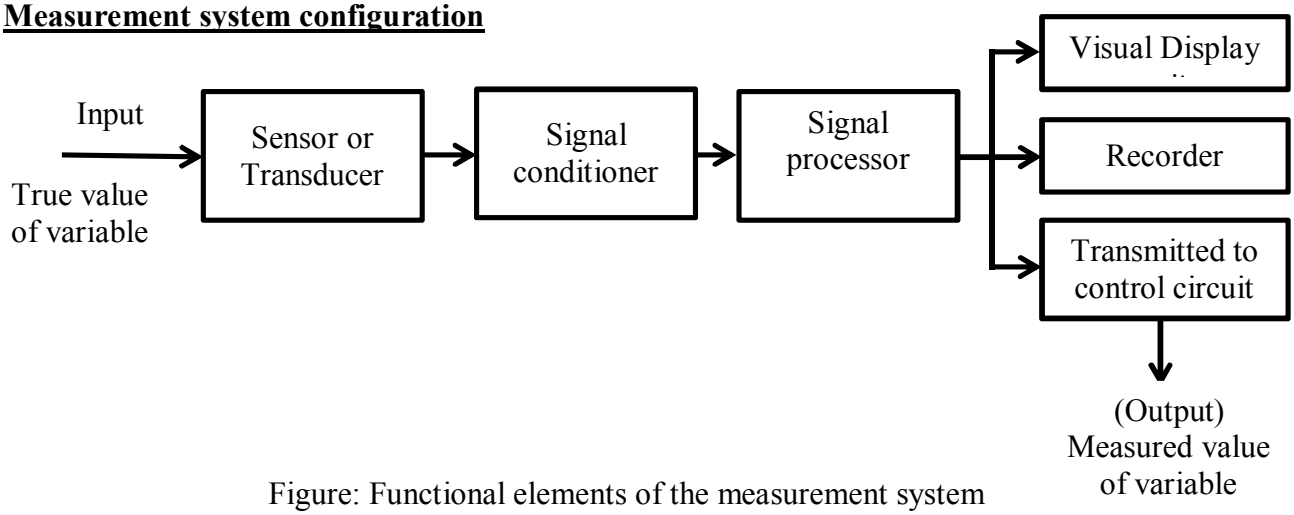


Figure: Functional elements of the measurement system

There are the four basic functional element of the measurement system and they are Sensor or transducer, signal conditioner, signal processor and data presentation element.

Sensor or Transducer

Transducer is a device that converts one form of energy into other form. For Example: Thermocouple which has input of temperature and output of small EMF, Resistance thermometer has input of temperature and output of Resistance change.

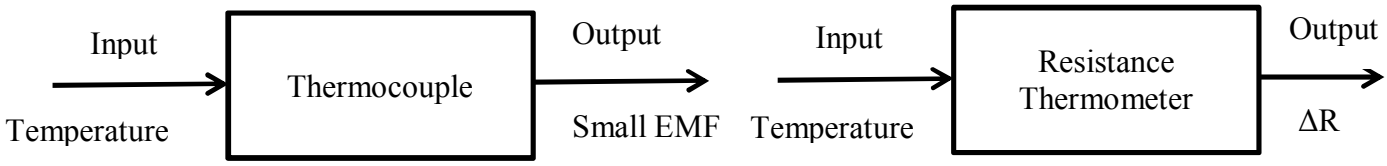


Figure: Block of sensor or transducer

Signal Conditioner

The signal conditioner puts the element from a sensor into a suitable condition for processing so that it can be displayed. In the case of Thermocouple, the signal conditioner may be an amplifier to make the signal large. In the case of resistance thermometer, there might be a Wheatstone bridge which transforms the resistance into a voltage change and then an amplifier to make the voltage large.

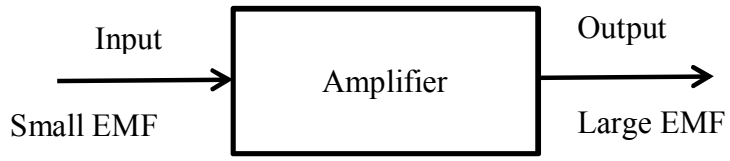


Figure: Block of signal conditioning (variable manipulations)

Signal Processor

The output from a signal conditioner is generally either a DC voltage/Current or variable frequency AC voltage. It is taken by signal processor and is then filtered from a subtracted, added, multiplied, divide, differentiated, integrated or compared, so as to bring out the desired data. Examples of signal processor are Analog to digital converter and filter.

Figure: Block of signal conversion

Data presentation

Those present a measured value in a form which enables an observer to recognize it. These may be done through DVC or through recorder or data may be transmitted to any control unit or circuit so that it can be compared with the required value.

<u>Microprocessor Based Instrumentation System</u>

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.

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.

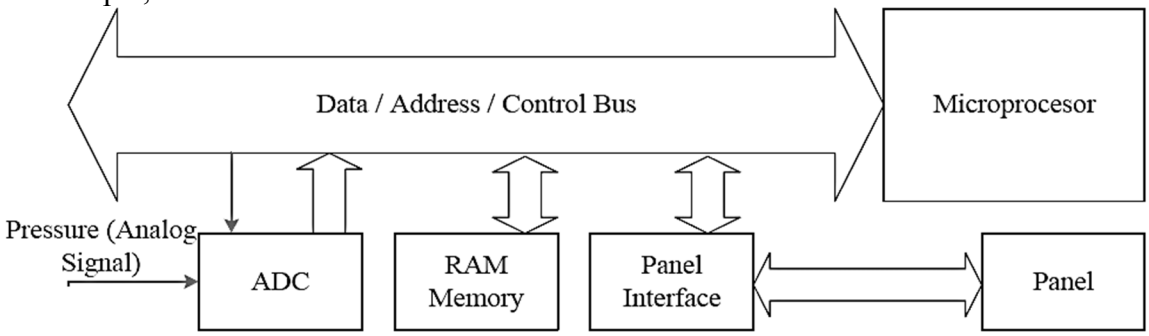


Figure: Block diagram of pressure monitoring system - Open loop control

- 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

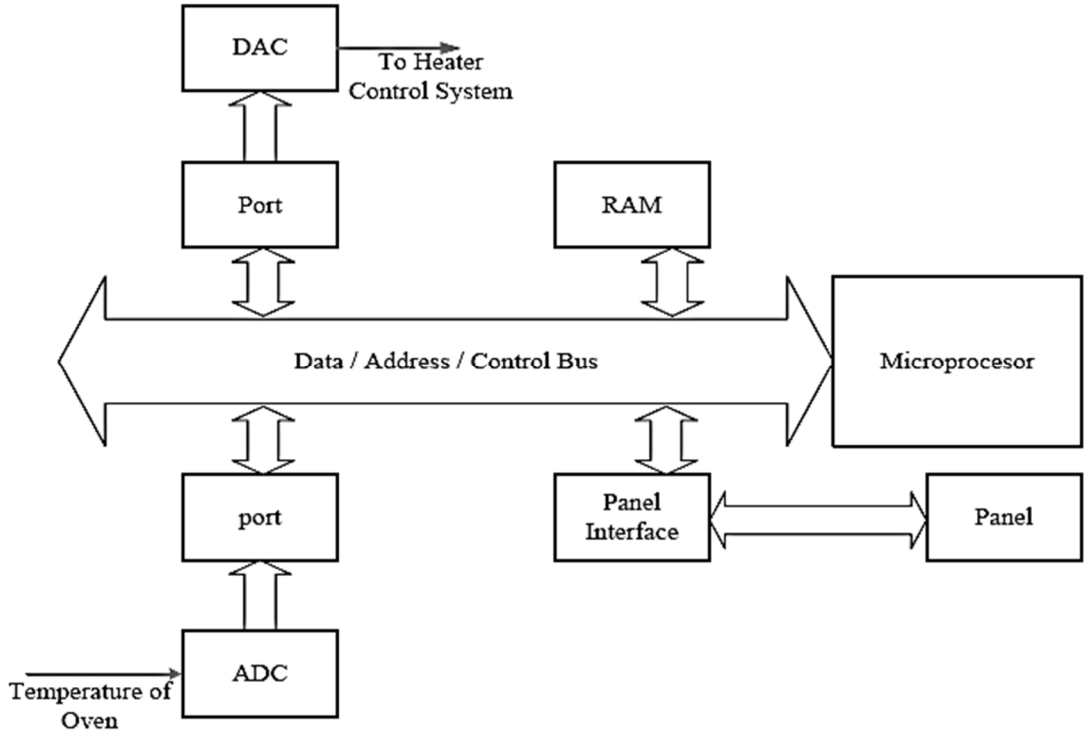


Figure: Block diagram of automatic temperature control system – Closed loop control

- Accurate and Adaptive
- No human operator required
- 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.

Benefits of Microprocessor Based System

- Complete automation
- Added intelligence
- Reduced manpower
- Flexibility to modify
- Economic design
- Reduced circuit complexity
- Reduced operating costs (eg. Fuel savings)
- Reduced product wearing; furnish more uniform operation; tighter control enforce ment.
- Improved responsiveness to changes in process: production rates, product specifications, addition of new products.
- Incorporate strategies to minimize production upsets; resulting from plant equipment failures by anticipated process conditions and improved plant safety.
- Improved timely information to plant operation and maintenance managers to enable them to keep a plant running longer and more efficiently.
- Improved integration and interaction of plant operation through coordinated strategy.
- Relational database management
- Statistical process control capabilities
- Information exchange with other plant system for process synchronization.

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

Applications of Microprocessor-Based System in Instrumentation Design

Microprocessor-based systems are extensively used in instrumentation design across various fields due to their versatility, processing power, and ability to interface with different sensors and actuators.

- **Data Acquisition Systems:** Microprocessors gather data from sensors (temperature, pressure, flow, etc.) and convert analog signals to digital for processing and transmission.
- **Control Systems:** Used in closed-loop control systems to regulate parameters like temperature, speed, and pressure by processing sensor data and adjusting actuators accordingly.

- **Monitoring and Supervisory Systems:** Employed in monitoring critical parameters in industrial processes, environmental conditions, and infrastructure.
- **Embedded Systems:** Integrated into devices for specific functions like medical instruments, automotive systems (engine control units), and consumer electronics.
- **Signal Processing:** Utilized in real-time processing of signals (audio, video) for applications such as digital signal processing (DSP) in communications and image processing.
- **Communication Interfaces:** Facilitate communication between different devices and systems using protocols like UART, SPI, I2C, and Ethernet, crucial in networking and IoT applications.
- **Testing and Measurement Equipment:** Found in oscilloscopes, spectrum analyzers, and multimeters for accurate measurement and analysis of electrical signals and parameters.
- **Automated Testing Systems:** Used in manufacturing for automated testing of products, ensuring quality control and efficiency.
- **Robotics and Automation:** Control of robotic systems in manufacturing, logistics, and even in home automation for tasks ranging from assembly lines to smart home devices.
- **Biomedical Instrumentation:** Monitoring vital signs, controlling medical devices, and processing medical imaging data for diagnosis and treatment.

Microcomputer on Instrumentation Design

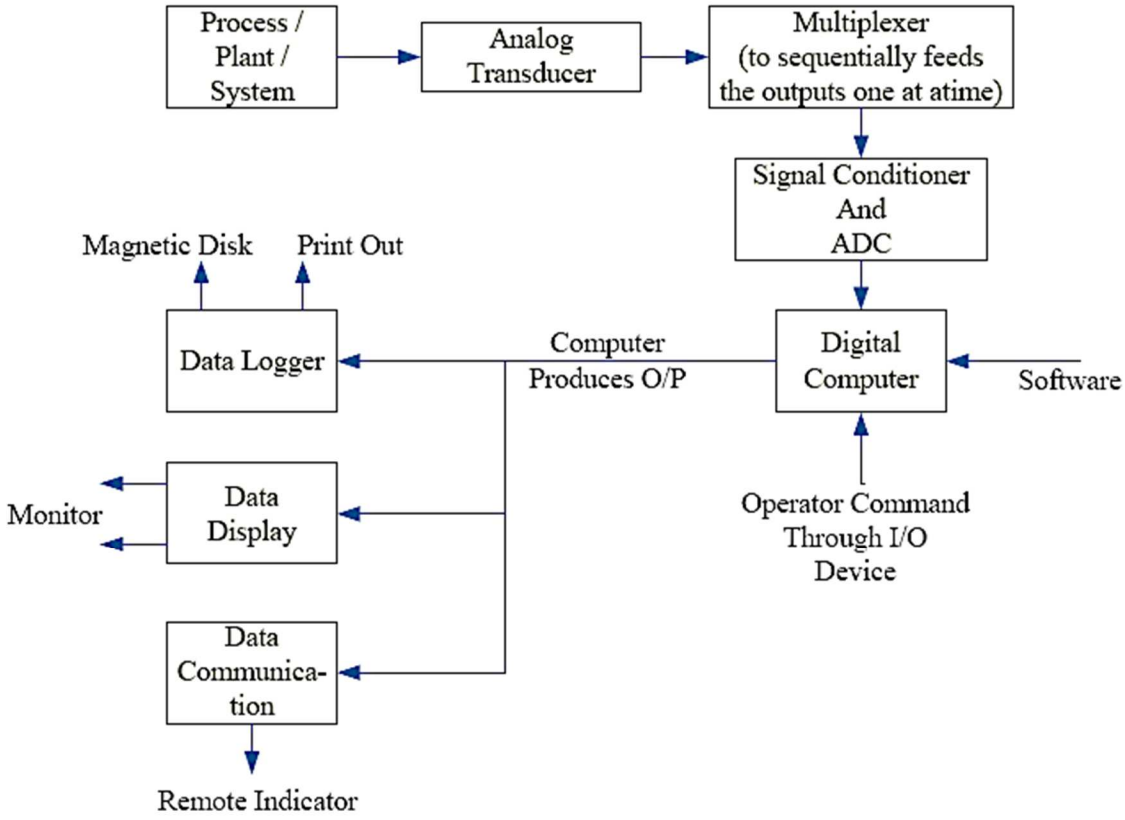


Figure: A typical digital computer based instrumentation system

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.