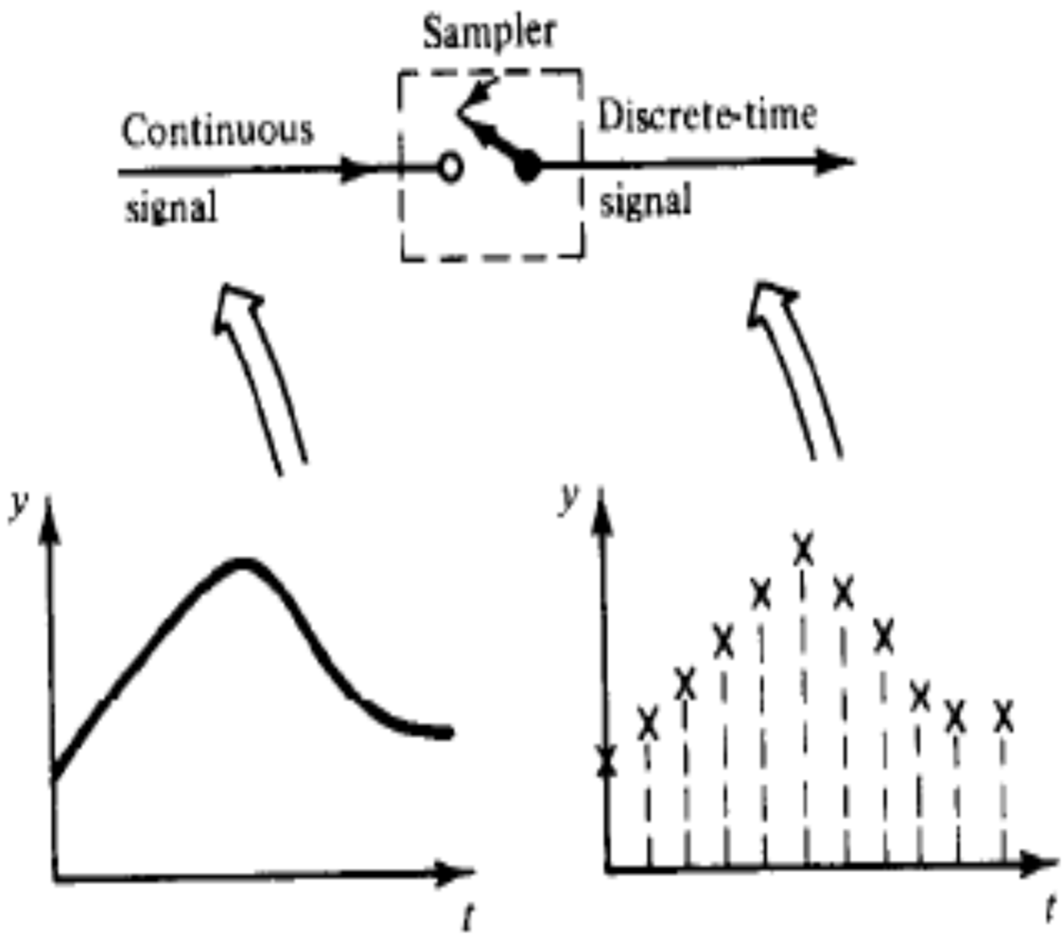
Computer-process interface for data acquisition and control

- In direct computer control individual controllers are replaced by digital computer.
- The feedback, P, PI, PID control functions will be performed by an executable program in BASIC, FORTRAN, assembly language, etc.
- The control programs receive the input data from measured output and estimate the output result as manipulated variables to control the process.
- For a digital computer *both input data and output results are in digital form and correspond to discrete time value*.

Samplers

- Flow rates, pressures, liquid levels, temperatures, etc, are provided continuously by the various sensors and transducers.
- The computer can handle information on a discrete time basis.
- Sampler is a switch which closes at specific time intervals within which the continuous signal is converted into sampled values. Each sampled value is used by the computer control algorithm to give output result within the specific time interval of sampling.
- If during this period (reading value, calculating error and making a control action) measured value changed, it is not recognized by the computer.

Cont.


Sampler
Continuous
signal
Discrete-time
signal
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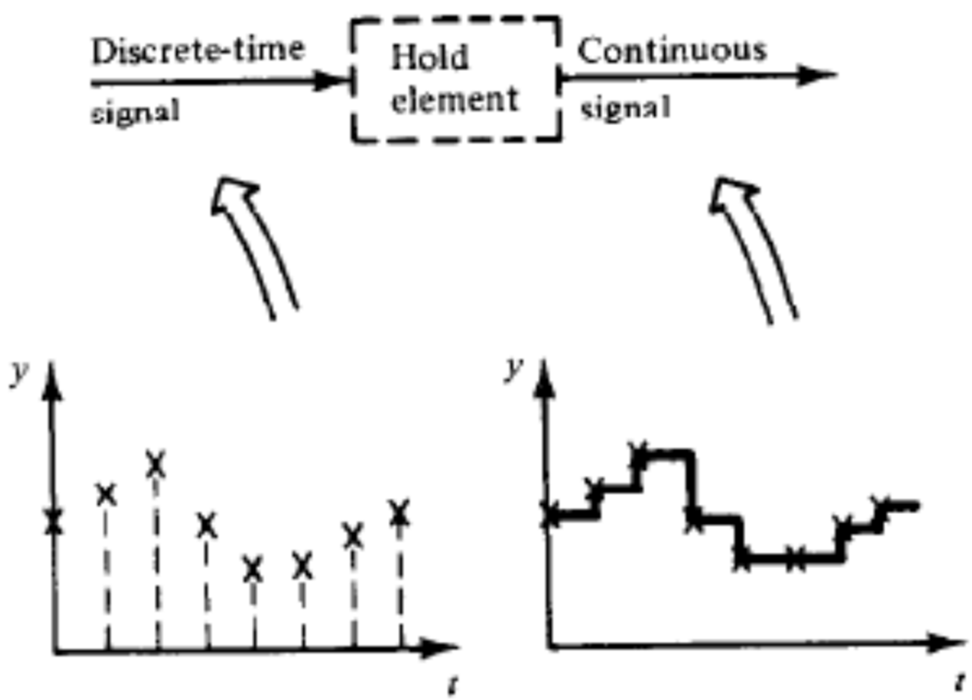
Hold element

- Most of the final control elements (pneumatic valves particularly) are actuated by continuous time signals (e.g., compressed air).
- The discrete time signal from computer output (computed by program) is converted into continuous signal by hold element.



Analog-to-digital converter

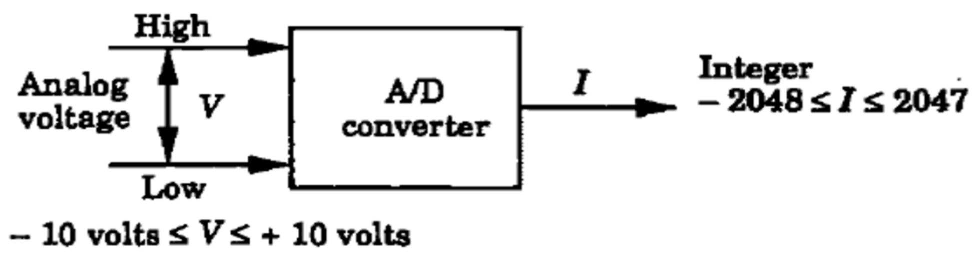
- **A/D converters convert an analog voltage signal lying within a specific range (such as ± 10 V, 0 to 5 V, etc.) to an integer number.**
- **The range of the integer I is given by $I_{range} = 2^N$, where *N* is the number of bits.**
- **For a 12 bit converter, maximum integer is $2^{12} = 4096$.**
- **So the range is 2048 ≤I ≤+ 2047, I=0 exists between +ve and –ve integers.**
- **For the positive range (2047), the *resolution* of the converter is the voltage range divided by the intervals between integers, Resolution = (10/2047) V = 0.00489 V.**
- **This gives an *expected error* of ± 1/2 of the resolution, or± 0.00244 V, Relative error = 0·00244** V/|measured voltage|
- **The throughput speed of A/D converters is routinely 50,000 - 100,000 conversions/s.**

Cont.

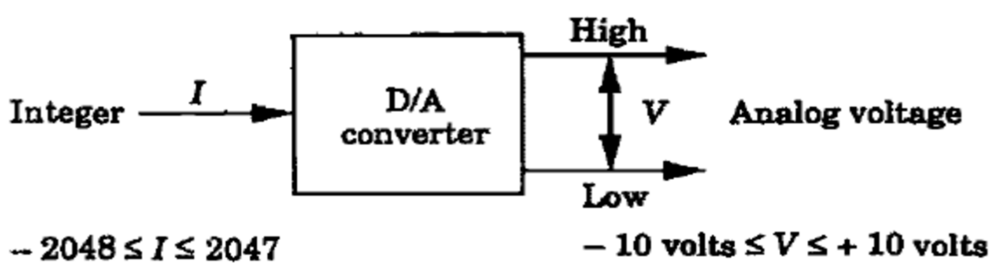
Ex: ***As*** **an illustration of A/D conversion, suppose the 12-bit converter measure voltages and reports the integer 1261 and 21 as a result of the conversion. Determine the actual measured voltage for I=1261 and 21. Assume *expected error is* ± 1/2 of the resolution.**

Ans: For I=1261, $V_{measured}$ = (10 ×1261/2047) = 6.16023 V

Relative error = ± 0·00244/6.16023 = ± 0.000397 =± 0.0397%



(a) Analog-to-digital conversion (12 bits)



(b) Digital-to-analog conversion (12 bits)

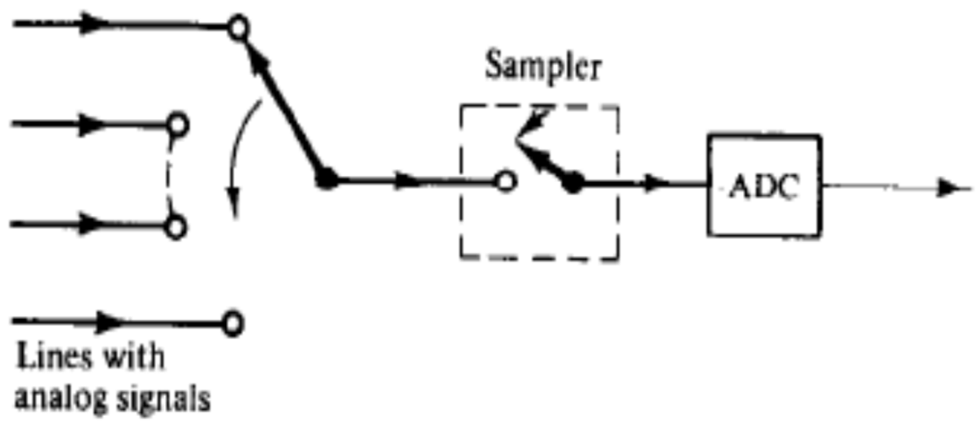
Digital-to-analog converter

- **D/A *converters are* the reverse of A/D conversion. An integer with range 2^N is converted to an analog voltage output.**
- **Ex: For output of 3.5 V determine the input integer for a D/A converter.**
- $I_{input} = 2047 \times V_{output}/10 = (2047)(3.5)/10 = 716.45 \approx 716$
- **It is rounded to $I_{input} = 716$. The actual output voltage of $V_{output} = 716 \times 10 / 2047 = 3.49780\ V \approx 3.5\ V$**

Multiplexer

- Multiplexers multiplex several similar measurements from a remote location and sequentially transmit these over only a few lines.
- Consider 10 thermocouple measurements from a process, each with a voltage signal of – 10 mV. First of all, one may not wish to run 10 lines and use 10 channels of our A/D converters just for these signals, so multiplexing is necessary.
- This is an electronic switch with several ports, which can serve sequentially several lines carrying analog signals.

A/D converter with multiplexer



Digital I/O

- **A digital computer is digital I/O. It is used in a control system for**

1. Information concerning

- Status of relays turning pumps, valves, lights, and other devices on or off.
- Status of multiplexers
- Settings of various switches
- Status of communication peripherals and various digital logic devices

2. Control commands to

- Relays, switches, solenoid, digital logic devices
- Stepping motors

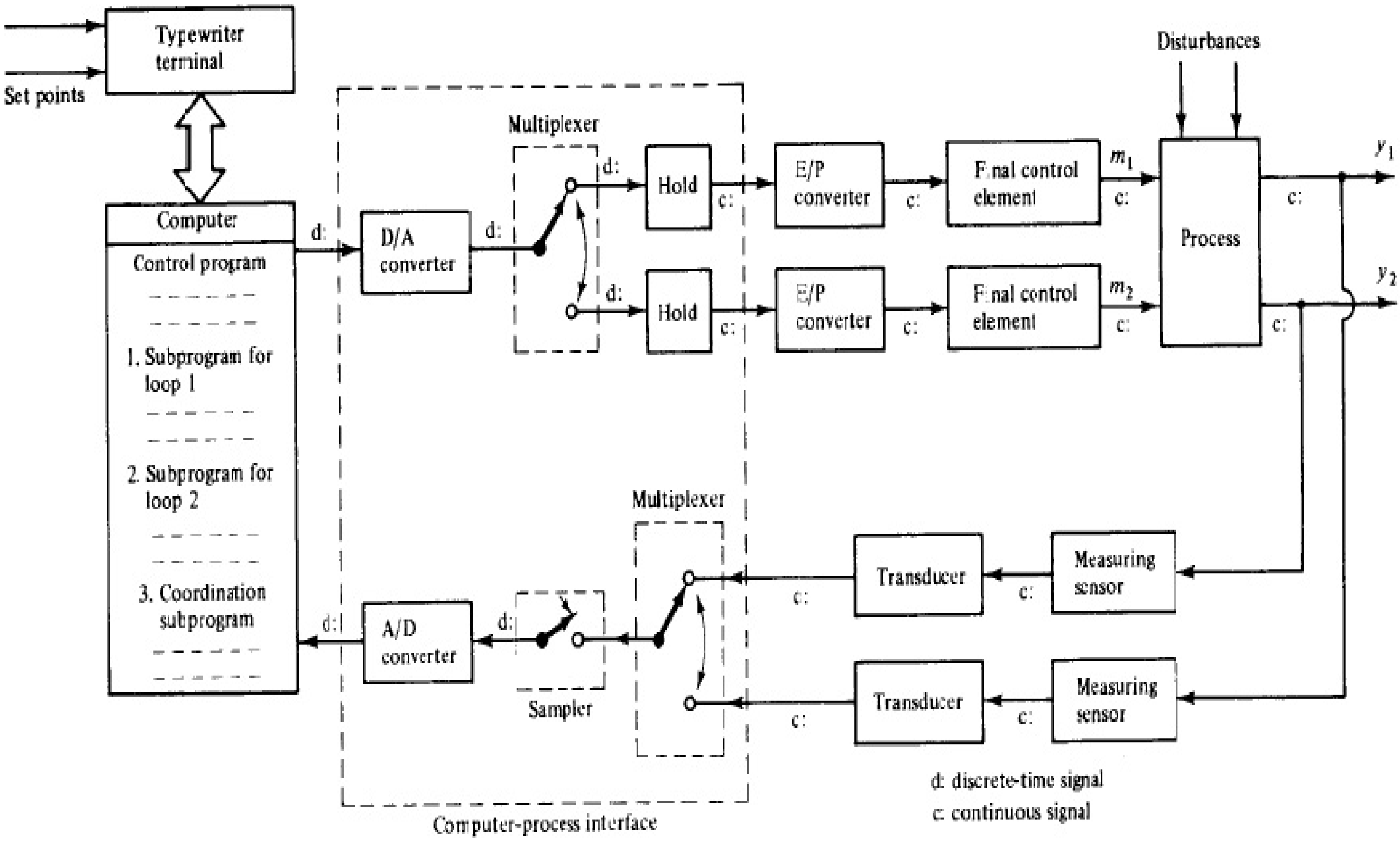
3. Communication between

- Several computers
- A computer and its peripherals, etc.

Cont.

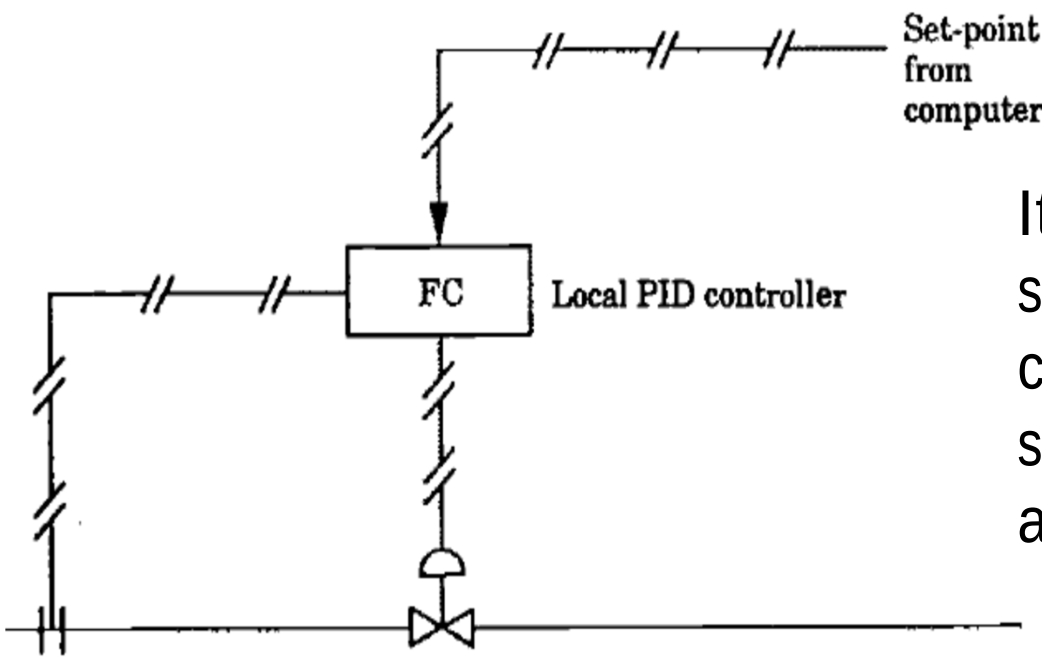
- The digital signals are fully compatible with a computer.
- The transmission (input/output) of digital signals by I/O interface can either in parallel (two way, in and out, simultaneous transmission) or in series (one way, in or out transmission).
- The transmission rates vary from very low to very high, and are expressed in terms of baud rates
- Baud rate=10 × (number of character transmitted/sec)

Computer control loops (multiple)



Modes of Computer Control

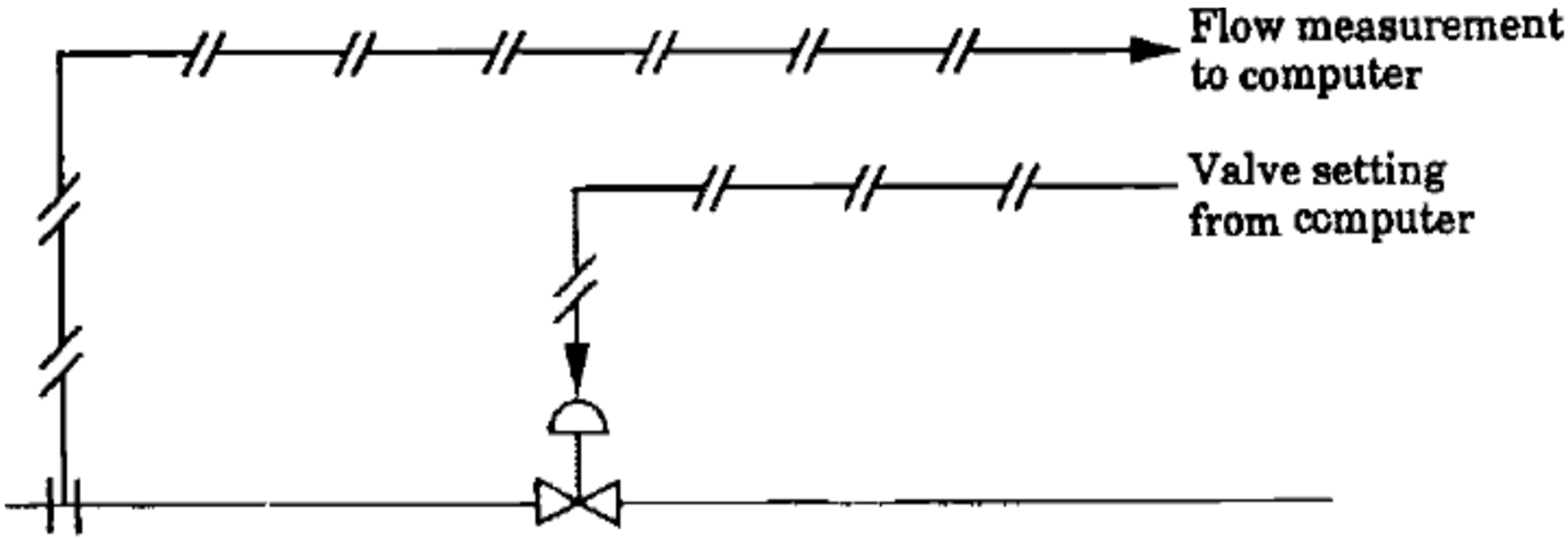
- Computer control is usually carried out in one of two modes: ***supervisory control*** or ***direct digital control*** (DDC).



(a) Supervisory control

It involves resetting the set-point of the local controller according to some computer algorithm.

Cont.



(b) Direct digital control

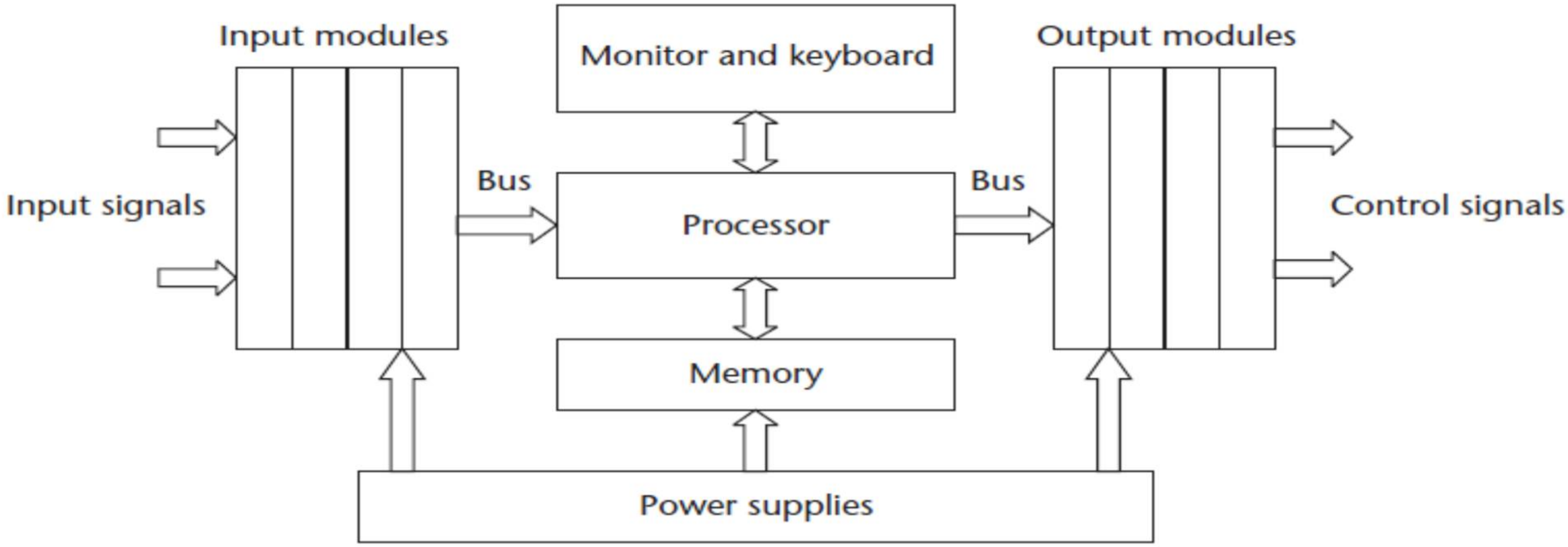
It requires that all the controller action be carried out by the digital computer. Measurements are sent to the computer and compared with the set point; then the computed control action is transmitted to the actuator.

Programmable logic controller (PLC)

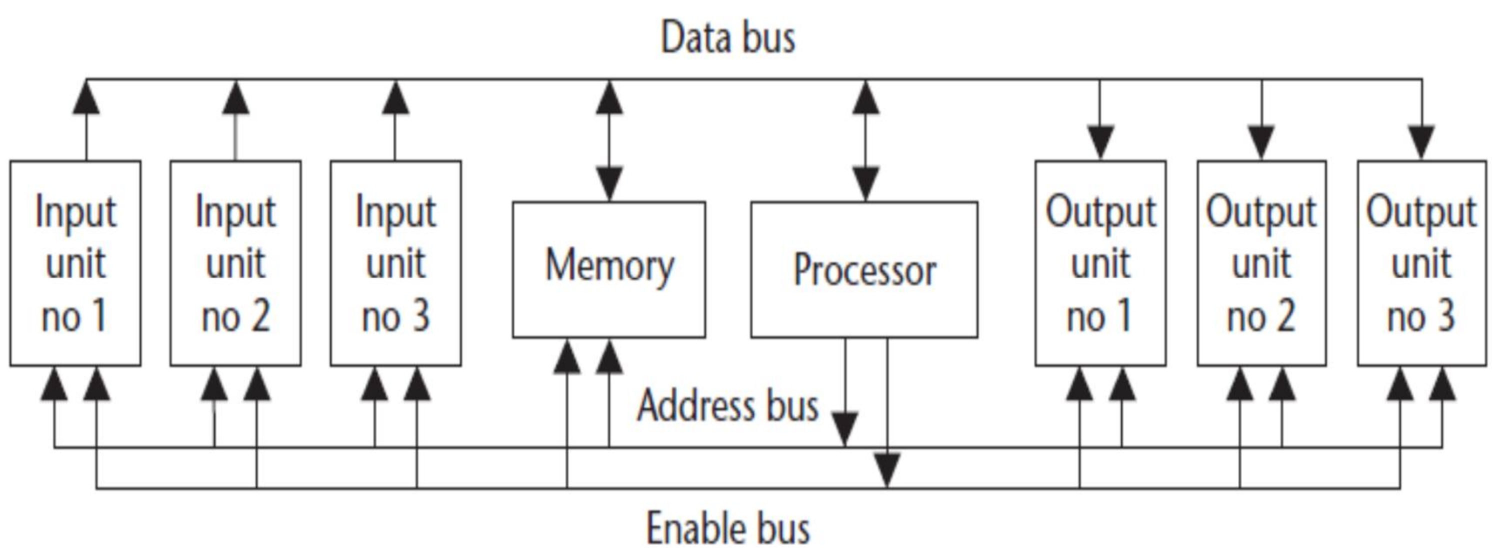
- Modern industrial control systems are microprocessor-based programmable systems containing hardware and software.
- These are direct digital control, distributed control, programmable control, and PID action.
- The processor in a PLC system has software that is easily programmable and flexible, making the initial program, updates, modifies.
- PLC are configured to receive a certain numbers of inputs(both analog and digital) and to control a certain number of outputs like actuators, displays or other types of devices.
- PLCs are categorized into low-end, midrange, and high- end.; Low-end is from 64 expandable up to 256 I/Os, midrange is expandable up to 2,048 I/Os, and high-end is expandable up to 8,192 I/Os.

Cont.

- PLCs have the ability to communicate with each other on a local area network (LAN) or a wide area network (WAN),- these send operational data to, and be controlled from, a central computer terminal.
- The individual control loops are not independent in a process but are interrelated.
- Measured variables may be monitored and manipulated variables controlled simultaneously.
- Several processors also may be connected to a mainframe computer for complex control functions.



Block diagram of programmable controller

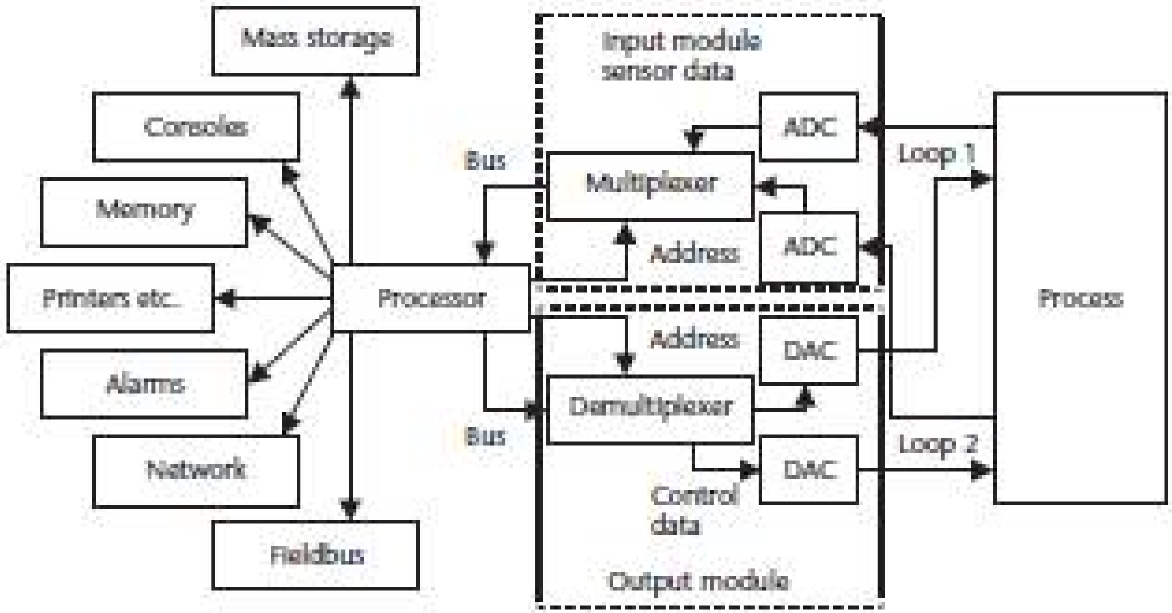


Block diagram processing unit

- The central processing unit can be divided into the processor, memory, and input and output units or modules.
- The units are interconnected by a two-way 16-bit data bus, a one-way address bus, and a one-way enable bus.
- The enable and address buses are controlled by the processor, which uses software instructions for its direction.
- When addressing an input module, the module is selected with its enable bus code.
- The address bus then can be used to select which external input data is to be put onto the two-way data bus.
- This data is then transferred to memory to wait for the next step from the software instructions.
- The output modules are addressed and selected in the same way as the input modules. The unit is selected by the enable code, and the address bus directs the data placed on the data bus from the memory by the processor to its output.

Operation cycle in the PLC

- The operation cycle of a PLC is made up of two separate modes; these are the I/O scan mode, followed by the execution mode.
- *I/O scan mode* is the period when the processor updates the output control signals, based on the information received from the previous I/O scan cycle after its evaluation of the signals. The processor then scans the inputs in a serial mode and updates its internal memory as to the status of the inputs.
- *Execution mode* follows the I/O scan mode. In this mode, the processor evaluates the input data stored in memory against the data programmed into the CPU. The processor then can determine the actions to be taken by the output modules, and puts the data into memory for transfer to the output modules during the next I/O scan mode.
- *Scan time* is the time required for the PLC to complete one I/O scan plus the execution cycle. This time depends on the number of input and output channels, the length of the ladder instruction sets, and the speed of the processor. A typical scan time is between 5 and 20 ms.



Computer based digitally controlled process

Distributed control system (DCS)

- DCS was originally considered as a replacement of huge panels, located in central control rooms and comprising 100 to 1000 process instruments.
- It has expanded information-processing role, adding advanced control such as, model reference control and expert systems; information-analysis tools, such as statistical process control and intelligent alarming; decision support applications such as predictive maintenance and document management; and business system integration capabilities.
- The DCS has three essential qualities
  1. first is to distribute its functions into relatively small sets of semiautonomous subsystems, which are interconnected via a high-speed communications network. These functions include data collection, process control, process analysis and supervision, storage and retrieval of archived information, and the presentation and reporting of information. The advantages are:
     - lower exposure to component or subsystem failure and better isolation to facilitate maintenance and upgrades.
     - better partitioning of application requirements
     - improved modularity for application development
     - geographical distribution reduces installation costs (reduced wiring) and provides more localized operational supervision

Cont.

2. 2nd to automate the manufacturing process by integrating advanced regulatory control, logic and sequential control, it also includes information such as:
   - activity-based cost accounting
   - production scheduling and dispatching
   - preventative or predictive maintenance scheduling
   - validation of employee job certification and readiness
   - information exchange with business, logistics, and transportation applications
3. 3rd a DCS organizes the command structure and information flow among its constituent parts so as to have it act as a single automation system unifying the various subsystems, including:
   - process signal input and conditioning
   - process actuator signal output
   - regulatory, combinatorial, and sequence logic and procedural and supervisory control
   - human readable process displays of current values, alarms, trends, and calculations
   - human actions including setpoint changes, manual overrides and alarm handling
   - application subsystems such as process optimization and manufacturing support
   - information-storage subsystems
   - communications subsystems

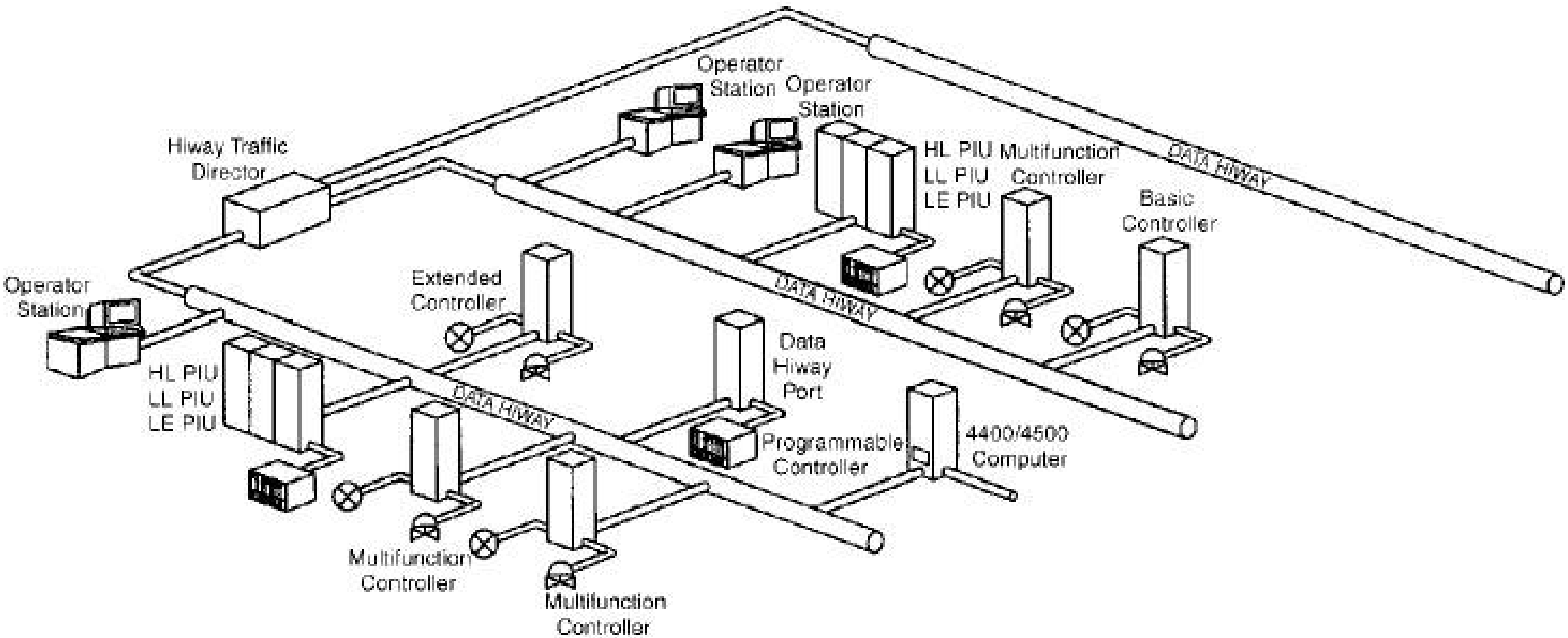


FIGURE TDC 2000 architecture (courtesy of Honeywell).

PROCESS/INDUSTRIAL INSTRUMENTS AND CONTROLS HANDBOOK by Gregory K. McMillan and Douglas M. Considine.

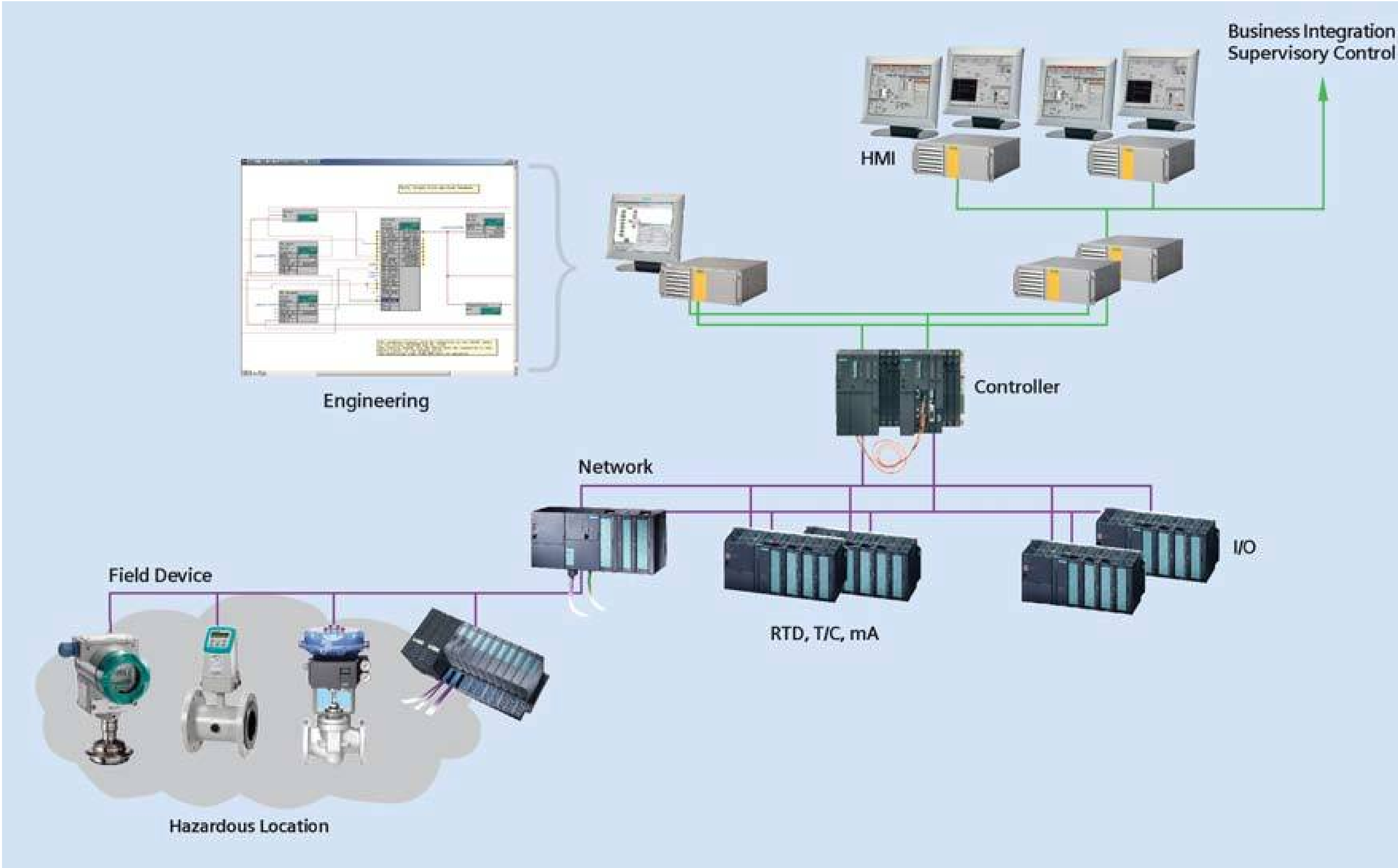


Figure: DCS presented by **Siemens Energy & Automation, Inc.**

Both DCS and PLC systems share the following components: Field devices; Input/output modules; Controllers ; Human machine interface (HMI); Engineering; Supervisory control; Business integration

Comparison between PLC and DCS by **Siemens Energy & Automation, Inc.**

PLC is applied	DCS is applied
Factory automation - manufacturing or assembly of specific items “thing”	Process automation applications Involves the combination and/or transformation of raw materials “stuff”
Product is visible as it moves through the process	Often impossible to visually see the product as it moves through the process
High-speed logic control (such as motors)	Regulatory/Analog (loop) control
Simple Batch control	Complex Batch Control
Value of the individual component being manufactured is relatively low	The value of a “batch” can be very high (either in raw material cost or market value)
Downtime mainly results in lost production	Downtime can result in process equipment damage (product hardens, etc.)
Return to steady state production after an outage is short and relatively straightforward	Return to steady state production after an unplanned outage can be long, expensive, and difficult
Typically, the heart of the system is the controller	Typically, the heart of the system is the HMI

PLC is applied	DCS is applied
The operator's primary role is to handle exceptions	The operator’s interaction is typically required to keep the process in its target performance range
Fast logic scan (approx. 10ms) is required to perform motor or motion control	Control loops require deterministic scan execution at a speed of 100 to 500 ms
Redundancy may not be cost justified	System redundancy is often required
System can be taken offline to make configuration changes	Online configuration often required changes
Analog Control: Simple PID only	Analog Control: Simple to advanced PID control up to Advanced Process Control
Diagnostics to tell you when something is broken	Asset Management alerts you to what might break before it does
High level programming languages are available for creating custom logic	Custom logic created from existing function blocks
Solution is generic in nature, to be applied on a wide variety of applications	Use of pre-defined, pre-tested functions saves time

Data processing for process plants

- In a process plant thousands of variables like flow rates, temperatures, pressures, levels, compositions, etc. are routinely measured and automatically recorded for ***process control***, ***online optimization*** or ***process economic evaluation***.
- In recent days, computers and data acquisition systems collect and process large volume of data sampled with low to moderate frequency in the order of minutes or seconds.
- Modern days computers not only access large volume of data at higher frequency but also ***eliminate errors*** in data to increase its ***accuracy and validity***.
- During process measurement and data transmission the data involve errors. Measurement errors are of two types, i) ***Random error***, ii) ***Gross error***.
- Outcome of ***random errors*** are uncertain with respect to its sign (+ve/-ve) and magnitude. If measurement is repeated with same process condition and instrument, dissimilar values are obtained from the measurement. The ***random errors*** are ***characterized by probability distribution function like Gaussian distribution***. The error is caused by ***power supply fluctuations, network transmission and signal conversion noise, analog input filtering, changes in ambient conditions***, etc. The errors are beyond the control of process engineer and always present in a measured data and it is ***characterized by high frequency and low magnitude*** unlike some occasional spike.

Cont.

- The ***gross error*** corresponds to non random events and is ***caused by instrument malfunctioning (due to improper installation of measuring devices), mal calibration, wear or corrosion of sensors, solid deposits***, etc. If measurement is repeated with same process condition and instrument, similar values of gross errors are obtained from the measurement. ***Good installation and maintenance procedures prevent gross error to involve***. Wear and fouling of sensors cause a gross errors which increases slowly over long period of time and can be eliminated by proper cleaning. The ***gross errors maintain a trend and are of larger magnitude than random error***.
- Small ***error in measured signal*** leads to ***deterioration of control performance***, ***uneconomic process*** and ***unsafe operation regimes***.
- Different data processing technique have been used to eliminate errors.
- ***Signal conditioning by analog and digital filters***. These are used to ***reduce the effect of high frequency noise*** in the measurement. Today ***smart sensors*** performs diagnostic check about the ***hardware problem*** and ***acceptability of the data***.
- ***Statistical quality control test (SQC)*** detects significant error in process data. It is used separately for each process variables and does not use knowledge of process model; hence does not ensure consistency of the data with respect to interrelationship among process variables. Obvious gross error is eliminated and first step for eliminating random error.
- ***Data reconciliation*** is a technique to ***improve accuracy of measurement by reducing random error***. It explicitly makes use of process model constrains to estimate process variables by adjusting process measurements in such a way to satisfy the process constrains.

Cont.

- The technique regulates process measurements with random errors by making them ***satisfy material and energy balance constraints to improve measurement from a process via DCS or data collection devices***.
- It involves ***steady state data reconciliation*** (Kuehn & Davidson, 1961) and is of two types- ***linear and nonlinear data reconciliation*** that utilizes steady state matrix and Jacobian matrix respectively from system governing mass, species and energy balances.
- A reconciliation problem can be expressed as (Özyurt & Pike, 2004)
- $min \sum_{i=1}^{n} \frac{(y_{i,,j}-x_{i,j})^2}{\sigma_{i,j}^2}$ such that Ax_i = 0 and $Lb \leq x \leq Ub$
- x = [$x_{1,j}$, $x_{2,j}$, $x_{3,j}$,..., $x_{i,j}$,...., $x_{n,j}$] is the set of system variables are to be measured. These variables are estimated using governing equation with constraints.
- y = [$y_{1,j}$, $y_{2,j}$, $y_{3,j}$,..., $y_{i,j}$,...., $y_{n,j}$] is the set of measurement vector.
- Where, i=1,2,...,n is the number of variables and j=1,2,....,m is the number of sets of measurement, and $\sigma_{i,j}^2$ is the variance of errors over the measurement sets.
- Standard error $\frac{(y_{i,,j}-x_{i,j})}{\sigma_{i,j}}$ is estimated using different probability distribution functions of errors.

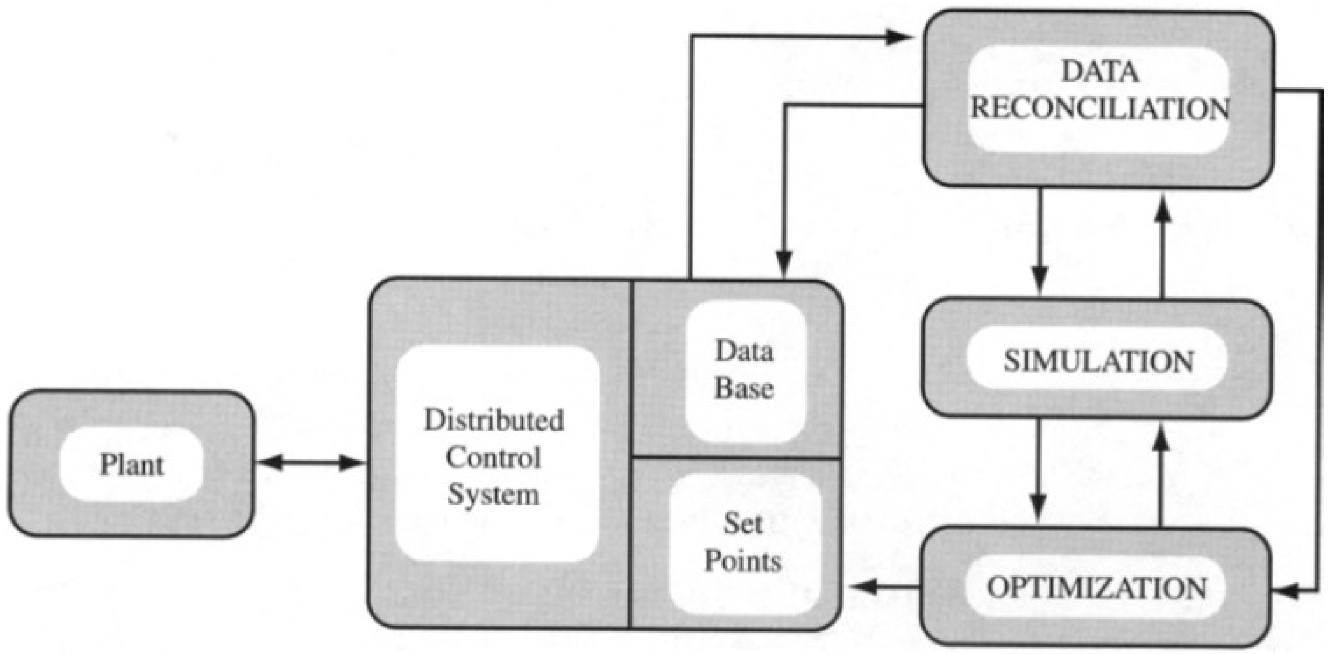
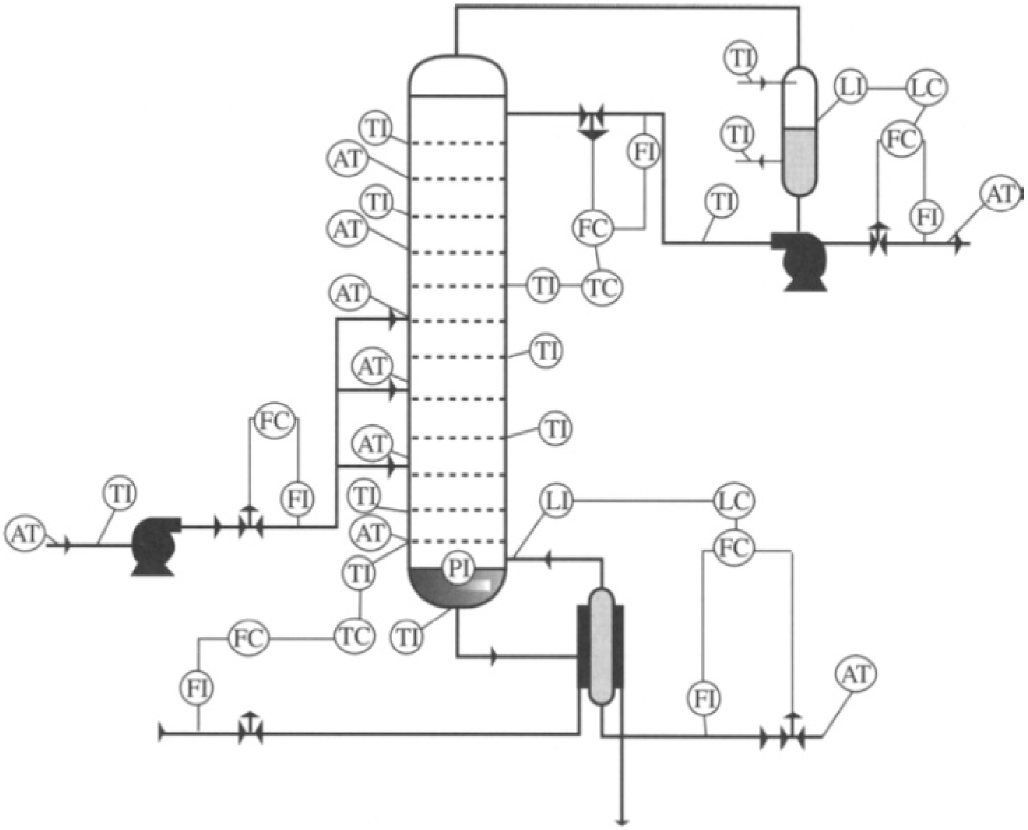


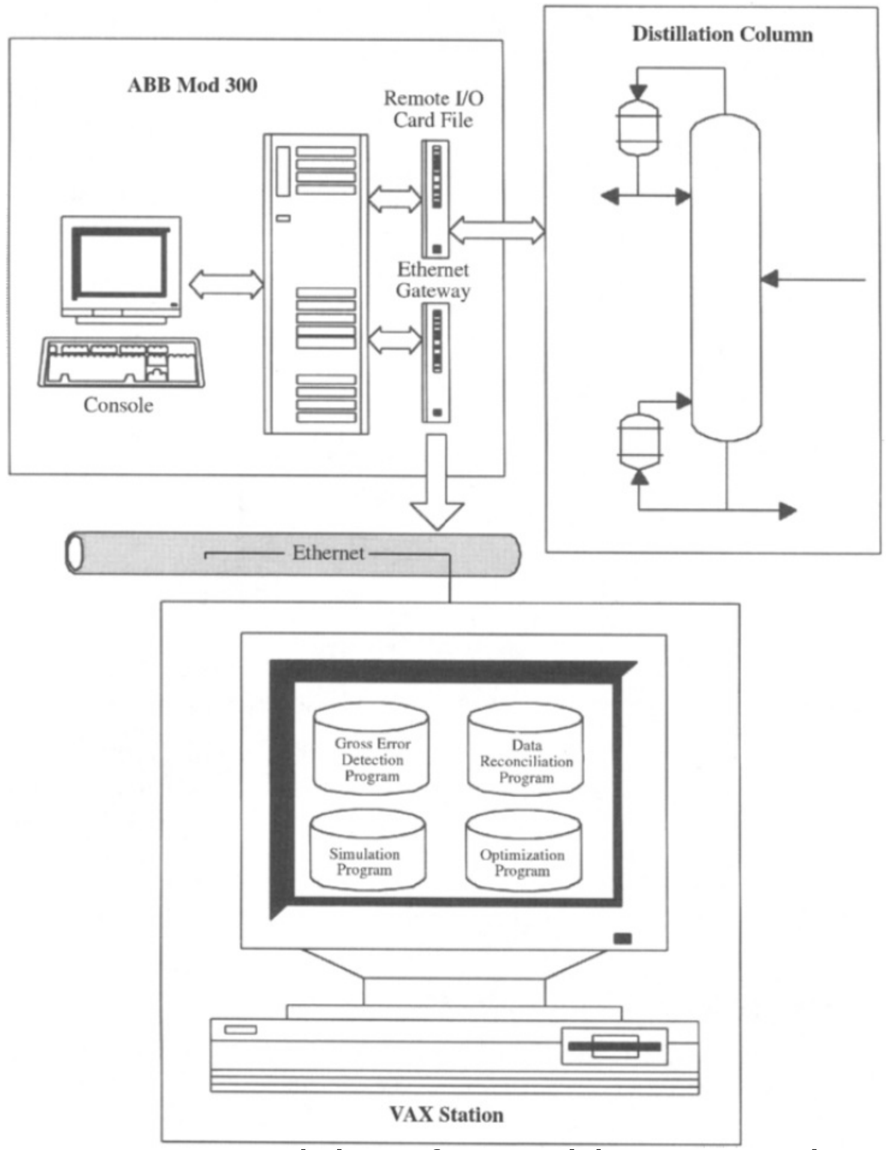
Fig: Typical arrangement between the DCS and the Data Reconciliation, Simulation, and Optimization procedures (from Simulation Sciences, Inc., 1989) presented by **Romagnoli & Sanchez, DATA PROCESSING AND RECONCILIATION FOR CH EM ICAL PROCESS OPERATIONS**



The following variables are monitored through the DCS:

- Temperatures at trays 12, 11, 9, 7, 5, 3, 1
- Temperatures of feed, distillate, bottoms, and water in and out of the condenser.
- Flowrates of steam to the reboiler, water to the condenser, feed, distillate, bottoms, and reflux
- Pressure at the bottom of the column
- Liquid levels in the condenser and the bottom of the column

- The 23-cm-diameter distillation column under study is used to separate ethanol and water. It contains 12 sieve trays with a 30-cm spacing (Fig.) as well as three possible feed locations, an external reboiler, and two condensers, which are used at the bottom and the top of the column. The second condenser is also used as a reflux drum; a pump sends the reflux back to the column (tray 1) and the product to the product tank. Presented by **Romagnoli & Sanchez, DATA PROCESSING AND RECONCILIATION FOR CH EM ICAL PROCESS OPERATIONS.**



The setup of the column, DCS, and interface with VAX-station and supervisory control Presented by **Romagnoli & Sanchez, DATA PROCESSING AND RECONCILIATION FOR CH EM ICAL PROCESS OPERATIONS.**

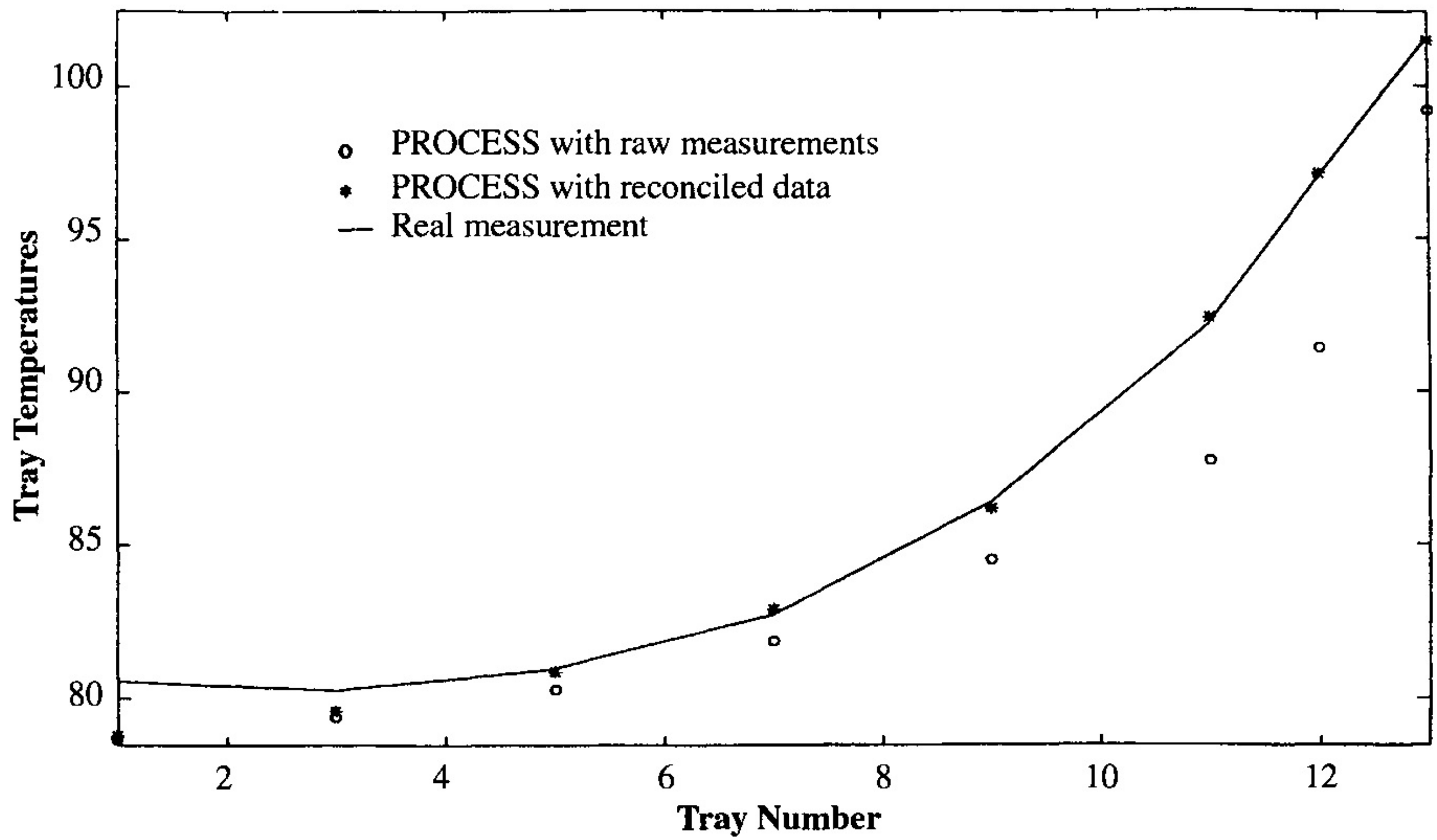


FIGURE 12 Comparison of tray temperatures from simulation (reconciled and raw data) with real-time temperatures (from Nooraii, 1996).

Presented by Romagnoli & Sanchez, DATA PROCESSING AND RECONCILIATION FOR CH EM ICAL PROCESS OPERATIONS.

TABLE 9 Comparison among Raw, Reconciled, and Bias Estimation Plus Reconciliation Data and the Results from Simulation (from Nooraii, 1996)

	Plant raw data	PROCESS with raw data	Reconciled data without bias deletion	Linear reconciliation with bias deletion	Nonlinear reconciliation with bias deletion	PROCESS with nonlinear reconciliation
Feed rate (kg/h)[a]	67.94	67.94	69.7	68.226	68.225	68.228
Feed temperature[a]	27.4	27.4	18.7	27.4	27.4	27.4
%(w) EtOH in feed[a]	36	36	33.3	34.4	34.4	34.4
Distillate rate (kg/h)[a]	27.24	27.24	27.18	27.134	27.133	27.133
Distillate temperature[a]	33.6	33.6	36	33.6	33.6	33.6
%(w) EtOH in distillate	85.47	86.2	84.97	85.49	85.5	85.45
Reflux rate (kg/h)[a]	43.58	43.58	43.59	43.58	43.58	43.58
Bottom rate (kg/h)	41.11	41.11	42.53	41.09	41.09	41.09
Bottom temperature	102	99.6	109.7	102	102	102
%(w) EtOH in bottom	0.67	2.3	0.34	0.67	0.7	0.7123
Bottom pressure[a]	1.09	1.09	1.42	1.1168	1.109	1.109
Condenser duty (mm kJ/h)	127	85.2	127	85	85	85.9
Reboiler duty (mm kJ/h)	144.5	97.6	144	98.3	98.3	99

Presented by **Romagnoli & Sanchez, DATA PROCESSING AND RECONCILIATION FOR CHEMICAL PROCESS OPERATIONS.**

Reference

- Stephanopoulos, G., "Chemical Process Control and Introduction to theory and practice", Prentice Hall.
- William C. Dunn, Introduction to Instrumentation, Sensors, and Process Control, ARTECH HOUSE, Norwood, MA, 2006.

Thank You