Ch 5 Industrial Control Systems

Sections:

1. Process Industries vs. Discrete Manufacturing Industries
2. Continuous vs. Discrete Control
3. Computer Process Control

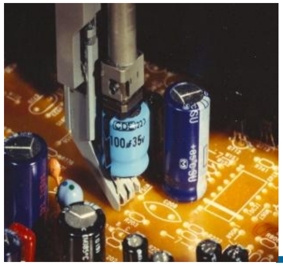
Industrial Control - Defined

The automatic regulation of unit operations and their associated equipment as well as the integration and coordination of the unit operations into the larger production system

- Unit operation
  - Usually refers to a manufacturing operation
  - Can also apply to material handling or other equipment

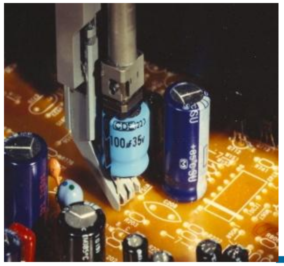
Process Industries vs. Discrete Manufacturing Industries

- Process industries
  - Production operations are performed on amounts of materials
  - Materials: liquids, gases, powders, etc.
- Discrete manufacturing industries
  - Production operations are performed on quantities of materials
  - Parts, product units



Definitions: Variable and Parameters

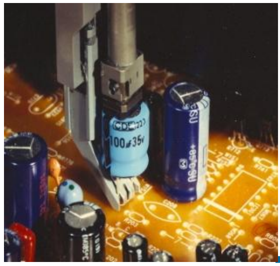
- Variables - outputs of the process
- Parameters - inputs to the process
- Continuous variables and parameters - they are uninterrupted as time proceeds
  - Also considered to be analog - can take on any value within a certain range
    - They are not restricted to a discrete set of values
- Discrete variables and parameters - can take on only certain values within a given range



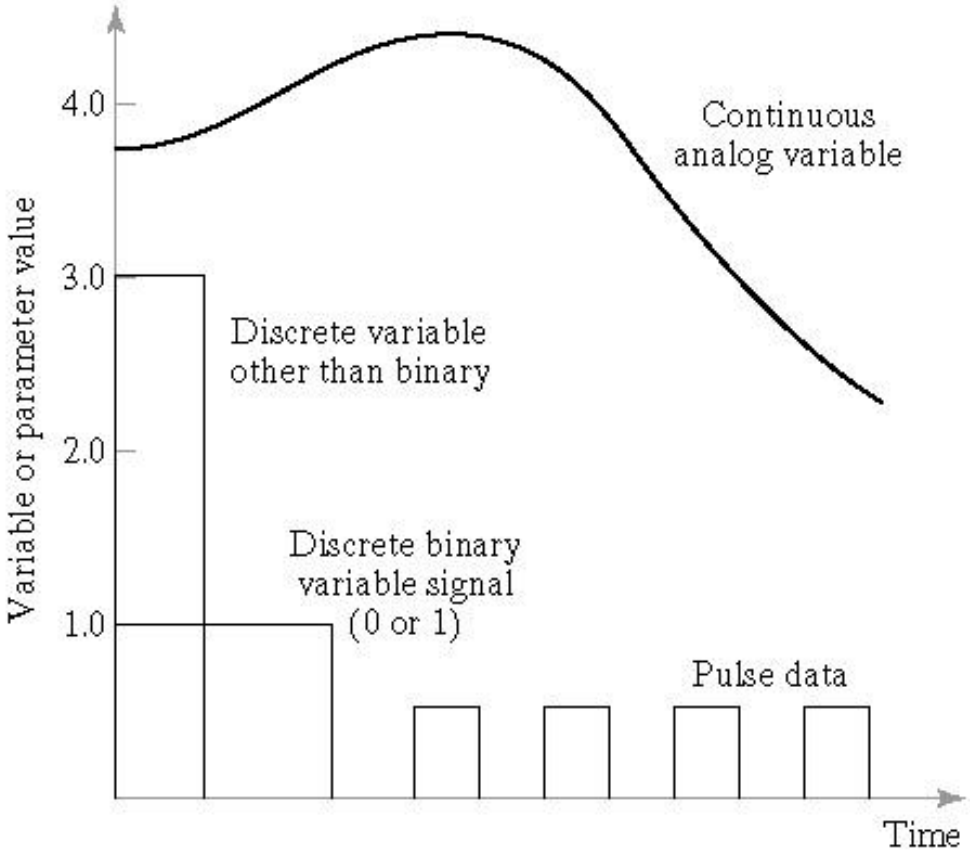
Discrete Variables and Parameters

Categories:

- Binary - they can take on either of two possible values, ON or OFF, 1 or 0, etc.
- Discrete other than binary - they can take on more than two possible values but less than an infinite number of possible values
- Pulse data - a train of pulses that can be counted

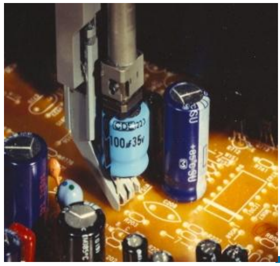


Continuous and Discrete Variables and Parameters



Types of Control

- Just as there are two basic types of variables and parameters in processes, there are also two corresponding types of control:
  - Continuous control - variables and parameters are continuous and analog
  - Discrete control - variables and parameters are discrete, mostly binary discrete

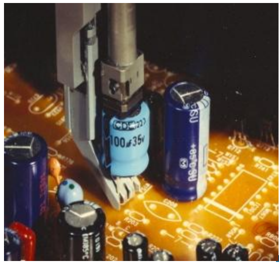


Continuous Control

- Usual objective is to maintain the value of an output variable at a desired level
  - Parameters and variables are usually continuous
  - Similar to operation of a feedback control system
  - Most continuous industrial processes have multiple feedback loops
- Examples of continuous processes:
  - Control of the output of a chemical reaction that depends on temperature, pressure, etc.
  - Control of the position of a cutting tool relative to workpart in a CNC machine tool

Types of Continuous Process Control

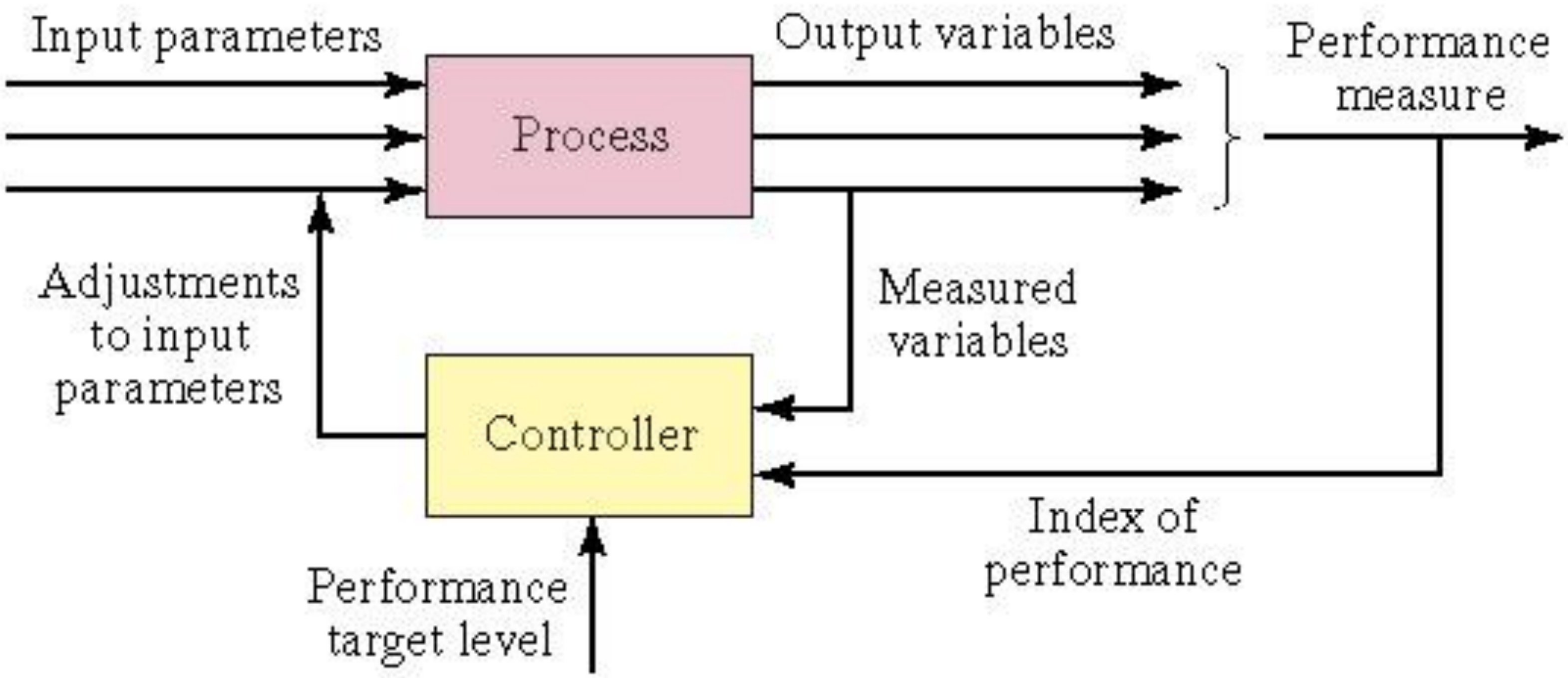
- Regulatory control
- Feedforward control
- Steady-State optimization
- Adaptive control
- On-line search strategies
- Other specialized techniques
  - Expert systems
  - Neural networks

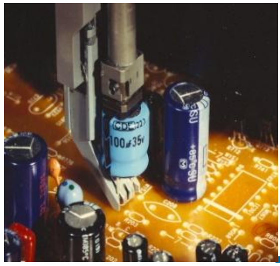


Regulatory Control

- Objective - maintain process performance at a certain level or within a given tolerance band of that level
  - Appropriate when performance relates to a quality measure
- Performance measure is sometimes computed based on several output variables
  - Performance measure is called the *Index of performance* (IP)
- Problem with regulatory control is that an error must exist in order to initiate control action

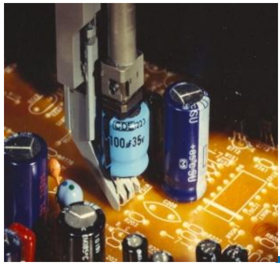
Regulatory Control



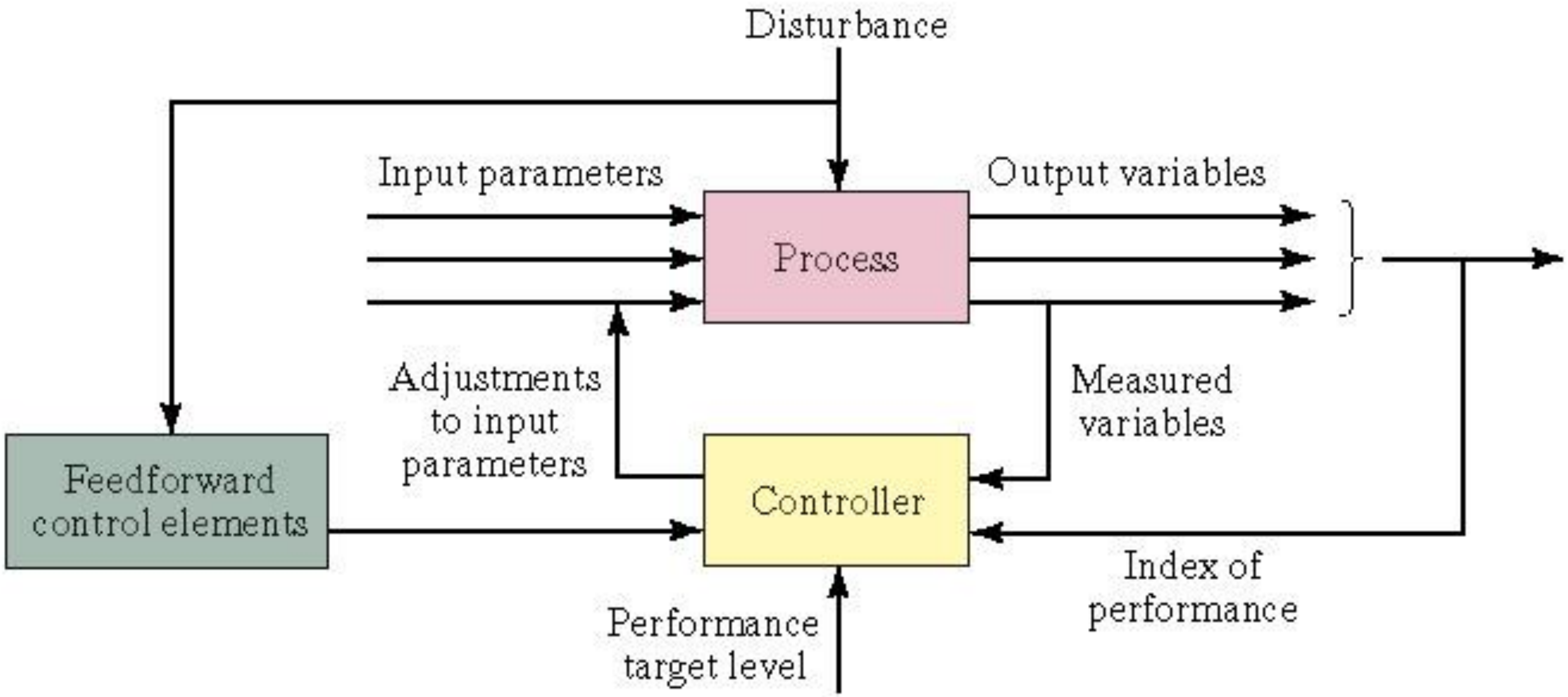


Feedforward Control

- Objective - anticipate the effect of disturbances that will upset the process by sensing and compensating for them before they affect the process
- Mathematical model captures the effect of the disturbance on the process
- Complete compensation for the disturbance is difficult due to variations, imperfections in the mathematical model and imperfections in the control actions
  - Usually combined with regulatory control
- Regulatory control and feedforward control are more closely associated with process industries



Feedforward Control Combined with Feedback Control



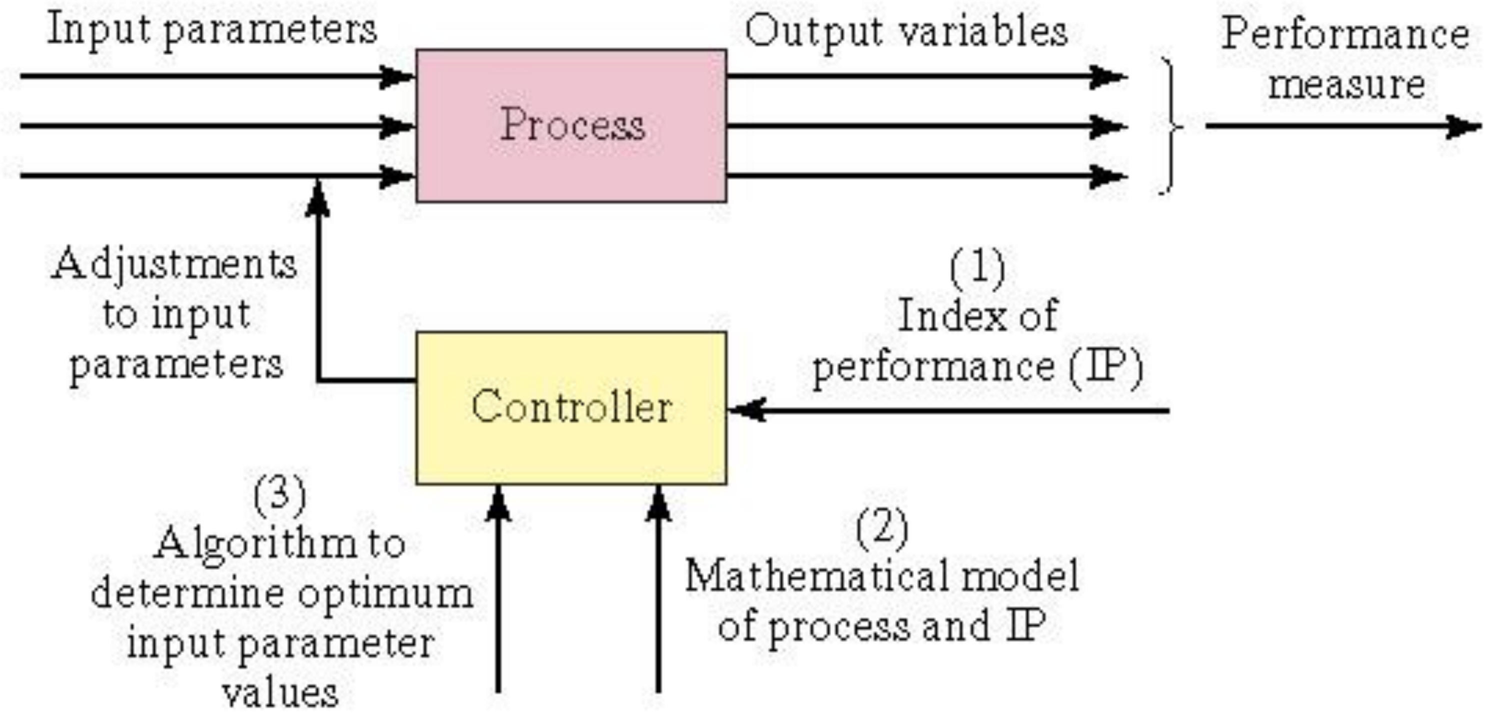
Steady-State Optimization

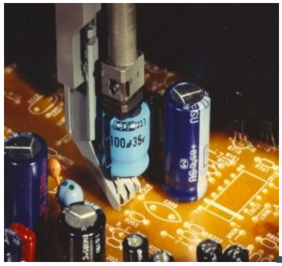
Class of optimization techniques in which the process exhibits the following characteristics:

1. Well-defined index of performance (IP)
2. Known relationship between process variables and IP
3. System parameter values that optimize IP can be determined mathematically

- Open-loop system
- Optimization techniques include differential calculus, mathematical programming, etc.

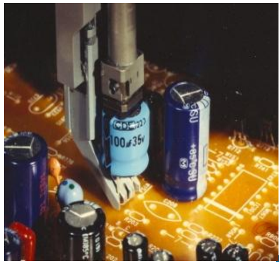
Steady State (Open-Loop) Optimal Control





Adaptive Control

- Because steady-state optimization is open-loop, it cannot compensate for disturbances
- Adaptive control is a self-correcting form of optimal control that includes feedback control
  - Measures the relevant process variables during operation (feedback control)
  - Uses a control algorithm that attempts to optimize some index of performance (optimal control)



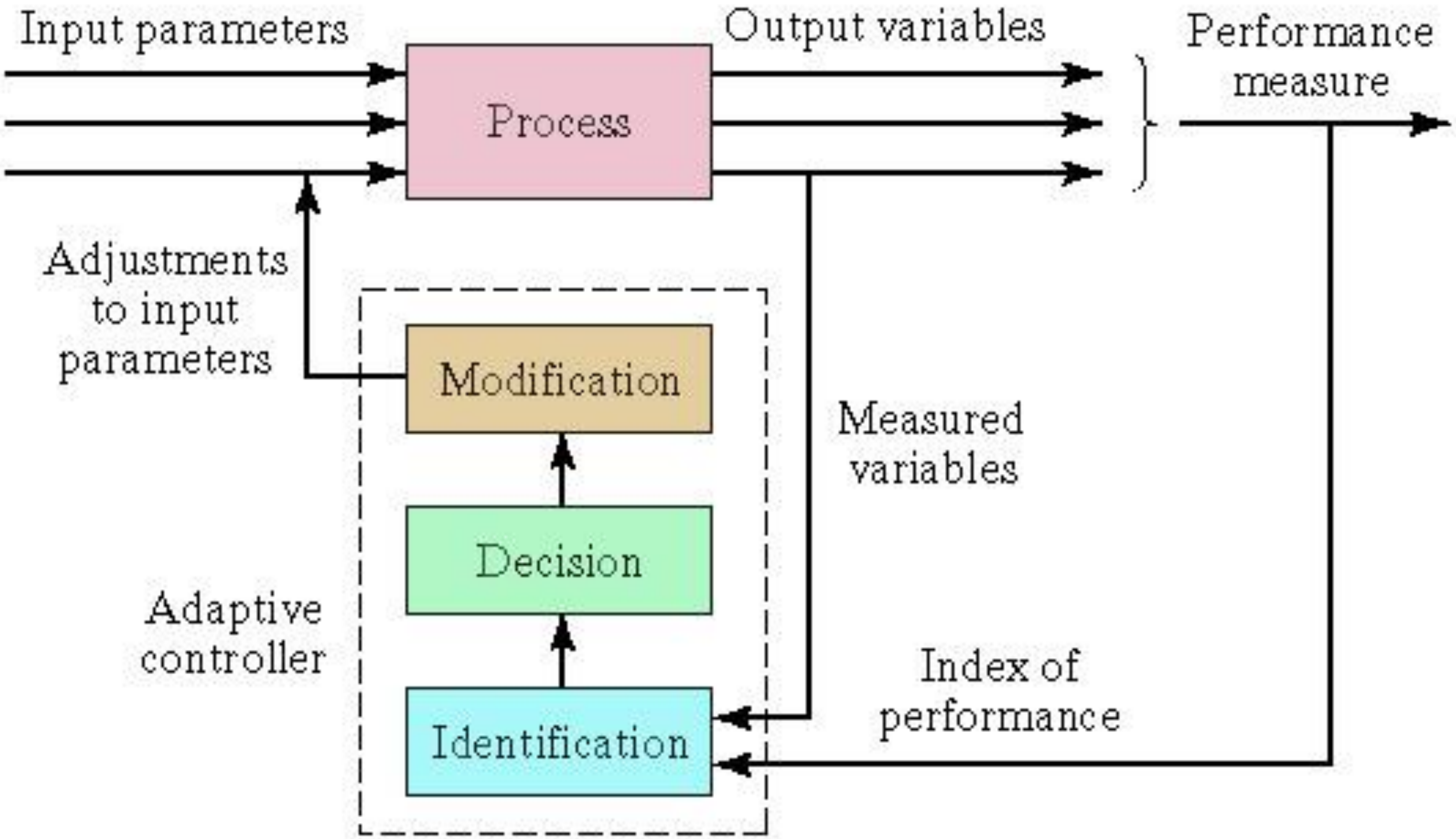
Adaptive Control Operates in a Time-Varying Environment

- The environment changes over time and the changes have a potential effect on system performance
  - Example: Supersonic aircraft operates differently in subsonic flight than in supersonic flight
- If the control algorithm is fixed, the system may perform quite differently in one environment than in another
- An adaptive control system is designed to compensate for its changing environment by altering some aspect of its control algorithm to achieve optimal performance

Three Functions in Adaptive Control

1. Identification function – current value of IP is determined based on measurements of process variables
2. Decision function – decide what changes should be made to improve system performance
   - Change one or more input parameters
   - Alter some internal function of the controller
3. Modification function – implement the decision function
   - Concerned with physical changes (hardware rather than software)

Adaptive Control System

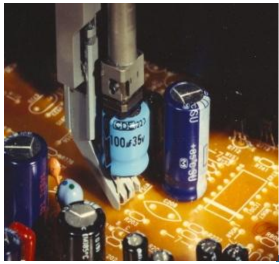


On-Line Search Strategies

- Special class of adaptive control in which the decision function cannot be sufficiently defined
  - Relationship between input parameters and IP is not known, or not known well enough to implement the previous form of adaptive control
- Instead, experiments are performed on the process
  - Small systematic changes are made in input parameters to observe effects
- Based on observed effects, larger changes are made to drive the system toward optimal performance

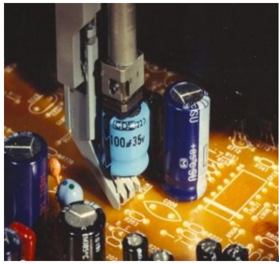
Discrete Control Systems

- Process parameters and variables are discrete
- Process parameters and variables are changed at discrete moments in time
- The changes are defined in advance by the program of instructions
- The changes are executed for either of two reasons:
  1. The state of the system has changed (event-driven changes)
  2. A certain amount of time has elapsed (time driven changes)



Event-Driven Changes

- Executed by the controller in response to some event that has altered the state of the system
- Examples:
  - A robot loads a workpart into a fixture, and the part is sensed by a limit switch in the fixture
  - The diminishing level of plastic in the hopper of an injection molding machine triggers a low-level switch, which opens a valve to start the flow of more plastic into the hopper
  - Counting parts moving along a conveyor past an optical sensor



Time-Driven Events

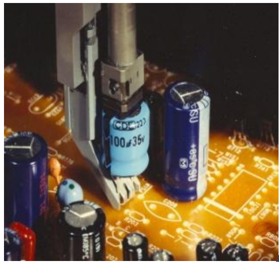
- Executed by the controller either at a specific point in time or after a certain time lapse
- Examples:
  - The factory “shop clock” sounds a bell at specific times to indicate start of shift, break start and stop times, and end of shift
  - Heat treating operations must be carried out for a certain length of time
  - In a washing machine, the agitation cycle is set to operate for a certain length of time
    - By contrast, filling the tub is event-driven

Two Types of Discrete Control

1. Combinational logic control – controls the execution of event-driven changes
   - Also known as logic control
   - Output at any moment depends on the values of the inputs
   - Parameters and variables = 0 or 1 (OFF or ON)
2. Sequential control – controls the execution of time-driven changes
   - Uses internal timing devices to determine when to initiate changes in output variables

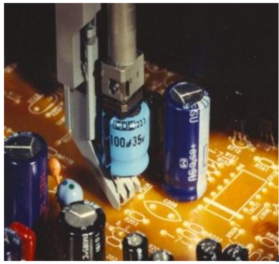
Computer Process Control

- Origins in the 1950s in the process industries
  - Mainframe computers – slow, expensive, unreliable
  - Set point control
  - Direct digital control (DDC) system installed 1962
- Minicomputer introduced in late 1960s, microcomputer introduced in early 1970s
- Programmable logic controllers introduced early 1970s for discrete process control
- Distributed control starting around 1975
- PCs for process control early 1990s



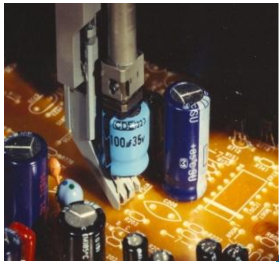
Two Basic Requirements for Real-Time Process Control

1. Process-initiated interrupts
   - Controller must respond to incoming signals from the process (event-driven changes)
   - Depending on relative priority, controller may have to interrupt current program to respond
2. Timer-initiated actions
   - Controller must be able to execute certain actions at specified points in time (time-driven changes)
   - Examples: (1) scanning sensor values, (2) turning switches on and off, (3) re-computing optimal parameter values



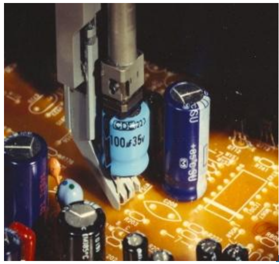
Other Computer Control Requirements

3. Computer commands to process
   - To drive process actuators
4. System- and program-initiated events
   - System initiated events - communications between computer and peripherals
   - Program initiated events - non-process-related actions, such as printing reports
5. Operator-initiated events – to accept input from personnel
   - Example: emergency stop



Capabilities of Computer Control

- Polling (data sampling)
- Interlocks
- Interrupt system
- Exception handling



Polling (Data Sampling)

Periodic sampling of data to indicate status of process

- Issues:
  1. Polling frequency – reciprocal of time interval between data samples
  2. Polling order – sequence in which data collection points are sampled
  3. Polling format – alternative sampling procedures:
     - All sensors polled every cycle
     - Update only data that has changed this cycle
     - High-level and low-level scanning

Interlocks

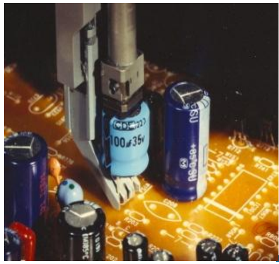
Safeguard mechanisms for coordinating the activities of two or more devices and preventing one device from interfering with the other(s)

1. Input interlocks – signal from an external device sent to the controller; possible functions:
   - Proceed to execute work cycle program
   - Interrupt execution of work cycle program
2. Output interlocks – signal sent from controller to external device

Interrupt System

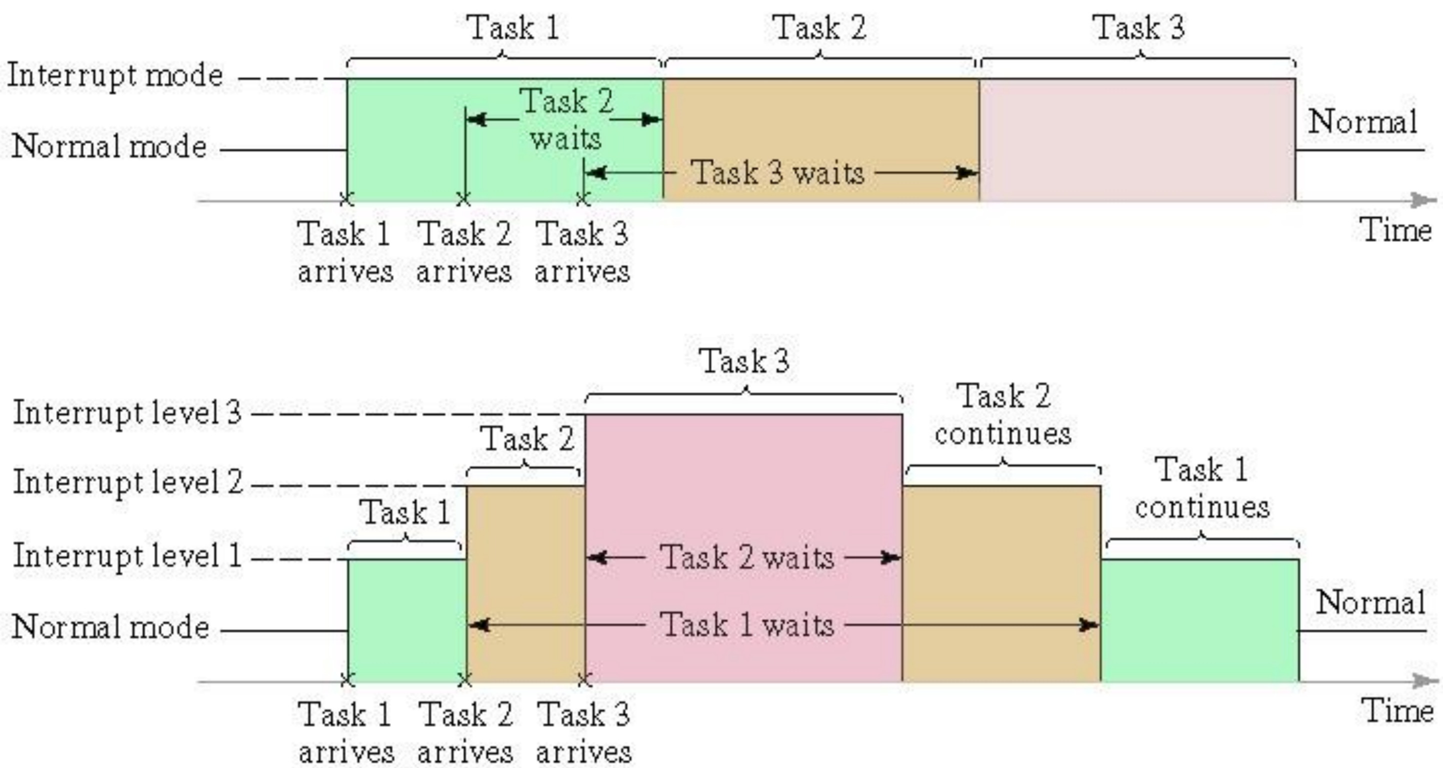
Computer control feature that permits the execution of the current program to be suspended in order to execute another program in response to an incoming signal indicating a higher priority event

- Internal interrupt – generated by the computer itself
  - Examples: timer-initiated events, polling, system- and program initiated interrupts
- External interrupts – generated external to the computer
  - Examples: process-initiated interrupts, operator inputs



Interrupt Systems: (a) Single-Level and (b) Multilevel

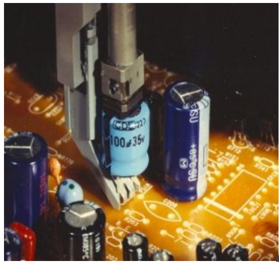
(a) (b)



Exception Handling

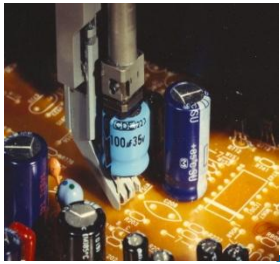
An exception is an event that is outside the normal or desired operation of the process control system

- Examples of exceptions:
  - Product quality problem
  - Process variable outside normal operating range
  - Shortage of raw materials
  - Hazardous conditions, e.g., fire
  - Controller malfunction
- Exception handling is a form of error detection and recovery



Forms of Computer Process Control

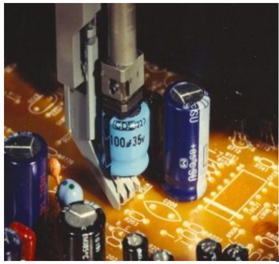
1. Computer process monitoring
2. Direct digital control (DDC)
3. Numerical control and robotics
4. Programmable logic control
5. Supervisory control
6. Distributed control systems and personal computers



Computer Process Monitoring

Computer observes process and associated equipment, collects and records data from the operation

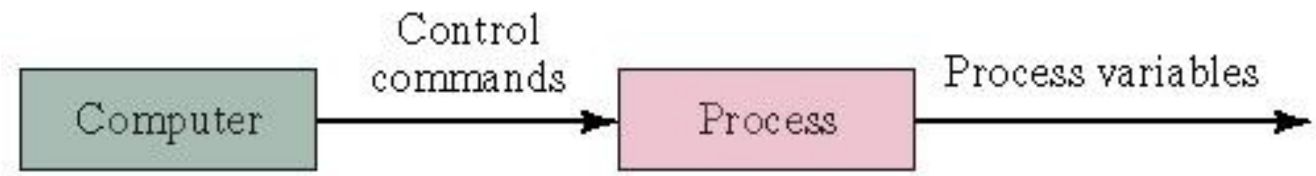
- The computer does not directly control the process
- Types of data collected:
  - Process data – input parameters and output variables
  - Equipment data – machine utilization, tool change scheduling, diagnosis of malfunctions
  - Product data – to satisfy government requirements, e.g., pharmaceutical and medical



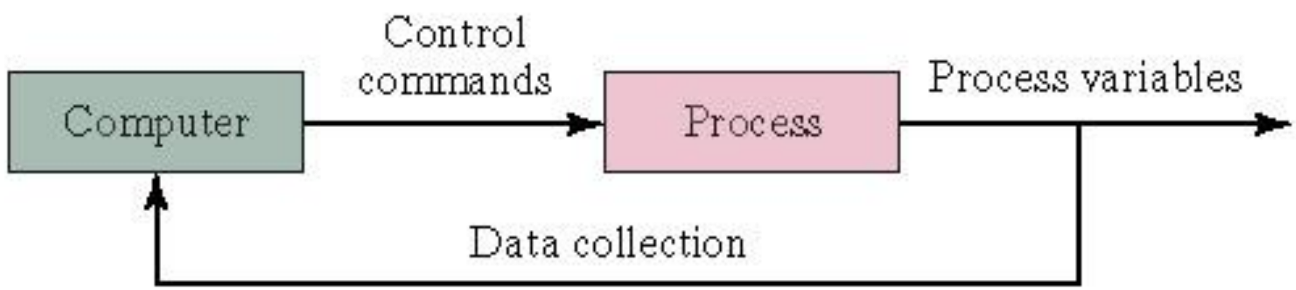
(a) Process Monitoring, (b) Open-Loop Control, and (c) Closed-Loop Control

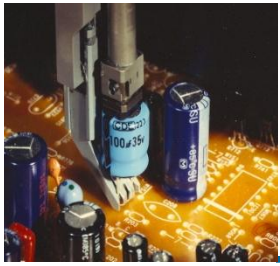
(a)

(b)



(c)



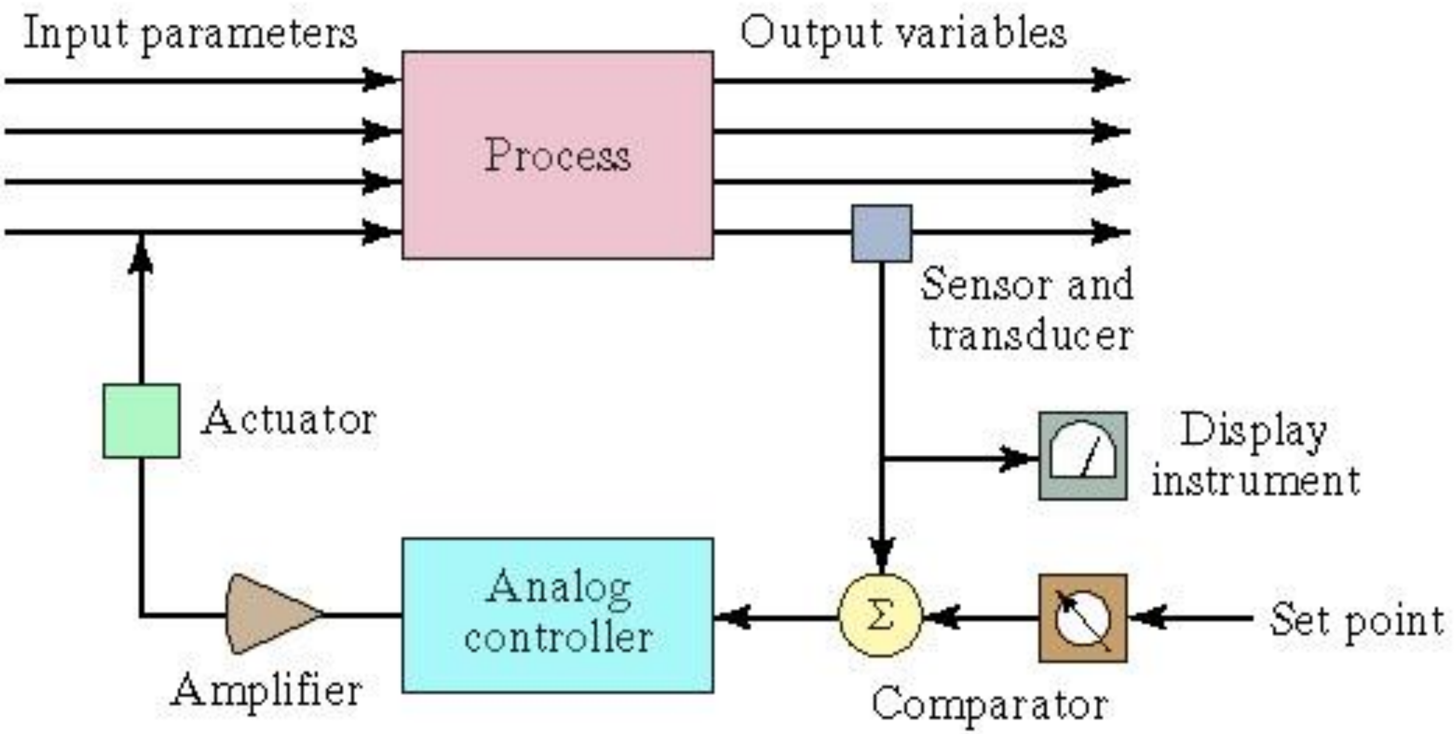


Direct Digital Control (DDC)

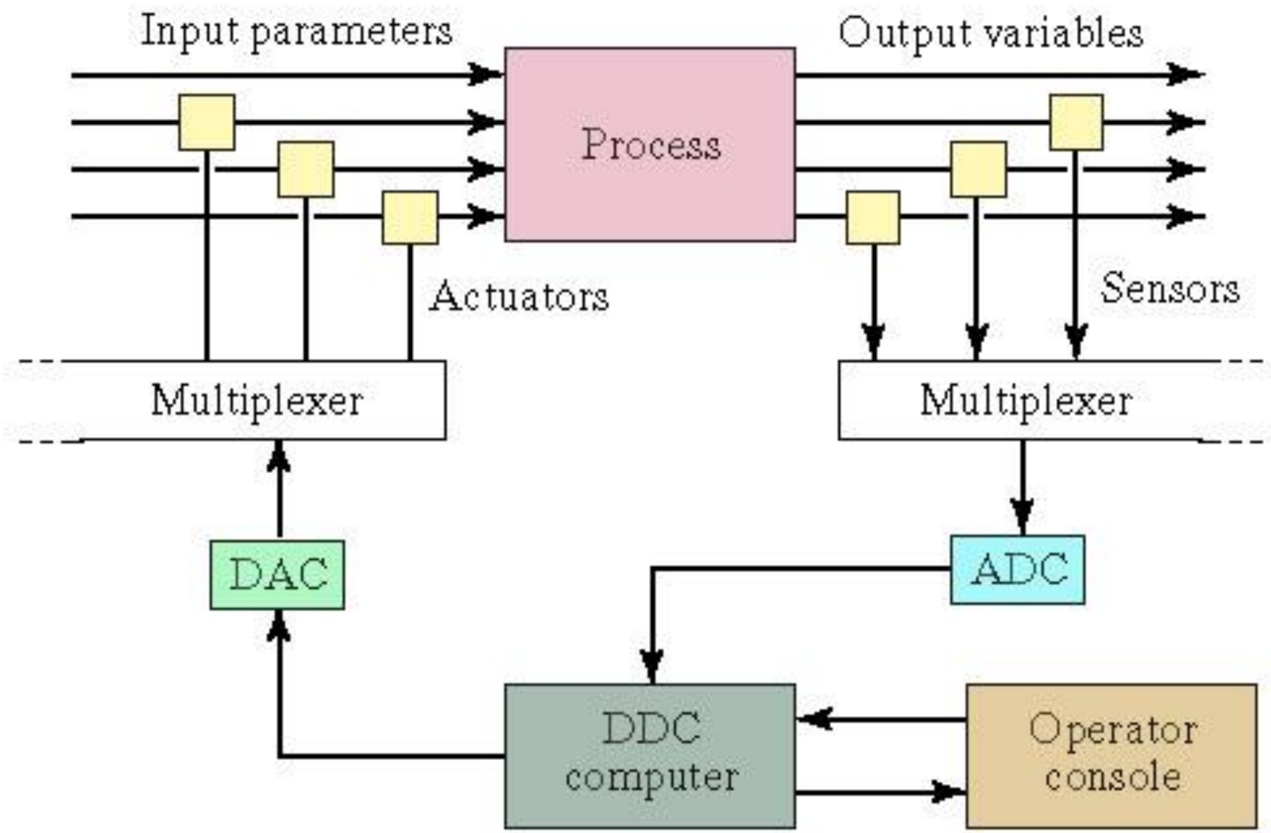
Form of computer process control in which certain components in a conventional analog control system are replaced by the digital computer

- Circa: 1960s using mainframes
- Applications: process industries
- Accomplished on a time-shared, sampled-data basis rather than continuously by dedicated components
  - Components remaining in DDC: sensors and actuators
  - Components replaced in DDC: analog controllers, recording and display instruments, set point dials

A Typical Analog Control Loop

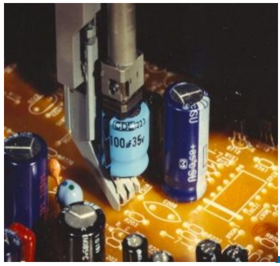


Components of a Direct Digital Control System



DDC (continued)

- Originally seen as a more efficient means of performing the same functions as analog control
- Additional opportunities became apparent in DDC:
  - More control options than traditional analog control (PID control), e.g., combining discrete and continuous control
  - Integration and optimization of multiple loops
  - Editing of control programs



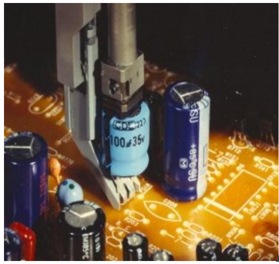
Numerical Control and Robotics

- Computer numerical control (CNC) – computer directs a machine tool through a sequence of processing steps defined by a program of instructions
  - Distinctive feature of NC – control of the position of a tool relative to the object being processed
  - Computations required to determine tool trajectory
- Industrial robotics – manipulator joints are controlled to move and orient end-of-arm through a sequence of positions in the work cycle

Programmable Logic Controller (PLC)

Microprocessor-based controller that executes a program of instructions to implement logic, sequencing, counting, and arithmetic functions to control industrial machines and processes

- Introduced around 1970 to replace electromechanical relay controllers in discrete product manufacturing
- Today's PLCs perform both discrete and continuous control in both process industries and discrete product industries



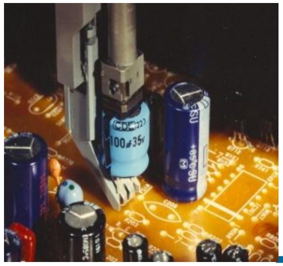
Supervisory Control

In the process industries, supervisory control denotes a control system that manages the activities of a number of integrated unit operations to achieve certain economic objectives

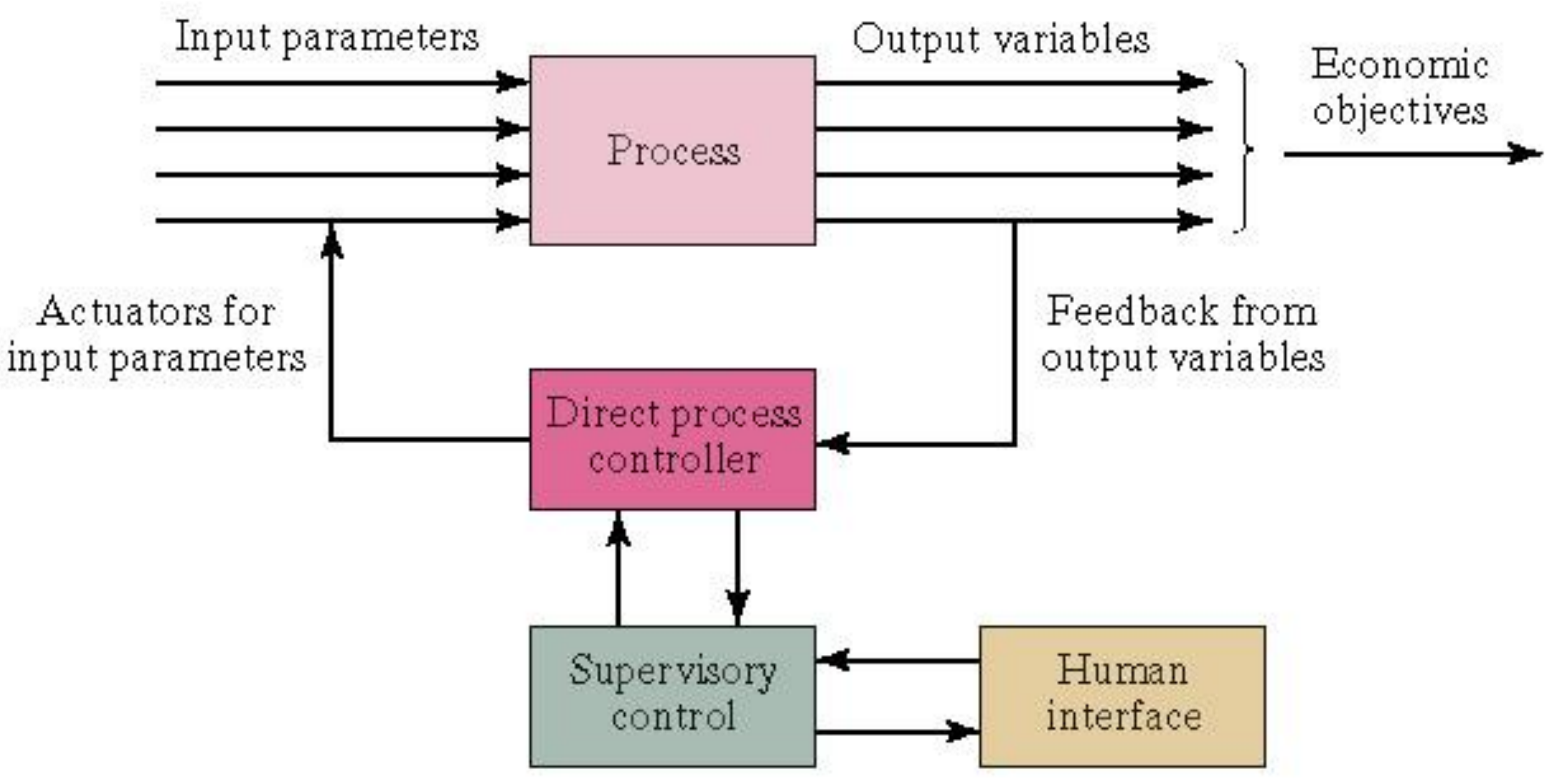
In discrete manufacturing, supervisory control is the control system that directs and coordinates the activities of several interacting pieces of equipment in a manufacturing system

- Functions: efficient scheduling of production, tracking tool lives, optimize operating parameters

- Most closely associated with the process industries



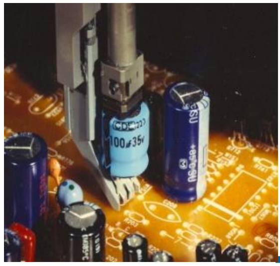
Supervisory Control Superimposed on Process Level Control System



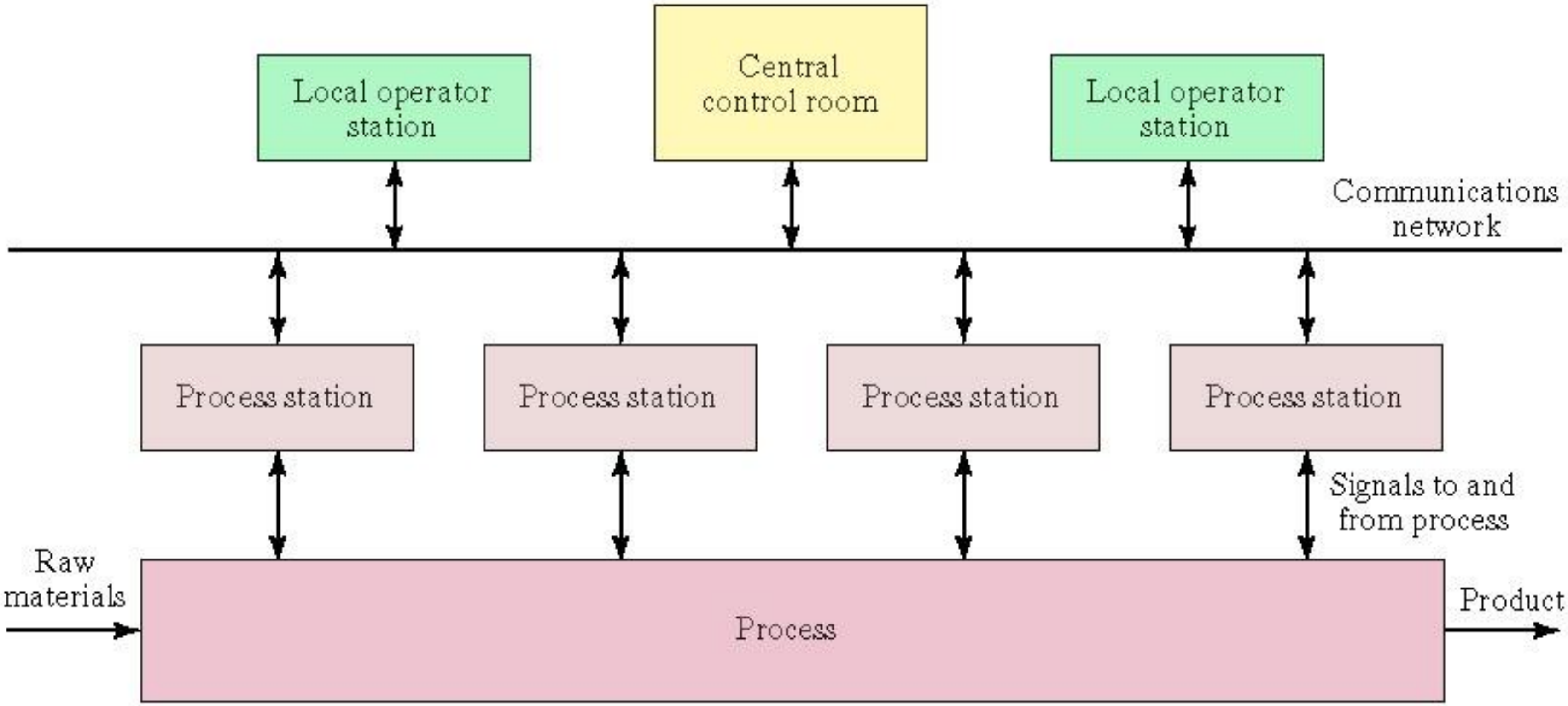
Distributed Control Systems (DCS)

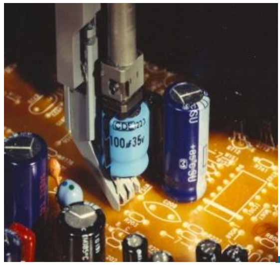
Multiple microcomputers connected together to share and distribute the process control workload

- Features:
  - Multiple process control stations to control individual loops and devices
  - Central control room where supervisory control is accomplished
  - Local operator stations for redundancy
  - Communications network (data highway)



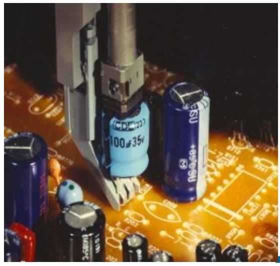
Distributed Control System





DCS Advantages

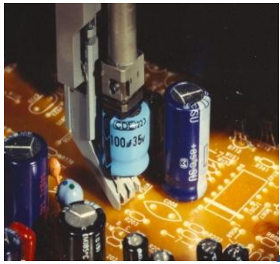
- Can be installed in a very basic configuration, then expanded and enhanced as needed in the future
- Multiple computers facilitate parallel multitasking
- Redundancy due to multiple computers
- Control cabling is reduced compared to central controller configuration
- Networking provides process information throughout the enterprise for more efficient plant and process management



PCs in Process Control

Two categories of personal computer applications in process control:

1. Operator interface – PC is interfaced to one or more PLCs or other devices that directly control the process
   - PC performs certain monitoring and supervisory functions, but does not directly control process
2. Direct control – PC is interfaced directly to the process and controls its operations in real time
   - Traditional thinking is that this is risky



Enablers of PCs for Direct Control

- Widespread familiarity of workers with PCs
- Availability of high performance PCs
  - Cycle speeds of PCs now exceed those of PLCs
- Open architecture philosophy in control system design
  - Hardware and software vendors comply with standards that allow their products to be interoperable
- PC operating systems that facilitate real-time control and networking
- PC industrial grade enclosures

Enterprise-Wide Integration of Factory Data

- Managers have direct access to factory operations
- Planners have most current data on production times and rates for scheduling purposes
- Sales personnel can provide realistic delivery dates to customers, based on current shop loading
- Order trackers can provide current status information to inquiring customers
- QC can access quality issues from previous orders
- Accounting has most recent production cost data
- Production personnel can access product design data to clarify ambiguities

Enterprise-Wide PC-based Distributed Control System