Factory Automation and Control Methods
Lecture 5: Industrial Control Systems

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Outline

- Process industries versus discrete manufacturing Industries
  - Level of automation
  - Variables and parameters in the two industries
- Continuous Versus Discrete Control
  - Continuous control systems
  - Discrete control systems
- Computer Process Control
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  - Capabilities of computer control
  - Forms of computer process control

What is industrial control?

"***Industrial control*** is defined here as the automatic regulation of unit operations and their associated equipment, as well as the integration and coordination of the unit operations in the larger production system."

Note: unit operations in this class refers to manufacturing processes.

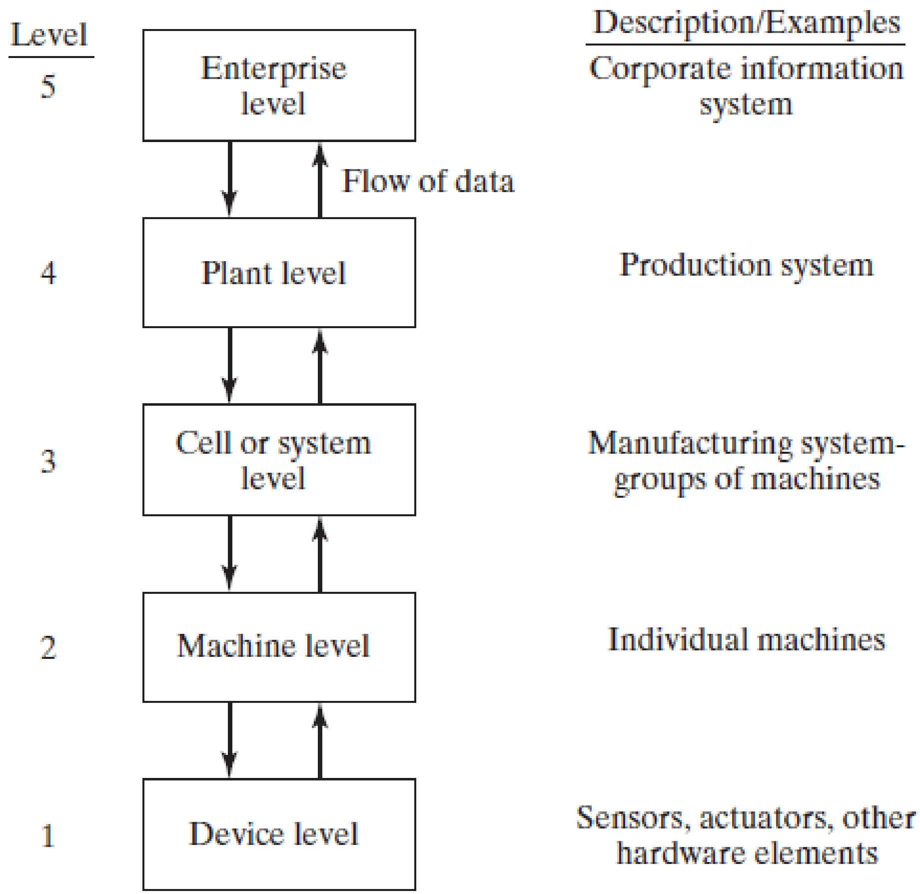
Process Industries Versus Discrete Manufacturing Industries

Industries and their production operations were divided into two basic categories:

- Process industries: perform their production operations on amounts of materials, because the materials tend to be liquids, gases, powders, etc.
- Discrete manufacturing industries: perform their operations on quantities of materials, because the materials tend to be discrete parts or productions.

Process Industries Versus Discrete Manufacturing Industry

Levels of Automation in the Two Industries



Process Industries Versus Discrete Manufacturing Industry

Levels of Automation in the Two Industries

Level	Process Industries	Discrete Manufacturing Industries
5	Enterprise level—management information system, strategic planning, high-level management of enterprise	Enterprise level—management information system, strategic planning, high-level management of enterprise
4	Plant level—scheduling, tracking materials, equipment monitoring	Plant or factory level—scheduling, tracking work-in-process, routing parts through machines, machine utilization
3	Supervisory control level—control and coordination of several interconnected unit operations that make up the total process	Manufacturing cell or system level—control and coordination of groups of machines and supporting equipment working in coordination, including material handling equipment
2	Regulatory control level—control of unit operations	Machine level—production machines and workstations for discrete product manufacture
1	Device level—sensors and actuators comprising the basic control loops for unit operations	Device level—sensors and actuators to accomplish control of machine actions

Process Industries Versus Discrete Manufacturing Industry

Variables and parameters in the two industries

In the process industries, the variables and parameters of interest tend to be continuous, whereas in discrete manufacturing, they tend to be discrete.

Process Industries	Discrete Manufacturing Industries
Chemical reactions	Casting
Comminution	Forging
Chemical vapor deposition	Extrusion
Distillation	Machining
Mixing and blending of ingredients	Plastic molding
Separation of ingredients	Sheet metal stamping

Process Industries Versus Discrete Manufacturing Industry

Variables and parameters in the two industries

A ***continuous variable*** (or parameter) is one that is uninterrupted as time proceeds, at least during the manufacturing operation.
Ex. force, temperature, flow rate, pressure, and velocity.

A ***discrete variable*** (or parameter) is one that can take on only certain values within a given range. Ex. limit switch open or closed, motor on or off, and work part present or not present in a fixture

Continuous Versus Discrete Control

- Process industries tend to emphasize the control of continuous variables and parameters.
- Manufacturing industries produce discrete parts and products, and their controllers tend to emphasize discrete variables and parameters.

There are also two basic types of control:

- Continuous control, in which the variables and parameters are continuous or analog
- Discrete control, in which the variables and parameters are discrete.

Continuous Versus Discrete Control

Comparison Factor	Continuous Control in Process Industries	Discrete Control in Discrete Manufacturing Industries
Typical measures of product output	Weight measures, liquid volume measures, solid volume measures	Number of parts, number of products
Typical quality measures	Consistency, concentration of solution, absence of contaminants, conformance to specification	Dimensions, surface finish, appearance, absence of defects, product reliability
Typical variables and parameters	Temperature, volume flow rate, pressure	Position, velocity, acceleration, force
Typical sensors	Flow meters, thermocouples, pressure sensors	Limit switches, photoelectric sensors, strain gages, piezoelectric sensors
Typical actuators	Valves, heaters, pumps	Switches, motors, pistons
Typical process time constants	Seconds, minutes, hours	Less than a second

Comparison between continuous and discrete control

Continuous Versus Discrete Control

Continuous control systems

In continuous control, the usual objective is to maintain the value of an output variable at a desired level.

There are several ways to achieve the control objective in continuous process control systems such as

- Regulatory control
- Feedforward control
- Steady-state optimization
- Adaptive control
- ……

Continuous Versus Discrete Control

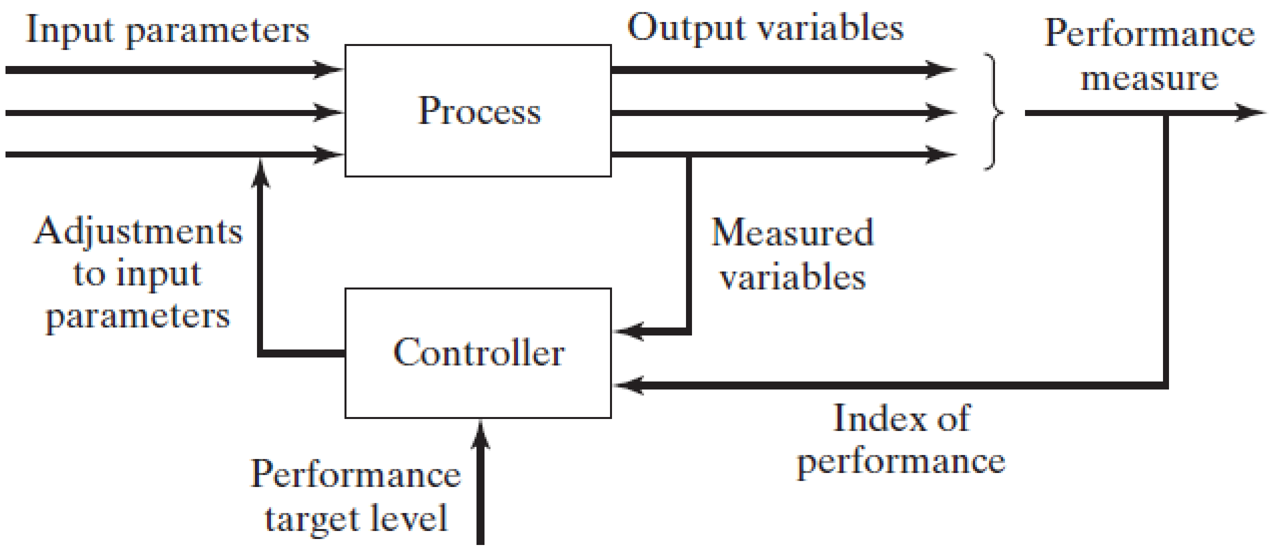
Continuous control systems

Regulatory Control: the objective is to maintain process performance at a certain level or within a given tolerance band of that level.

Applications: appropriate when the performance attribute is some measure of product quality, and it is important to keep the quality at the specified level or within a specified range.

Continuous Versus Discrete Control

Continuous control systems

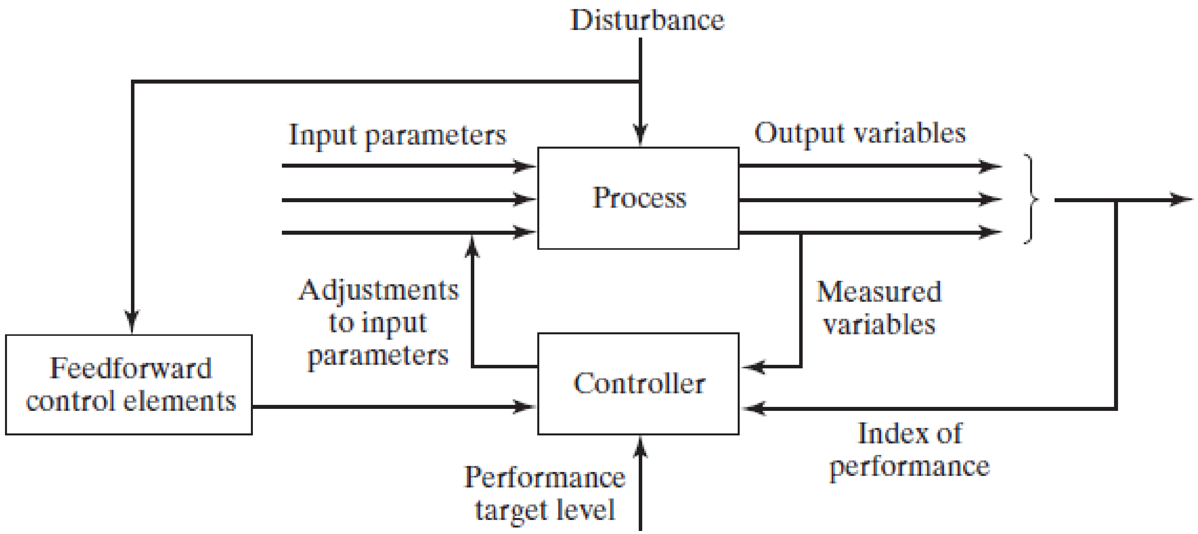


Note: The trouble with regulatory control (and also with a simple feedback control loop) is that compensating action is taken only after a disturbance has affected the process output. An error must be present for any control action to be taken.

Continuous Versus Discrete Control

Continuous control systems

Feedforward Control: anticipate the effect of disturbances that will upset the process by sensing them and compensating for them before they affect the process.



Note: In the ideal case, the compensation is completely effective. However, complete compensation is unlikely because of delays and/or imperfections in the feedback measurements, actuator operations,

Continuous Versus Discrete Control

Continuous control systems

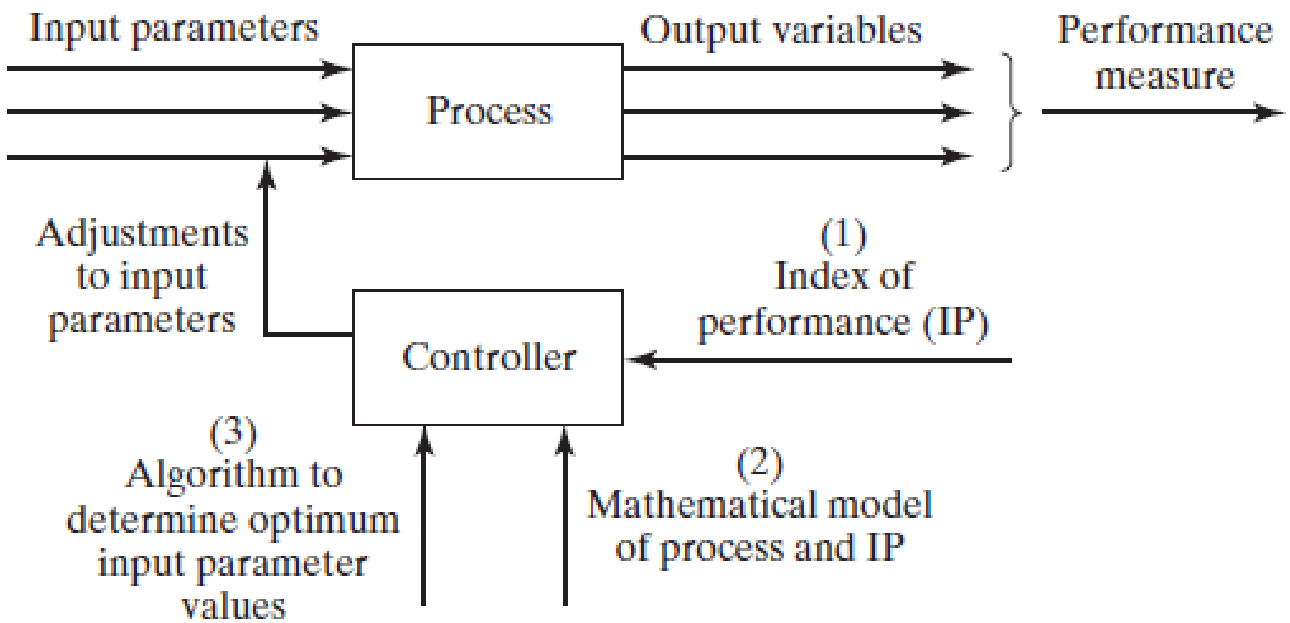
Steady-State Optimization. This term refers to a class of optimization techniques in which the process exhibits the following characteristics:

- there is a well-defined index of performance, such as product cost, production rate, or process yield.
- the relationship between the process variables and the index of performance is known
- the values of the system parameters that optimize the index of performance can be determined mathematically.

When these characteristics apply, the control algorithm is designed to make adjustments in the process parameters to drive the process toward the optimal state.

Continuous Versus Discrete Control

Continuous control systems



Steady-state (open loop) optimal control

Continuous Versus Discrete Control

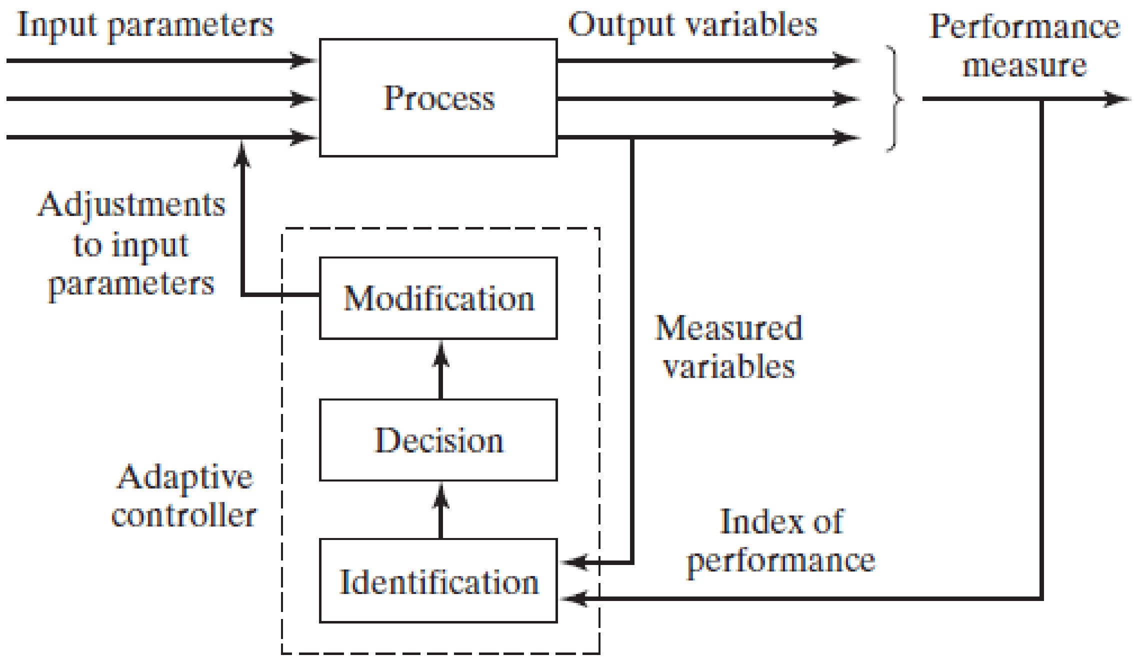
Continuous control systems

Steady-state optimal control operates as an open-loop system. It works successfully when there are no disturbances. When such disturbances are present in the application, a self-correcting form of optimal control can be used, called
adaptive control.

Continuous Versus Discrete Control

Continuous control systems

Adaptive Control



Continuous Versus Discrete Control

Discrete control systems

- In discrete control, the parameters and variables of the system are changed at discrete moments in time, and the changes involve variables and parameters that are also discrete, typically binary (ON/OFF).

- The changes are defined in advance by means of a program of instructions, for example, a work cycle program. The changes are executed either because the state of the system has changed or because a certain amount of time has elapsed.

Continuous Versus Discrete Control

Discrete control systems

These two cases can be distinguished as

- Event-driven changes: executed by the controller in response to some event that has caused the state of the system to be altered.

  Ex. Counting parts moving along a conveyor, A robot loads a work part into the fixture,…

- Time-driven changes: executed by the control system either at a specific point in time or after a certain time lapse has occurred.

  Ex. Heat-treating operations, operation of a washing machine,

References

Mikell P. Groover, "Automation, Production Systems and Computer-integrated Manufacturing" , 4th edition, Pearson, chapter 2

Computer Process Control

Control requirement

A ***real-time controller*** is a controller that is able to respond to the process within a short enough time period that process performance is not degraded.

Real-time control usually requires the controller to be capable of ***multitasking***, which means coping with multiple tasks concurrently without the tasks interfering with one another.

Computer Process Control

Control requirement

There are two basic requirements that must be managed by the controller to achieve real-time control:

Process-initiated interrupts **:** The controller must be able to respond to incoming signals from the process. The computer may need to interrupt execution of a current program to service a higher-priority need of the process.

A process-initiated interrupt is often triggered by abnormal operating conditions, indicating that some corrective action must be taken promptly.

Computer Process Control

Control requirement

Timer-initiated actions: The controller must be capable of executing certain actions at specified points in time. Timer-initiated actions can be generated at regular time intervals.

Ex. scanning sensor values from the process at regular sampling intervals, turning on and off switches, motors, and other binary devices associated with the process at discrete points in time during the work cycle, displaying performance data on the operator’s console at regular times during a production run, and recomputing optimal process parameter values at specified times.

Computer Process Control

Control requirement

These two requirements correspond to the two types of changes mentioned previously in the context of discrete control systems: (1) event-driven changes and (2) time-driven changes.

Computer Process Control

Control requirement

In addition to these basic requirements, the control computer must also deal with other types of interruptions and events. These include the following

3. *Computer commands to process*. In addition to receiving incoming signals from the
process, the control computer must send control signals to the process to accomplish
a corrective action. These output signals may actuate a certain hardware device or readjust a set point in a control loop.

Computer Process Control

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4. *System- and program-initiated events*. These are events related to the computer system itself. They are similar to the kinds of computer operations associated with business and engineering applications of computers. A system-initiated event involves communications among computers and peripheral devices linked together in a network. In these multiple computer networks, feedback signals, control commands, and other data must be transferred back and forth among the computers in the overall control of the process. A program-initiated event occurs when the program calls for some non-process-related action, such as the printing or display of reports on a printer or monitor. In process control, system- and program-initiated events generally occupy a low level of priority compared with process interrupts, commands to the process, and timer-initiated events.

Computer Process Control

Control requirement

In addition to these basic requirements, the control computer must also deal with other types of interruptions and events. These include the following

5. Operator-initiated events. Finally, the control computer must be able to accept input
from operating personnel. Operator-initiated events include (1) entering new programs;
(2) editing existing programs; (3) entering customer data, order number,
or startup instructions for the next production run; (4) requesting process data; and (5) calling for emergency stops.

Computer Process Control

Capabilities of computer control

The above requirements can be satisfied by providing the controller with certain capabilities that allow it to interact on a real-time basis with the process and the operator. These capabilities are

(1) polling
(2) interlocks,
(3) interrupt system, and
(4) exception handling.

Computer Process Control

Capabilities of computer control

Polling. In computer process control, polling refers to the periodic sampling of data that indicates the status of the process.

Computer Process Control

Capabilities of computer control

Interlocks. An interlock is a safeguard mechanism for coordinating the activities of two or more devices and preventing one device from interfering with the other(s).

Computer Process Control

Capabilities of computer control

Interrupt System. Closely related to interlocks is the interrupt system. There are occasions when it becomes necessary for the process or operator to interrupt the regular controller operation to deal with more pressing matters. All computer systems are capable of being interrupted, if nothing else, by turning off the power.

Computer Process Control

Capabilities of computer control

Exception Handling. In process control, an exception is an event that is outside the normal or desired operation of the process or control system. Dealing with the exception is an essential function in industrial control and generally occupies a major portion of the control algorithm.

Computer Process Control

Forms of computer process control

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