Unit 3 Industrial Control Systems

Assigned Core Text Reading for this Unit:

3.1 Unit Introduction
3.2 Unit Learning Objectives
3.3 Basic Elements of an Automated System
3.4 Advanced Automation Functions
3.5 Levels of Automation
3.6 Process and Discrete Industries
3.7 Continuous Versus Discrete Control
3.8 Computer Process Control
3.9 Unit Review
3.10 Self-Assessment Questions
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Section 3.1 Unit Introduction

Automation is defined as the technology that is applied to accomplish a process or procedure without human assistance. It is characterised by having a programme of instructions and a control system for programme execution. Power is required to drive the programme and its control system. Sensors and actuators (e.g. motors) are also frequently required to allow the control system interact with the process that is being automated.

Throughout this unit we investigate technologies that have been developed to automate manufacturing operations. Automation and control technologies hold a considerable place in the larger scheme of the manufacturing system; they are deployed right across the gambit of the manufacturing technologies, and assist and power manufacturing processes and assembly operations.

LEARNING ACTIVITY 3.1
The history of the development of automation, when considered from the development of basic mechanical devices in ancient times, to the creation of modern computing systems, has a long and complex history. Investigate various facets of the concept’s history at www.wikipedia.org, keyword: automation
END LEARNING ACTIVITY 3.1

We begin this unit with a survey of automation and discuss the basic elements of an automated system: the automated programme of instructions, the control system, and the power used to drive the system and sensors and actuators. We look at large computer integrated systems of automation for controlling entire factories.
The application of automation is examined from the point of view of process industries and discrete manufacturing industries. This leads on to an examination of the forms of control that can be implemented across both industry types, from continuous control to discrete control. Finally, we investigate computer process control systems which, from their emergence in the late 1950s, have increasingly dominated the automation environment especially across manufacturing industries.

Section 3.2 Unit Learning Objectives

After completing this unit you will be able to:

BULLET LIST
List the basic elements of an automation system

Outline the difference between process parameters and process variables

Outline two types of control systems

Explain what makes advanced automation functions possible

State the automation levels hierarchy

State differences between process industries and discrete manufacturing industries

Explain differences between continuous control and discrete control

List methods that can be used by continuous control systems to achieve the control objective

Define an event-driven change and a time-driven change

List control requirements to allow computer process control systems to reach real-time control

List various forms of computer process monitoring and computer process control in use today
ENDLIST
Section 3.3 Basic Elements of an Automated System

Automation consists of three basic elements when applied to a particular transformation process: power to achieve the process and operate the system; a programme of instructions to direct the process; and a control system to actuate the instructions. The control systems can be further divided into the controller and its sensors and actuators that interact physically with the transformation process. Power is generally applied to operate both the programme of instructions and the control system (See Figure 3.1). The program of instructions are typically stored and executed in the control system. We can look at each of these basic elements in turn.

KEYPOINT
Automation consists of three basic elements: power; a programme of instructions; and a control system to actuate the instructions and sense feedback from the transformation process.

END KEYPOINT

Figure 3.1: Three elements of automation

The chief source of power used in automated systems comes in the form of electricity. Electrical power has the following advantages:

BULLETLIST
It is widely available and is relatively cheap

It can be converted into mechanical, thermal, light, acoustic, hydraulic, and pneumatic energy forms to suit different automated processes

It can accomplish a wide variety of functions, such as signal transmission, information processing, and data storage and communication
It can be conveniently stored in the form of battery power for later use, or for off-location use.

Alternative power sources include: fossil fuels, solar energy, water and wind; however, their exclusive use is rare in automated systems. If required at all, it is usually in conjunction with electrical power, whereby electricity is used to run the control system, and the alternative power source the process itself.

A list of common manufacturing processes and their associated power forms are given in Table 3.1. The power 'source' for practically all of these power 'forms' is electrical energy. Power is also used in the material handling system, to load and unload the work unit, to place parts—often with human assistance, and to move materials between locations.

Table 3.1: Common manufacturing processes and their associated power forms

<table>
<thead>
<tr>
<th>Process</th>
<th>Power form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casting</td>
<td>Thermal power for melting metal</td>
</tr>
<tr>
<td>Electric discharge machining</td>
<td>Electrical power to remove metal by electrical discharge</td>
</tr>
<tr>
<td>Forging</td>
<td>Mechanical power to deform metal parts, and thermal power to heat parts</td>
</tr>
<tr>
<td>Heat treating</td>
<td>Thermal power to heat parts</td>
</tr>
<tr>
<td>Injection moulding</td>
<td>Thermal power applied to make polymers highly plastic, mechanical power for injection</td>
</tr>
<tr>
<td>Laser beam cutting</td>
<td>Light power used to cut material, thermal power used for vaporisation and melting</td>
</tr>
<tr>
<td>Machining</td>
<td>Mechanical power used to cut and metal parts</td>
</tr>
<tr>
<td>Sheet metal punching and blanking</td>
<td>Mechanical power for shearing</td>
</tr>
<tr>
<td>Welding</td>
<td>Thermal power to heat and coalesce different metal parts</td>
</tr>
</tbody>
</table>

The programme of instructions used by the automated system is the series of controlled actions that are carried-out in the manufacturing or assembly process. Parts or products are usually processed as part of a work cycle, and it is within this work cycle structure that programme steps may be defined, hence the term work cycle programmes. In numerical control work cycle programmes are called part programmes. Program of instructions can also be called software program.

**KEYPOINT**

The programme of instructions is a series of controlled actions that are carried-out in the manufacturing or assembly process.

**END KEYPOINT**

The content and complexity of work cycle programmes depends very much upon the number and process-content of the steps involved in the work cycle. A work cycle of one step contains the simplest type of automated processes, and hence
the most simplistic programme levels; an example is the maintenance of a furnace at a designated temperature during a work process.

For more complicated systems the work cycle consists of a number of work steps that are repeated with no deviation from one cycle to the next. An example of this work cycle can be drawn from discrete-part manufacturing operation systems, and consists of the following steps:

NUMLIST
Load part into production machine
Perform process
Unload part from production machine
ENDLIST

Throughout each step process parameters are being changed. Process parameters are inputs to the process, such as the initial process settings, and can be distinguished from process variables, which are outputs from the process—these include actual process settings as the process is being performed. Different process parameters may be changed in each step. See Figure 3.2.

![Diagram](image)

Figure 3.2: Process parameters and variables for closed loop control system

**KEYPOINT**
Process parameters are inputs to the process; process variables are outputs from the process.

**END KEYPOINT**

In the past, programmes of instructions were often based upon a series of limit switches, timers, cams and other mechanical effects, which—when operated—controlled the work cycle. While they operated adequately they were highly inflexible.
Physical programmes have been replaced, for the most part, by soft programmes developed to be operated by computing systems. Physical components, such ascams, timers etc. have been replaced by modern storage technologies, such as magnetic tape, diskettes, CDs and computer memory; while, with the removal of the physical element of the programme, updates and changes, may be scheduled quickly and with no appreciable delay in production.

**KEYPOINT**
Programmes of instructions may be based upon physical components or more commonly upon computing systems.

**END KEYPOINT**

The control system interacts with the process through actuators (e.g. motors) and sensors (e.g. measuring distance). Input parameters to the controller are converted to signals that release power to the actuators. The output parameters from the process are converted by the sensors into signals that are fed back to the controller and typically compared with the input parameters (see Figure 3.2).

Work cycles in a typical process may be mixed—that is, work cycles may contain human and automated process steps. In such scenarios the automated programme of instructions may be simplified and/or made more flexible, by the assumption that some difficult work steps will be performed by human operators.

Some automated manufacturing operations require decisions to be made during the programmed work cycle to cope with variations that may arise within the cycle. In other cases variations are routine elements that are incorporated into the regular part programme. These cases include: operator interaction—that is, the human input of data that allows automated equipment to function, or choose between decision-types; different part or product styles processed by the system—that is, depending upon the part or product entering the system the automated equipment is programmed to perform different work cycles; and variations in the starting work units—that is, handling inconsistencies that may arise from input parts or products.

**KEYPOINT**
Some automated manufacturing operations require decisions to be made by an operator during the programmed work cycle to cope with variations that will or may arise within the cycle.

**END KEYPOINT**

Infrequent and unexpected variations may also occur, such as equipment failure. In such cases programmes generally contain contingency instructions that carry it over the unexpected variation that has occurred.
The control system executes the programme of instructions. Two types may be encountered, a closed-loop control system, or an open loop control system. The two types are outlined in Table 3.2.

Table 3.2: Closed- and open loop control systems

<table>
<thead>
<tr>
<th>System</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed-loop</td>
<td>Also known as a feedback control system, it consists of a system whereby the output variable is compared with the input parameter, so that the system may be adjusted in future iterations so that the input and output come closer and closer together. There are six basic elements to the system: 1. the input parameter; 2. the process; 3. the output variable; 4. the feedback sensor; 5. the controller; and 6. the actuator. See Figure 3.2.</td>
</tr>
<tr>
<td>Open loop</td>
<td>An open loop system (see Figure 3.3) operates without a feedback loop; that is, there is no way for the system to compare its output against its input. Instead, confidence is placed in the correct performance of the actuator. It is generally a less expensive system to implement than a closed-loop system.</td>
</tr>
</tbody>
</table>

Generally closed-loop control systems are favoured, except in the following situations:

NUMLIST
Where control operations are simple

Where the actuator may be shown to be highly reliable

Where forces operating on the actuator are deemed to be insignificant
ENDLIST

KEYPOINT
There are two types of control systems: closed-loop and open loop.
END KEYPOINT

Input
Parameters

Controller  Actuators

Process

Figure 3.4: Open loop Control system.
LEARNING ACTIVITY 3.2
Use the internet or a company with which you are familiar to identify one example of an open loop and one example of a closed loop control system. Identify the various elements used in each system and how they operate. Describe how the control system works.

END LEARNING ACTIVITY 3.2

Section 3.4 Advanced Automation Functions

An automated system may also be capable of performing some advanced automation functions, not particularly associated with any work unit. These functions are generally concerned with the safety and performance of the equipment. Advanced automation functions are made possible by special subroutines included in the programme of instructions. Table 3.3 outlines particular advanced automation functions.

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety Monitoring</td>
<td>Automation systems can be designed to operate safely when human operators are in attendance. The automation system must also work in a way that is not self-destructive. It therefore must protect the human operator, and its own equipment. Safety monitoring involves the use of sensors to track the system’s operation and to spot potentially unsafe working conditions. Based upon this monitoring, the system is programmed to take necessary measures to counteract the hazards met. Possible responses vary, from stopping the system, to warning operators, or taking corrective actions to remove the risk involved.</td>
</tr>
<tr>
<td>Maintenance and Repair Diagnostics</td>
<td>Complex equipment is generally harder to repair and maintain. Maintenance and repair diagnostics uses the system itself to participate in the identification and sourcing of malfunctions and failures of the system. There are three modes: status monitoring—key sensors and parameters are continually examined during system operation, to detect malfunctions as they might occur; failure diagnostics—this is invoked so that the cause of a failure can be identified; and recommendation of repair procedure—suggestions for repair procedures are supplied to the repair crew.</td>
</tr>
<tr>
<td>Error Detection and Recovery</td>
<td>An error detection and recovery system uses an interrupt subroutine: this allows the main programme to be interrupted, upon the detection of an error, so that a recovery subroutine may be run instead. In error detection the system’s sensors determine, interpret and classify an error when it occurs. Three types of errors may occur: random errors—which result from the normal stochastic nature of the process; systematic errors—which result from an assignable cause in material or equipment; and aberrations—which result from human mistakes or equipment failure. Collecting and classifying all possible errors is the largest problem in error detection.</td>
</tr>
</tbody>
</table>

KEYPOINT
Advanced automation functions are made possible by special subroutines included in the programme of instructions and include safety monitoring, maintenance and repair diagnostics, and error detection and recovery.

**END KEYPOINT**

**Section 3.5 Levels of Automation**

There are various levels at which automation can be applied in the context of the enterprise. A temperature sensor that feeds back information to a regular in a shower is a reasonably low level of automation. On the other hand a high level automation system is required to run a train system in a city. Five levels of automation can be identified and are outlined in Table 3.4.

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device level</td>
<td>The lowest level, it includes hardware components that comprise the machine level, such as actuators and sensors. Control loop devices are predominant here.</td>
</tr>
<tr>
<td>Machine level</td>
<td>Hardware at the device level is assembled into individual machines. Control functions at this level include performing the sequence of steps in the programme of instructions.</td>
</tr>
<tr>
<td>Cell or system level</td>
<td>This operates under instructions from the plant level. Consists of a group of machines or workstations connected and supported by a material handling system, computers and other appropriate equipment, including production lines.</td>
</tr>
<tr>
<td>Plant level</td>
<td>Factory or production systems level, it receives instruction from the corporate information system and translates them into operational plans for production.</td>
</tr>
<tr>
<td>Enterprise level</td>
<td>The highest level, it consists of the corporate information system, and is concerned with all the functions that are necessary to manage and coordinate the entire company.</td>
</tr>
</tbody>
</table>

**KEYPOINT**

Automation can be examined at five different levels, in a hierarchy that runs from the single device, the machine, the cell or system, the plant, to the enterprise level.

**END KEYPOINT**

**PROFESSIONAL TRANSFERABLE SKILLS [CRIT] [PROB] [WCOMM]**

**LEARNING ACTIVITY 3.3**

Use the internet or other information source to identify one example for each of the level of automation described in Table 3.4. Go online and identify specific vendors or suppliers for technology in each of the levels i.e. what systems can be purchased to provide enterprise level automation and so on. Write a brief report of your findings.

**END LEARNING ACTIVITY 3.3**

**Section 3.6 Process Industries and Discrete Manufacturing Industries**
Having examined the basic elements and contents of automation, we can now look in more detail at industrial control systems. In unit 2 we divided industries and their production operations into process industries and discrete manufacturing industries. These labels are also useful here to describe the sorts of automation that occurs in each type of industry. Table 3.5 details the two industry types, and their respective automation uses for each level of automation.

<table>
<thead>
<tr>
<th>Level</th>
<th>Process Industry Automation</th>
<th>Discrete Manufacturing Industry Automation</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Corporate level: Management information systems; strategic planning systems; high-level management of enterprise</td>
<td>Corporate level: Management information systems; strategic planning systems; high-level management of enterprise</td>
</tr>
<tr>
<td>4</td>
<td>Plant level: Scheduling; tracking materials; equipment monitoring</td>
<td>Plant or factory level: Scheduling; tracking work-in-process; routing parts through machines; machine utilisation</td>
</tr>
<tr>
<td>3</td>
<td>Supervisory control level: control and co-ordination of several interconnected unit operations that make up the total process</td>
<td>Manufacturing cell or system level: control and co-ordination of groups of machines and supporting equipment working in co-ordination, including material handling equipment</td>
</tr>
<tr>
<td>2</td>
<td>Regulatory control level: Control of unit operations</td>
<td>Machine level: Production machines and workstations for discrete part and product manufacture</td>
</tr>
<tr>
<td>1</td>
<td>Device level: Sensors and actuators comprising the basic control loops for unit operations</td>
<td>Device level: Sensors and actuators to accomplish control of machine actions</td>
</tr>
</tbody>
</table>

Significant variations exist at lower levels owing to the differences in devices and equipment used in the two industries. At higher levels, the control of the unit, or the control of machinery provides the basis for the differences between levels two and three. Levels four and five are, in comparison, fairly similar across both process industries and discrete manufacturing industries.

Figure 3.5: Process and discrete industries respectively
KEYPOINT
Automation is applied differently across process industries and discrete manufacturing industries, especially at the lower levels of automation.

END KEYPOINT

The variables and parameters used by the productive operations of the two industries also differ significantly. In process industries variables and parameters tend to be continuous; in discrete manufacturing industries they tend to be discrete. A continuous variable or parameter is one that is uninterrupted as time proceeds: it is considered to be analogue—that is, it can take on any value within a certain range; examples include 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: the most common examples are binary (open/closed, on/off, etc.), and discrete other than binary—that is, it can take on more than two possible values but less than an infinite number.

KEYPOINT
In process industries variables and parameters tend to be continuous control; in discrete manufacturing industries they tend to be discrete control.

END KEYPOINT

Section 3.7 Continuous Versus Discrete Control

There are two types of control: continuous control, and discrete control. In continuous control the variables and parameters are continuous and analogue; in discrete control the variables and parameters are discrete—mostly in binary format. Continuous and discrete control factors are compared in Table 3.6.

Table 3.6: Continuous and discrete control

<table>
<thead>
<tr>
<th>Factor</th>
<th>Continuous control (process industries)</th>
<th>Discrete control (discrete manufacturing industries)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product output measures</td>
<td>Weights, liquid volumes, solid volumes</td>
<td>Numbers of parts and products</td>
</tr>
<tr>
<td>Quality measures</td>
<td>Consistency, solution concentration, absence of contaminants, specification conformance</td>
<td>Dimensions, surface finish, appearance, absence of defects, product reliability</td>
</tr>
<tr>
<td>Variables and parameters</td>
<td>Temperature, volume flow rate, pressure</td>
<td>Position, velocity, acceleration, force</td>
</tr>
<tr>
<td>Sensors</td>
<td>Flow meters, thermocouples, pressure sensors</td>
<td>Limit switches, photoelectric sensors, strain gauges, piezoelectric sensors</td>
</tr>
<tr>
<td>Actuators</td>
<td>Valves, heaters, pumps</td>
<td>Switches, motors, pistons</td>
</tr>
<tr>
<td>Process time constraints</td>
<td>Seconds, minutes, hours</td>
<td>Less than a second</td>
</tr>
</tbody>
</table>

KEYPOINT
There are two types of control: continuous control—where the variables and parameters are continuous and analogue; and discrete control—where the
variables and parameters are discrete—mostly binary or two state format e.g. on or off.

**END KEYPOINT**

In reality a combination of both control types actually exist in both process and discrete manufacturing industries. This means industrial controllers have to be designed to capture both data forms – continuous and discrete. Further, with the emergence of computer systems taking-over from out-dated analogue controllers, continuous process variables have started to be measured in samples, thus creating a discrete sample-data system that approximates the actual continuous system. One example of a controller that uses both continuous and discrete control and where continuous control is achieved using frequent sampling of continuous data is the Lego NXT controller illustrated in Figure 3.6.

Continuous control systems have as their objective the maintenance of an output value at a desired level, in a similar fashion to the operation of a closed-loop control system, as described earlier. In reality, continuous control systems are often segmented into smaller parts, with many feedback loops, all of which have to be individually controlled and co-ordinated, so as to maintain the overall output variable. Continuous control systems are to be found throughout the chemical industry, where many parameters related to chemical reactants—such as temperature, pressure, and flow rates—must be maintained. They are also to be found in conventional manufacturing systems, in certain situations, such as the positioning of a work-part relative to a cutting tool by using x, y, z co-ordinates.

![Figure 3.6: NXT controller with three actuators (motors) and four sensors](image)

**KEYPOINT**

Continuous control systems have as their objective the maintenance of an output value at a desired level. Often, however, continuous control systems may be segmented into smaller parts, all of which have to be individually controlled and co-ordinated, so as to maintain the overall output variable.
Continuous control systems can achieve its control objective in a number of ways; these are reviewed in Table 3.7.

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulatory control</td>
<td>Objective is to maintain process performance at a certain level or within a given tolerance band of that level. Performance measures, or the index of performance, is calculated based on the output of several variables. Disadvantage with regulatory control is that compensatory actions can only occur after a disturbance, and not before.</td>
</tr>
<tr>
<td>Feed-forward control</td>
<td>Objective is to anticipate the effect of disturbances on the system, and to compensate for them before they can occur. Corrective action takes place as the process is ongoing, by the correction of variables that act as new inputs (i.e. a feed-forward) into the system. Disadvantage is a reliance upon measurement of variables in mid-process, which may not be 100% accurate, thus affecting final output variables. Feed-forward control often combined with feedback control in many models to overcome problems.</td>
</tr>
<tr>
<td>Steady-state optimisation</td>
<td>Open-loop control system that uses performance measures, the index of performance, mathematical models of the process, and optimisation algorithms to determine input parameters, to drive the process. The control system is effectively separate from the process system, and relies upon the quality and excellence of its performance models to input correctly suitable input parameters to achieve required output variables. Disadvantage is obviously related to the creation and maintenance of such accurate performance models for the control system, which can be affected by disturbances to the process system not accounted for in the control system design.</td>
</tr>
<tr>
<td>Adaptive control</td>
<td>To overcome the disturbances which steady-state optimisation is prone to, adaptive control uses feedback control and optimisation by combining both practices. Feedback is provided in its usual guise by the system, but the results are then utilised by a control algorithm that attempts to optimise an index of performance, as in the steady-state optimisation system. Thus adaptive control can cope with a time-varying environment, as its internal parameters and mechanisms are not fixed. It has three principle functions: the identification function—which determines a current index of performance, based upon feedback from the process system; the decision function—which determines what changes have to be made to improve performance, and alters input parameters accordingly; and the modification function—which implements the decision function's output.</td>
</tr>
<tr>
<td>On-line search strategies</td>
<td>Objective is to improve the adaptive control decision function, described above. Sometimes the decision function cannot be sufficiently defined; that is, the relationship between the input parameters and the index of performance is not known precisely enough to take action. In such cases experiments must be performed on the process to determine the appropriate input parameters to input. Small changes in experimental input parameters gives a pattern, or tendency, that controllers can used to implement input parameters with the confidence that they are correct. Techniques deployed in experiments range from trial-and-error methods, to gradient methods.</td>
</tr>
<tr>
<td>Others</td>
<td>There are some specialised techniques that may be used, including: learning systems, expert systems, neural networks, and artificial intelligence methods.</td>
</tr>
</tbody>
</table>

Table 3.7: Control objectives for continuous control systems
Continuous control systems can achieve its control objective in a number of ways; these include methods of: regulatory control; feed-forward control; steady-state optimisation; and adaptive control.

For discrete control systems, parameters and variables may change at discrete moments in time, with the parameters and variables themselves being discrete, typically binary discrete i.e. on or off. The changes are scheduled, for example as part of the work cycle, and are executed either because the system has changed, or because a certain period of time has elapsed. These two changes are called: event-driven changes; and time-driven changes.

An event-driven change occurs when the system is altered, for some reason, and the controller reacts to this alteration by executing some action in response. Examples of event-driven changes in manufacturing include: a status change for a production machine, from being idle to becoming active, which is triggered by the placing of a part into the machine’s work-fixture, thus starting the automatic machining cycle; and part-counting by a sensor on a conveyor belt, whereby the sensor—once it detects a part—triggers the movement of the conveyor.

A time-driven change is executed using time as the parameter of change; that is, after a specific quantity of time has elapsed, or at a specific point in time. The change occurs regardless of the status of the system, as in the event-driven change, but rather as a result of the time constraints imposed upon the system. As a result, for time-driven changes, the deployment of accurate timings is crucial for the change to operate effectively. Examples of time-driven changes in manufacturing include: specific starting and ending times of shift workers; and the length of time of heat treatments in some manufacturing processes.

Example
Here is very simple example of event driven change and timer driven change programme of instructions to a controller:

NUMBERLIST
Start up the machine
If the failsafe sensor is activated then apply alarm until sensor is deactivated
Heat the part for 10 seconds
Stop the machine
End If
END LIST

This program starts up a machine. It immediately begins sensing a failsafe sensor to see if it is activated or not. If sensor is not activated the cycle can continue otherwise the machine is stopped. This would be an event driven change. The machine is instructed to perform an operation (i.e. heating) for a time of ten seconds. The failsafe sensor is still being monitored and if activated the machine will stop. After ten seconds the machine is stopped. This is a time driven change. Finally, the sensing of the failsafe sensor is stopped (i.e. End If).

Section 3.8 Computer Process Control

With the advent of digital computers, and their initial exploitation in continuous process industries in the late 1950s, comes the concept of computer process control. Previously analogue controllers for continuous control systems, coupled with relay systems for discrete control implementation, dominated manufacturing system control. These systems were gradually replaced by computing systems throughout the 1960s and 70s, as computer technology embraced one innovation after another. Today, with the development of the computing microprocessor, we have a situation whereby virtually all industrial processes are controlled by one form or other of computer process control, based upon microprocessor technology.

Digital computers are programmed to coordinate and manage all aspect of continuous and discrete control of an automated system. The computer issues digital signals to actuators and receives digital signals from sensors. The computer communicates with non-digital actuators and sensors using digital to analogue converters (DAC) and analogue to digital converters (ADC). These converters are typically housed within separate circuitry to the computer controller but together make up a controller element of the control system.

KEYPOINT
Virtually all of today's industrial processes are controlled by computer process control in one form or another.
END KEYPOINT

There are a number of specific control requirements that are required if computer process control is to be made operable. These requirements typically revolve around the need to communicate and interact with the process on a real-time basis. A real-time controller is one which can respond to the process within a short enough time period to stop the onset of performance degradation. A real-time controller usually needs to be able to handle more than one task simultaneously, without letting them interfere with one another; this is called multi-tasking.
The control requirements to allow a computer process control system to reach real-time control are presented in Table 3.8. The first two requirements, process-initiated interrupts and timer-initiated actions, are deemed to be most important.

**Table 3.8: Control requirements for computer process control**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process-initiated interrupts</td>
<td>Controller must be able to respond to incoming signals from the process. This may involve prioritising tasks to be performed by the computer, as the emergence of higher priority issues must be dealt with first, regardless of their order of appearance. A typical example is abnormal working conditions requiring immediate corrective action.</td>
</tr>
<tr>
<td>Timer-initiated actions</td>
<td>Controller must have the ability to implement certain actions at specific points in time, as necessary. Time intervals can range from milliseconds to several minutes, depending on what action is being performed. Typical examples include the operation of sensors, switches, motors and other binary devices in the process, as necessary.</td>
</tr>
<tr>
<td>Computer commands to process</td>
<td>Controller must be able to send instructions to the process and have them obeyed.</td>
</tr>
<tr>
<td>System- and programme-initiated events</td>
<td>These relate to the commands and instructions that are passed between the computer system to itself, and to peripheral devices. System-initiated events refers to communication and control between networks of computers; programme-initiated events refers to communication and control between the computer and peripheral devices, such as monitors and printers.</td>
</tr>
<tr>
<td>Operator-initiated events</td>
<td>Controller must be able to accept input from operating personnel. Examples typically include: loading new programmes; entering performance instructions; requesting process data; etc.</td>
</tr>
</tbody>
</table>

**KEYPOINT**

A number of control requirements are necessary to allow a computer process control system to reach real-time control and include: process-initiated interrupts; timer-initiated actions; computer commands to the process; system- and programme-initiated events; and operator-initiated events.

**END KEYPOINT**

The above controller requirements provide it with a number of important system capabilities or specifications. These capabilities are outlined in Table 3.9.

**Table 3.9: Capabilities of computer control**

<table>
<thead>
<tr>
<th>Capability</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polling, or Data sampling</td>
<td>To understand the status of the process we must regularly sample, or poll, the process for its data. In general, whether the control system is discrete or continuous, polling occurs by sampling a discrete series of numerical values that represent the continuous or discrete signal of the process.</td>
</tr>
<tr>
<td>Interlocks</td>
<td>This prevents interference between devices when they are operating simultaneously. They allow for the sequencing of activities in a work cell, and ensure that one sequence of actions is complete before the next set start. Interlocks operate by regulating control signals between the device and controller. There are two types of interlock, defined relative to the controller: input interlocks—which uses a signal from an external device, and sends it to...</td>
</tr>
</tbody>
</table>
the controller; and an output interlock—which uses a signal from the controller, and sends it to the external device.

| Interrupt system | A feature that allows the execution of the current programme to be suspended or aborted, so as to allow the processing of more pressing programmes, at any moment in time. Typically, once the urgency is dealt with, the system can return to the break-off point in the interrupted programme and continue its operation. Two types exist: internal interrupts—which are generated by the computer itself; and external interrupts—which are generated outside the computer system. System designer must decide beforehand the priority of programmes, and which may be interrupted and which can’t. Different systems of prioritising interruptions have been developed, including single-level interrupt systems, and multi-level interrupt systems. |
| Exception handling | An exception is an event outside of normal operating procedures. Dealing with exceptions is of high-priority to the control system, and is a form of error detection and recovery, as dealt with earlier. |

**KEYPOINT**

Computer process controllers have the following capabilities: data sampling; interlocks; interrupt signals; and exception handling.

**END KEYPOINT**

Computers can be used to control a process via process monitoring or process control. As the names suggest, in process monitoring the computer is used as a facility to collect sufficient data from the process to build a picture of its operative performance; whereas in process control, which in turn can be broken-into open loop and closed-loop process control (based upon the delineation of those terms made previously), the computer has a direct impact upon the process itself, by acting as a regulator on its operation.

**KEYPOINT**

Computers can be used to control a process via process monitoring or process control.

**END KEYPOINT**
The various forms of computer process monitoring and computer process control systems that are in use today are listed in Table 3.10.

### Table 3.10: Forms of computer process control

<table>
<thead>
<tr>
<th>Form</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer process monitoring</td>
<td>The computer observes, collects and records data on the process, but is not used to directly control the process. Control is human-oriented, but use is made of the computer collected data in decision-making for the process. Three types of data may be collected: process data—such as process performance indicators, for example input parameters and output variables; equipment data—such as equipment status indicators, for example utilisation metrics, breakdown data etc.; and product data—performance metrics on product type, volumes or numbers etc.; often required by regulatory bodies.</td>
</tr>
<tr>
<td>Direct digital control</td>
<td>One of the first computer control systems, no longer in use, but showed the way forward for later innovations. First used as a more efficient substitute for the old analogue control loop, it replaced much existing analogue technology with 'direct digital' control facilitated by the computer. Later innovations meant that the concept became more than just a substitute for outdated technology, and, in time, it offered the following benefits in its own right: more control options than with analogue—that is, more complex control algorithms could be used; integration and optimisation of multiple loops—that is, it efficiently integrated multiple feedback loops and could optimise strategies for new input parameters; and the ability to edit control programmes—that is, unlike the hardware of analogue equipment, software control programmes could be reprogrammed and changed as necessary.</td>
</tr>
</tbody>
</table>
Direct digital control is a forerunner of distributed control systems (see below).

### Numerical control

Numerical control involves the use of a computer to direct a machine tool through a particular sequence of process steps defined by a programme of instructions specifying all necessary details. Geometric calculations are also involved as the work part is processed in three-dimensional space. Robotics is related to numerical control. A robot arm, or manipulator, is controlled by the movement of arm joints through a selected sequence of positions to carry-out the work task during a work-cycle. Typically the arm works with other production equipment with which it may be in communication with. Again geometric calculations are involved as the robotic arm moves through various positions.

### Programmable logic controllers

This is a micro-processor based controller that uses stored instructions in a programmable memory to implement logic, sequencing, timing, counting, and arithmetic control functions for controlling machines and processes.

### Supervisory control

A control system that is tightly integrated with lower systems of control (i.e. those in the rows above) to direct their overall operations. In both discrete manufacturing and in continuous process industries, supervisory control manages the activities of a number of units or production machinery based upon predefined parameters of performance. Supervisory control generally has an interface with human operators which allows it to be programmed to optimise specific performance parameters—such as economic or productivity metrics—which it can then monitor and oversee for the entire production unit.

### Distributed control systems

Thanks to the microprocessor, control could become distributed to multiple computer systems, and re-integrated as necessary via a communications network to a central control room. In this way, the following benefits have arisen: individual process control issues can be handled separately, but still integrated at an overall level; supervisory control could be run in the central control room to oversee distributed control systems; and local operator stations could be distributed across the plant to take-over control activities at a local level, or at an overall level, should central control fail. The system can be easily extended or reduced as necessary; it was found to be ideal for multi-tasking purposes; it had built-in redundancy, whereby other parts of the system could take-over should a specific locational failure occur; cabling was found to be reduced when compared against central computer control facilities; and the benefits of networking were felt plant-wide. See Figure 3.7.

### PCs in process control

PC implementations in manufacturing consist of operator interfaces, and direct control. As an operator interface PCs can be connected as peripheral devices, or as more integral parts of the control system. In this capacity the PC performs a human-led monitoring and supervisory function that can oversee all control operations of programmable logic controllers. PCs can also be used for direct control. PCs, in effect, have made the concept of the distributed control system far easier to operate and to populate; and with the general inexpensiveness of PCs this can be done without the heavy financial outlay that was once required. Certain issues with early PCs, such as their unsuitability for industrial environments, have been solved, and this has allowed them to be seriously considered for direct control purposes in the factory.

### Enterprise-wide integration of factory data

The widespread use of PCs, a flatter management structure, more administrative tasks done by operators, and the deployment of extensive networking technologies—all of these relatively recent innovations has led to a call for a greater consistency and coherence in the data that is produced in the factory. If possible it should be streamlined, efficiently stored, and made available wherever and whenever it is necessary.
KEYPOINT
There are various forms of computer process monitoring and computer process control in use today; these include: numerical control and robotics; programmable logic controllers; supervisory control; distributed control systems; Personal Computers; and enterprise-wide integration of factory data.
END KEYPOINT

Enterprise wide control systems have emerged that use complex networks of computers and associated management software to control the entire production system. Enterprise resource planning (ERP) systems for example can be used to control a large number of subsystems (See Figure 3.8). a computer software system that achieves company-wide integration of not only factory data but all other data required to execute the business functions of the organisation.

Figure 3.8: Enterprise wide integration of factory data

PROFESSIONAL TRANSFERABLE SKILLS [CRIT] [PROB] [WCOMM] [NETW]
LEARNING ACTIVITY 3.4
Use the internet to research the Lego NXT controller and associated sensors and actuators (See Figure 3.6). Discover how the controller was invented and how it is designed to operate through its various sensors and actuators.
END LEARNING ACTIVITY 3.4
Section 3.9 Unit Review

BULLET LIST
Automation consists of three basic elements when applied to a particular process: power to achieve the process and operate the system; a programme of instructions to direct the process; and a control system to actuate the instructions.

Electrical power is the chief source of power used in automated systems.

Power is used to drive the most familiar manufacturing processes, and the material handling system.

The programme of instructions is a series of controlled actions that are carried-out in the manufacturing or assembly process. Parts or products are usually processed as part of a work cycle, with the aid of work cycle programmes.

The content and complexity of work cycle programmes depends upon the number and process-content of the steps involved in the work cycle.

Process parameters are inputs to the process; process variables are outputs from the process.

Programmes of instructions may be based upon physical components or upon computing systems. In general modern production operations are designed with computer controllers to execute their process cycles.

Some automated manufacturing operations require decisions to be made during the programmed work cycle to cope with variations that may arise within the cycle.

There are two types of control systems: a closed-loop control system, and an open loop control system.

Advanced automation functions are made possible by special subroutines included in the programme of instructions. Special subroutines include those for safety monitoring, maintenance and repair diagnostics, and error detection and recovery.

Automation can be examined at five different levels, in a hierarchy that runs from the single device, the machine, the cell or system, the plant, to the enterprise level.

Automation is applied differently across process industries and discrete manufacturing industries, especially at the lower levels of automation.
In process industries variables and parameters tend to be continuous; in discrete manufacturing industries they tend to be discrete. A continuous variable or parameter is one that is uninterrupted as time proceeds; a discrete variable or parameter is one that can take on only certain values within a given range.

There are two types of control: continuous control—where the variables and parameters are continuous and analogue; and discrete control—where the variables and parameters are discrete—mostly in binary format.

Like closed-loop control systems, continuous control systems have as their objective the maintenance of an output value at a desired level. Often, however, continuous control systems may be segmented into smaller parts, all of which have to be individually controlled and co-ordinated, so as to maintain the overall output variable.

Continuous control systems can achieve its control objective in a number of ways; these include methods of: regulatory control; feed-forward control; steady-state optimisation; and adaptive control with optional on-line search strategies. Specialist techniques such as learning systems, expert systems, neural networks, and artificial intelligence methods may also be deployed.

For discrete control systems, parameters and variables may change at discrete moments in time, with the parameters and variables themselves being discrete, typically binary discrete. The changes that are undergone can be either event-driven, or time-driven.

An event-driven change occurs when the system is altered, for some reason, and the controller reacts to this alteration by executing some action in response. A time-driven change is executed using time as the parameter of change; that is, after a specific quantity of time has elapsed, or at a specific point in time.

Virtually all of today's industrial processes are controlled by computer process control, in one form or another.

A number of control requirements are necessary to allow a computer process control system to reach real-time control; these include: process-initiated interrupts; timer-initiated actions; computer commands to the process; system- and programme-initiated events; and operator-initiated events.

To satisfy computer process control requirements, the controller must have the following capabilities: to be able to poll data; to be able to use interlocks; to be able to interrupt the system; and to be able to handle exceptions.

Computers can be used to control a process via process monitoring or process control.
There are various forms of computer process monitoring and computer process control in use today; these include: computer process monitoring; direct digital control; numerical control and robotics; programmable logic controllers; supervisory control; distributed control systems; PCs in process control; and enterprise-wide integration of factory data.

Section 3.10 Self-Assessment Questions

What are the three basic elements of automation?

Explain the difference between process parameters and process variables.

Outline the difference between open and closed loop control.

What makes advanced automation functions possible?

What is the automation levels hierarchy? Describe it briefly.

What are the automation and process differences between process industries and discrete manufacturing industries?

What are the differences between continuous control and discrete control?

List the methods that can be used by continuous control systems to achieve the control objective.

Explain the difference between an event-driven change and a time-driven change.

What are the control requirements that allow computer process control systems to reach real-time control?

List various forms of computer process monitoring and computer process control in use today.

Section 3.11 Answers to Self-Assessment Questions

Automation consists of the following three basic elements when applied to a particular process: power to achieve the process and operate the system; a
programme of instructions to direct the process; and a control system to actuate the instructions.

Process parameters are inputs to the process; process variables are outputs from the process.

There are two types of control systems: a closed-loop control system, and an open loop control system. A closed-loop system is also known as a feedback control system, it consists of a system whereby the output variable is compared with the input parameter, so that the system may be adjusted in future iterations so that the input and output come closer and closer together. An open loop system operates without a feedback loop; that is, there is no way for the system to compare its output against its input. Instead, confidence is placed in the correct performance of the actuator.

Advanced automation functions are made possible by special subroutines included in the programme of instructions. Special subroutines include those for safety monitoring, maintenance and repair diagnostics, and error detection and recovery.

The automation levels hierarchy is a structure that allows automation to be examined at five different levels. The hierarchy levels are: single device, machine, cell or system, plant, and enterprise.

Automation is applied differently across process industries and discrete manufacturing industries, especially at the lower levels of automation. In process industries variables and parameters tend to be continuous; in discrete manufacturing industries they tend to be discrete.

Continuous control is where the variables and parameters are continuous and analogue. Discrete control is where the variables and parameters are discrete—mostly in a binary format.

Continuous control systems can achieve its control objective in a number of ways; these include methods of: regulatory control; feed-forward control; steady-state optimisation; and adaptive control with optional on-line search strategies. Specialist techniques such as learning systems, expert systems, neural networks, and artificial intelligence methods may also be deployed.

An event-driven change occurs when the system is altered, for some reason, and the controller reacts to this alteration by executing some action in response. A time-driven change is executed using time as the parameter of change; that is, after a specific quantity of time has elapsed, or at a specific point in time.

The control requirements necessary to allow a computer process control system to reach real-time control include: process-initiated interrupts; timer-initiated
actions; computer commands to the process; system- and programme-initiated events; and operator-initiated events.

The various forms of computer process monitoring and computer process control in use today include: computer process monitoring; direct digital control; numerical control and robotics; programmable logic controllers; supervisory control; distributed control systems; PCs in process control; and enterprise-wide integration of factory data.

END LIST