Module 1

Introduction

Lesson
1
Introduction to Industrial Automation and Control

Lesson Objectives

- To define Automation and Control and explain the differences in the sense of the terms
- To explain the relation between Automation and Information Technology
- To underline the basic objectives of a manufacturing industry and explain how automation and control technologies relate to these
- To introduce the concept of a Product Life Cycle and explain how Automation and Control technologies relate to the various phases of the cycle
- To classify Manufacturing plants and categorise the different classes of Automation Systems that are appropriate for these

Understanding the Title of the Course

Let us first define the three key words in the title, namely,

Industry

In a general sense the term "Industry" is defined as follows.

Definition:* *Systematic Economic Activity that could be related to ***Manufacture/Service/ Trade.***

In this course, we shall be concerned with Manufacturing Industries only.

Automation

The word 'Automation' is derived from greek words "Auto"(self) and "Matos" (moving). Automation therefore is the mechanism for systems that "move by itself". However, apart from this original sense of the word, automated systems also achieve significantly superior performance than what is possible with manual systems, in terms of power, precision and speed of operation.

Definition: ***Automation is a set of technologies that results in operation of machines and systems without significant human intervention and achieves performance superior to manual operation***

A Definition from Encyclopaedia Britannica

The application of machines to tasks once performed by human beings or, increasingly, to tasks that would otherwise be impossible. Although the term mechanization is often used to refer to the simple replacement of human labour by machines, automation generally implies the integration of machines into a self-governing system.

Point to Ponder: 1

A. *Why does an automated system achieve superior performance compared to a manual one?*

B. *Can you give an example where this happens?*

Control

It is perhaps correct to expect that the learner for this course has already been exposed to a course on Control Systems, which is typically introduced in the final or pre-final year of an undergraduate course in Engineering in India. The word control is therefore expected to be familiar and defined as under.

Definition: Control is a set of technologies that achieves desired patterns of variations of operational parameters and sequences for machines and systems by providing the input signals necessary.

Point to Ponder: 2

A. *Can you explain the above definition in the context of a common control system, such as temperature control in an oven?*

B. *Is the definition applicable to open-loop as well as closed loop control?*

It is important at this stage to understand some of the differences in the senses that these two terms are generally interpreted in technical contexts and specifically in this course. These are given below.

1. Automation Systems may include Control Systems but the reverse is not true. Control Systems may be parts of Automation Systems.
2. The main function of control systems is to ensure that outputs follow the set points. However, Automation Systems may have much more functionality, such as computing set points for control systems, monitoring system performance, plant startup or shutdown, job and equipment scheduling etc.

Automation Systems are essential for most modern industries. It is therefore important to understand why they are so, before we study these in detail in this course.

Point to Ponder: 3

A. *Can you give an example of an automated system, which contains a control system as a part of it?*

B. *What are the other parts of the system?*

Industrial Automation vs. Industrial Information Technology

Industrial Automation makes extensive use of Information Technology. Fig. 1.1 below shows some of the major IT areas that are used in the context of Industrial Automation.

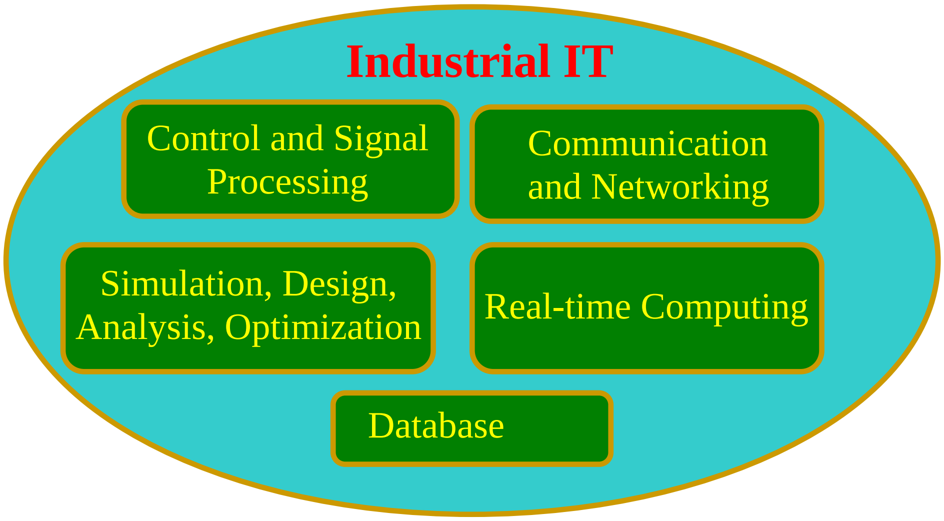

Fig. 1.1 Major areas of IT which are used in the context of Industrial Automation.

Point to Ponder: 4

A. *Try to find an example automated system which uses at least one of the areas of Industrial IT mentioned in Fig. 1.1 (Hint: Try using the internet)*

However, Industrial Automation is distinct from IT in the following senses

A. Industrial Automation also involves significant amount of hardware technologies, related to Instrumentation and Sensing, Actuation and Drives, Electronics for Signal Conditioning, Communication and Display, Embedded as well as Stand-alone Computing Systems etc.

B. As Industrial Automation systems grow more sophisticated in terms of the knowledge and algorithms they use, as they encompass larger areas of operation comprising several units or the whole of a factory, or even several of them, and as they integrate manufacturing with other areas of business, such as, sales and customer care, finance and the entire supply chain of the business, the usage of IT increases dramatically. However, the lower level Automation Systems that only deal with individual or , at best, a group of machines, make less use of IT and more of hardware, electronics and embedded computing.

Point to Ponder: 5

A. *Can you give an example of an automated system, some of whose parts makes a significant application of Industrial IT?*

B. *Can you give an example of an automated system, none of whose parts makes a significant application of Industrial IT?*

Apart from the above, there are some other distinguishing features of IT for the factory that differentiate it with its more ubiquitous counterparts that are used in offices and other business.

A. Industrial information systems are generally reactive in the sense that they receive stimuli from their universe of discourse and in turn produce responses that stimulate its environment. Naturally, a crucial component of an industrial information system is its interface to the world.

B. Most of industrial information systems have to be real-time. By that we mean that the computation not only has to be correct, but also must be produced in time. An accurate result, which is not timely may be less preferable than a less accurate result produced in time. Therefore systems have to be designed with explicit considerations of meeting computing time deadlines.

C. Many industrial information systems are considered mission-critical, in the sense that the malfunctioning can bring about catastrophic consequences in terms of loss of human life or property. Therefore extraordinary care must be exercised during their design to make them flawless. In spite of that, elaborate mechanisms are often deployed to ensure that any unforeseen circumstances can also be handled in a predictable manner. Fault-tolerance to emergencies due to hardware and software faults must often be built in.

Point to Ponder: 6

A. *Can you give an example of an automated system, which is reactive in the sense mentioned above?*

B. *Can you give an example of an automated system, which is real-time in the sense mentioned above*

C. *Can you give an example of an automated system, which is mission-critical in the sense mentioned above*

Role of automation in industry

✓ Manufacturing processes, basically, produce finished product from raw/unfinished material using energy, manpower and equipment and infrastructure.

✓ Since an industry is essentially a “systematic economic activity”, the fundamental objective of any industry is to make profit.

✓ Roughly speaking,

$$\text{Profit} = (\text{Price/unit} - \text{Cost/unit}) \times \text{Production Volume} \quad (1)$$

So profit can be maximised by producing *good quality products*, which may sell at *higher price*, in *larger volumes* with *less production cost and time*. Fig 1.2 shows the major parameters that affect the cost/unt of a mass-manufactured industrial product.

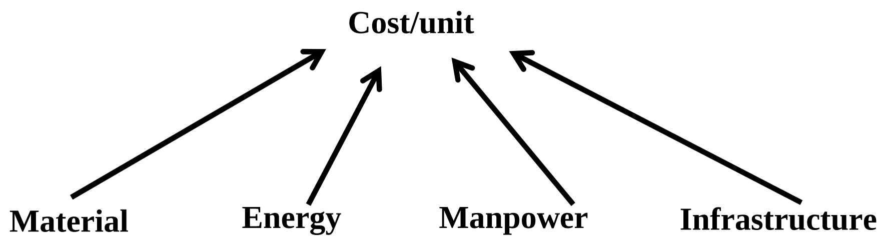

Fig. 1.2 The Components of per unit Manufacturing Cost

Automation can achieve all these in the following ways,

- ✓ Figure 1.4 shows how overall production time for a product is affected by various factors. Automation affects all of these factors. Firstly, automated machines have significantly lower production times. For example, in machine tools, manufacturing a variety of parts, significant setup times are needed for setting the operational configuration and parameters whenever a new part is loaded into the machine. This can lead to significant unproductive for expensive machines when a variety of products is manufactured. In Computer Numerically Controlled (CNC) Machining Centers set up time is reduced significantly with the help of Automated Tool Changers, Automatic Control of Machines from a Part Program loaded in the machine computer. Such a machine is shown in Figure 1.3. The consequent increase in actual metal cutting time results in reduced capital cost and an increased volume of production.

Point to Ponder: 7

A. *With reference to Eq. (1), explain how the following automation systems improve industrial profitability.*

   a. *Automated Welding Robots for Cars*

   b. *Automated PCB Assembly Machines*

   c. *Distributed Control Systems for Petroleum Refineries*

Fig. 1.3 A CNC Machine with an Automated Tool Changer and the Operator Console with Display for Programming and Control of the Machine

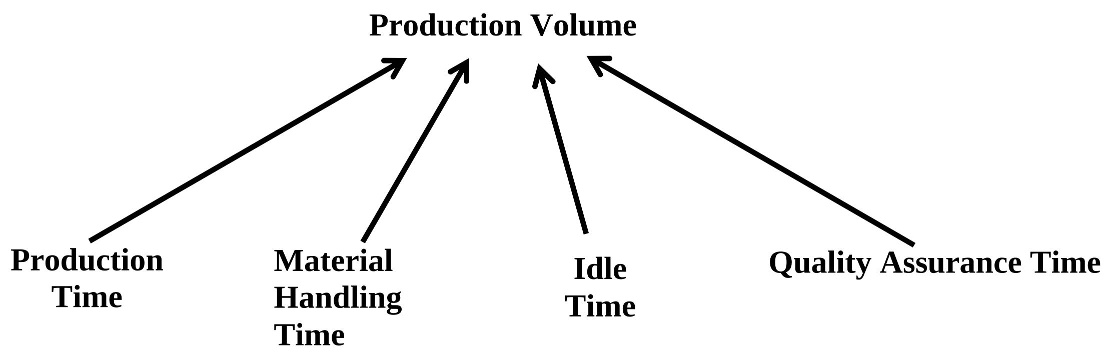

Fig. 1.4 The major factors that contribute to Overall Production Time

- ✓ Similarly, systems such as Automated Guided Vehicles, Industrial Robots, Automated Crane and Conveyor Systems reduce material handling time.
- ✓ Automation also reduces cost of production significantly by efficient usage of energy, manpower and material.
- ✓ The product quality that can be achieved with automated precision machines and processes cannot be achieved with manual operations. Moreover, since operation is automated, the same quality would be achieved for thousands of parts with little variation.
- ✓ Industrial Products go through their life cycles, which consists of various stages.

- ➢ At first, a product is conceived based on Market feedbacks, as well as Research and Development Activities.
- ➢ Once conceived the product is designed. Prototype Manufacturing is generally needed to prove the design.
- ➢ Once the design is proved, Production Planning and Installation must be carried out to ensure that the necessary resources and strategies for mass manufacturing are in place.
- ➢ This is followed by the actual manufacture and quality control activities through which the product is mass-produced.
- ➢ This is followed by a number of commercial activities through which the product is actually sold in the market.
- ➢ Automation also reduces the over all product life cycle i.e., the time required to complete (i) Product conception and design (ii) Process planning and installation (iii) Various stages of the product life cycle are shown as in Figure 1.5.

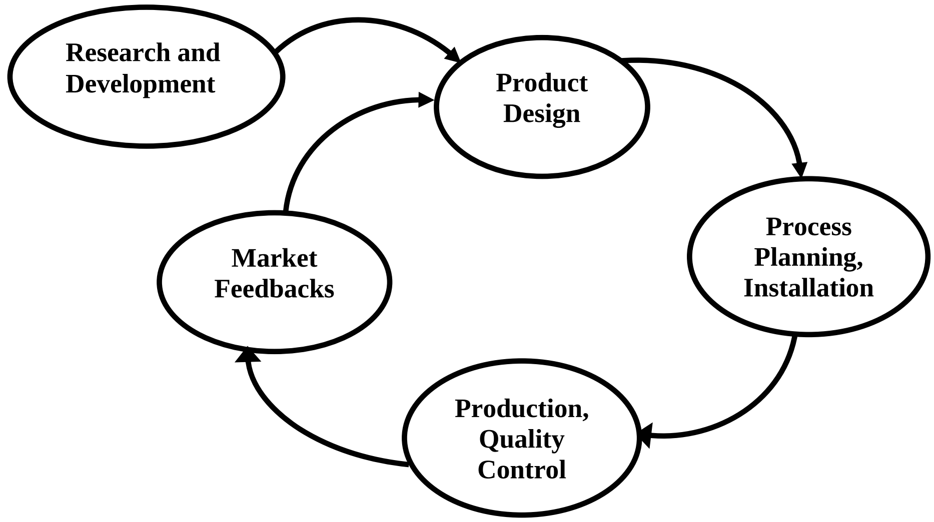

Fig. 1.5 A Typical Industrial Product Life Cycle

Economy of Scale and Economy of Scope

In the context of Industrial Manufacturing Automation, Economy of Scale is defined as follows.

Economy of Scale

Definition: Reduction in cost per unit resulting from increased production, realized through operational efficiencies. Economies of scale can be accomplished because as production increases, the cost of producing each additional unit falls.

Obviously, Automation facilitates economy of scale, since, as explained above, it enables efficient large-scale production. In the modern industrial scenario however, another kind of economy, called the economy of scope assumes significance.

Economy of Scope

Definition : The situation that arises when the cost of being able manufacture multiple products simultaneously proves more efficient than that of being able manufacture single product at a time.

Economy of scope arises in several sectors of manufacturing, but perhaps the most predominantly in electronic product manufacturing where complete product life cycle, from conception to market, are executed in a matter of months, if not weeks. Therefore, to shrink the time to market drastically use of automated tools is mandated in all phases of the product life cycle. Additionally, since a wide variety of products need to be manufactured within the life period of a factory, rapid programmability and reconfigurability of machines and processes becomes a key requirement for commercial success. Such an automated production system also enables the industry to exploit a much larger market and also protects itself against fluctuations in demand for a given class of products. Indeed it is being driven by the economy of scope, and

enabled by Industrial Automation Technology that Flexible Manufacturing (i.e. producing various products with the same machine) has been conceived to increase the scope of manufacturing.
Next let us see the various major kinds of production systems, or factories, exist. This would be followed by a discussion on the various types of automation systems that are appropriate for each of these categories.

Point to Ponder: 8

A. *Can you give an example of an industry where economy of scope is more significant than the economy of scale?*

B. *Can you give an example of an industry where economy of scale is more significant than the economy of scope?*

C. *Can you give an example of an industry where both economy of scope, and economy of scale are significant?*

Types of production systems

Major industrial processes can be categorized as follows based on their scale and scope of production.

- *Continuous flow process:* Manufactured product is in continuous quantities i.e., the product is not a discrete object. Moreover, for such processes, the volume of production is generally very high, while the product variation is relatively low. Typical examples of such processes include Oil Refineries, Iron and Steel Plants, Cement and Chemical Plants.
- *Mass Manufacturing of Discrete Products:* Products are discrete objects and manufactured in large volumes. Product variation is very limited. Typical examples are Appliances, Automobiles etc.
- *Batch Production:* In a batch production process the product is either discrete or continuous. However, the variation in product types is larger than in continuous-flow processes. The same set of equipment is used to manufacture all the product types. However for each batch of a given product type a distinct set of operating parameters must be established. This set is often referred to as the “recipe” for the batch. Typical examples here would be Pharmaceuticals, Casting Foundries, Plastic moulding, Printing etc.
- *Job shop Production:* Typically designed for manufacturing small quantities of discrete products, which are custom built, generally according to drawings supplied by customers. Any variation in the product can be made. Examples include Machine Shops, Prototyping facilities etc.

The above types of production systems are shown in Figure 1.6 categorized according to volumes of production and variability in product types. In general, if the quantity of product is more there is little variation in the product and more varieties of product is manufactured if the quantity of product is lesser.

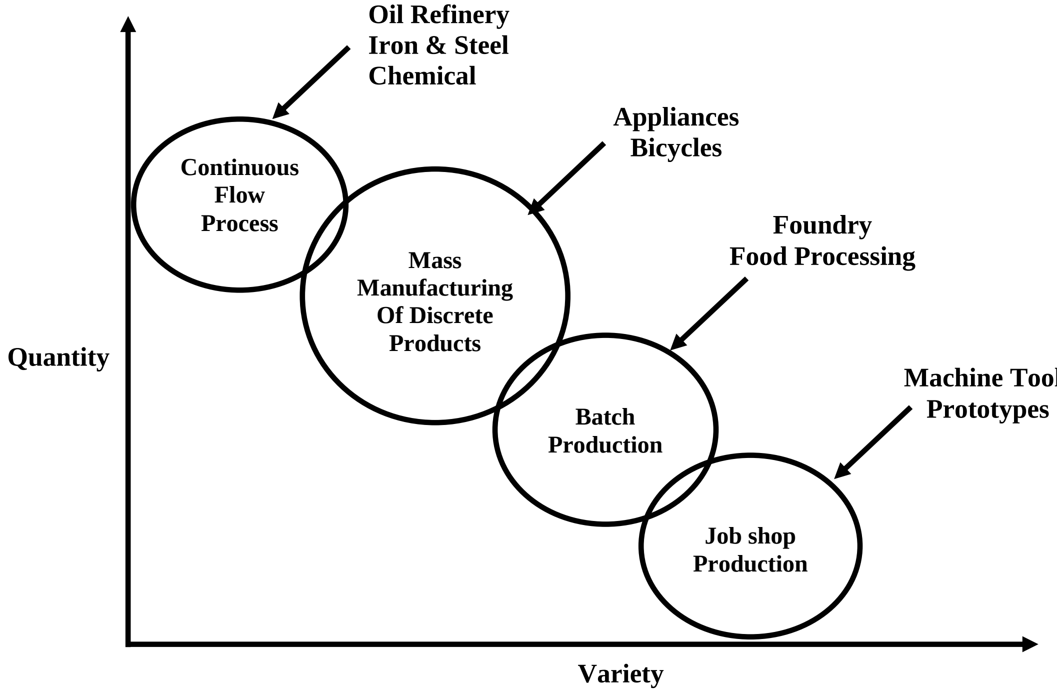

Fig. 1.6 Types of Production Systems

Types of Automation Systems

Automation systems can be categorized based on the flexibility and level of integration in manufacturing process operations. Various automation systems can be classified as follows

- *Fixed Automation:* It is used in high volume production with dedicated equipment, which has a fixed set of operation and designed to be efficient for this set. Continuous flow and Discrete Mass Production systems use this automation. e.g. Distillation Process, Conveyors, Paint Shops, Transfer lines etc.
  A process using mechanized machinery to perform fixed and repetitive operations in order to produce a high volume of similar parts.
- *Programmable Automation:* It is used for a changeable sequence of operation and configuration of the machines using electronic controls. However, non-trivial programming effort may be needed to reprogram the machine or sequence of operations. Investment on programmable equipment is less, as production process is not changed frequently. It is typically used in Batch process where job variety is low and product volume is medium to high, and sometimes in mass production also. e.g. in Steel Rolling Mills, Paper Mills etc.
- *Flexible Automation:* It is used in Flexible Manufacturing Systems (FMS) which is invariably computer controlled. Human operators give high-level commands in the form of codes entered into computer identifying product and its location in the sequence and the lower level changes are done automatically. Each production machine receives settings/instructions from computer. These automatically loads/unloads required tools and carries out their processing instructions. After processing, products are automatically transferred to next machine. It is typically used in job shops and batch processes where

product varieties are high and job volumes are medium to low. Such systems typically use Multi purpose CNC machines, Automated Guided Vehicles (AGV) etc.

- *Integrated Automation:* It denotes complete automation of a manufacturing plant, with all processes functioning under computer control and under coordination through digital information processing. It includes technologies such as computer-aided design and manufacturing, computer-aided process planning, computer numerical control machine tools, flexible machining systems, automated storage and retrieval systems, automated material handling systems such as robots and automated cranes and conveyors, computerized scheduling and production control. It may also integrate a business system through a common database. In other words, it symbolizes full integration of process and management operations using information and communication technologies. Typical examples of such technologies are seen in Advanced Process Automation Systems and Computer Integrated Manufacturing (CIM)

As can be seen from above, from Fixed Automation to CIM the scope and complexity of automation systems are increasing. Degree of automation necessary for an individual manufacturing facility depends on manufacturing and assembly specifications, labor conditions and competitive pressure, labor cost and work requirements. One must remember that the investment on automation must be justified by the consequent increase in profitability. To exemplify, the appropriate contexts for Fixed and Flexible Automation are compared and contrasted.

Fixed automation is appropriate in the following circumstances.

A. Low variability in product type as also in size, shape, part count and material
B. Predictable and stable demand for 2- to 5-year time period, so that manufacturing capacity requirement is also stable
C. High production volume desired per unit time
D. Significant cost pressures due to competitive market conditions. So automation systems should be tuned to perform optimally for the particular product.

Flexible automation, on the other hand is used in the following situations.

A. Significant variability in product type. Product mix requires a combination of different parts and products to be manufactured from the same production system
B. Product life cycles are short. Frequent upgradation and design modifications alter production requirements
C. Production volumes are moderate, and demand is not as predictable

Point to Ponder: 9

A. During a technical visit to an industry how can you identify the type of automation prevailing there from among the above types?

B. For what kind of a factory would you recommend computer integrated manufacturing and why?

C. What kind of automation would you recommend for manufacturing

a. *Light bulbs*
b. *Garments*
c. *Textile*
d. *Cement*
e. *Printing*
f. *Pharmaceuticals*
g. *Toys*

Lesson Summary

In this lesson we have dealt with the following topics:

A. *Definition of Automation and its relations with fields of Automatic Control and Information Technology:* It is seen that both control and IT are used in automation systems to realize one or more of its functionalities. Also, while Control Technology is used for operation of the individual machines and equipment, IT is used for coordination, management and optimized operation of overall plants.

B. *The role played by Automation in realizing the basic goal of profitability of a manufacturing industry:* It is seen that Automation can increase profitability in multiple ways by reducing labour, material and energy requirements, by improving quality as well as productivity. It is also seen that Automation is not only essential to achieve Economy of Scale, but also for Economy of Scope.

C. *Types of Factories and Automation Systems that are appropriate for them:* Factories have been classified into four major categories based on the product volumes and product variety. Similarly Automation Systems are also categorized into four types and their appropriateness for the various categories of factories explained.

Exercises

A. Describe the role of Industrial Automation in ensuring overall profitability of a industrial production system. Be specific and answer point wise. Give examples as appropriate.

B. State the main objectives of a modern industry (at least five) and explain the role of automation in helping achieve these.

C. Explain with examples the terms "economy of scale" and "economy of scope". How does industrial automation help in achieving these? Cite examples.

D. Differentiate between a job shop and a flow shop with example what are their 'process plant' analogues? Give examples.

E. Run any internet search engine and type "History of Automation" to prepare a term paper on the subject.

F. There are some aspects of automation that have not been treated in the lesson. Consult references and prepare term papers on the impact of automation on

   a. Environmental Appropriateness for Industries

   b. Industrial Standardisation Certification such as ISO 9001

   c. Industrial Safety

G. Locate the major texts on Manufacturing Automation

H. From the internet find alternate definitions of the terms : Industry, Automation and Control

Answers, Remarks and Hints to Points to Ponder

Point to Ponder: 1

A. *Why does an automated system achieve superior performance compared to a manual one?*

Ans: Because such systems can have more precision, more energy and more speed of operation than possible manually. Moreover using computing techniques, much more sophisticated and efficient operational solutions can be derived and applied in real-time.

B. *Can you give an example where this happens?*

Ans: This is the rule. Only few exceptions exist. How many of the millions of industrial products could be made manually?

Point to Ponder: 2

A. *Can you explain the above definition in the context of a common control system, such as temperature control in an oven?*

Ans: Consider a temperature-controlled oven as found in many kitchens. A careful examination of the dials would show that one could control the temperature in the oven. This is a closed loop control operation. One can also control the time for which the oven is kept on. Note that in both cases the input signal to the process is the applied voltage to the heater coils. This input signal is varied as required to hold the temperature, by the controller.

B. *Is the definition applicable to open-loop as well as closed loop control?*

Ans: Yes

Point to Ponder: 3

C. *Can you give an example of an automated system, which contains a control system as a part of it?*

Ans: Many examples can be given. One of these is the following:

In an industrial CNC machine, the motion control of the spindle, the tool holder and the job table are controlled by a position and speed control system, which, in fact, uses a separate processor. Another processor is used to manage the other automation aspects.

Another example is that of A pick and place automated robot is used in many industrial assembly shops. The robot motion can be programmed using a high level interface. The motion of the robot is controlled using position control systems driving the various joints in the robotic manipulator.

D. *What are the other parts of the system?*

Ans: The other functional parts of the CNC System include:
The operator interface, the discrete PLC controls of indicators, lubricant flow control, tool changing mechanisms.

Point to Ponder: 4

Try to find an example automated system which uses at least one of the areas of Industrial IT mentioned in Fig. 1.2. (Hint: Try using the internet)

Ans: Distributed Control Systems (DCS) used in many large Continuous-Flow processes such as Petroleum Refining and Integrated Steel Plants use almost all components of Industrial IT

Point to Ponder: 5

A. *Can you give an example of an automated system, some of whose parts makes a significant application of Industrial IT?*

Ans: Distributed Control Systems (DCS) used in many large Continuous-Flow processes such as Petroleum Refining and Integrated Steel Plants use almost all components of Industrial IT

B. *Can you give an example of an automated system, none of whose parts makes a significant application of Industrial IT?*

Ans: An automated conveyor system used in many large Discrete Manufacturing Plants such as bottled Beverage Plants use no components of Industrial IT.

Point to Ponder: 6

A. *Can you give an example of an automated system, which is reactive in the sense mentioned above?*

Ans: Any feedback controller, such as an industrial PID controller is reactive since it interacts with sensors and actuators.

B. *Can you give an example of an automated system, which is real-time in the sense mentioned above*

Ans: Any feedback controller, such as an industrial PID controller is real-time, since it has to compute its output within one sampling time.

C. *Can you give an example of an automated system, which is mission-critical in the sense mentioned above*

Ans: An automation system for a Nuclear Power Plant is mission critical since a failure is unacceptable for such a system.

Point to Ponder: 7

A. *With reference to Eq. (1), explain how the following automation systems improve industrial profitability.*
   d. *Automated Welding Robots for Cars*
   e. *Automated PCB Assembly Machines*
   f. *Distributed Control Systems for Petroleum Refineries*

Ans: Some of the factors that lead to profitability in each case, are mentioned.

a. *Automated Welding Robots for Cars*
   Increased production rate, Uniform and accurate welding, Operator safety.
b. *Automated PCB Assembly Machines*
   Increased production rate, Uniform and accurate placement and soldering
c. *Distributed Control Systems for Petroleum Refineries*
   Energy efficiency, Improved product quality

Point to Ponder: 8

A. *You give an example of an industry where economy of scope is more significant than the economy of scale?*

Ans: One such example would a job shop which manufactures custom machine parts by machining according to customer drawings. Another example would be a factory to manufacture Personal Computer components

B. *Can you give an example of an industry where economy of scale is more significant than the economy of scope?*

Ans: One such example would be a Power plant. Another one would be a Steel Plant.

Point to Ponder: 9

A. *During a technical visit to an industry how can you identify the type of automation prevailing there from among the above types?*

Ans: Check for the following.

- Whether automatic control exists for majority the equipment
- Whether supervisory control is manual, partially automated or largely automated
- Whether operator interfaces are computer integrated or not.
- Whether communication with individual control units can be done from supervisory interfaces through computers or not

- Whether any information network exists, to which automation system and controllers are connected
- Product variety, product volumes, batch sizes etc.
- Whether the material handling systems are automated and if so to what extent.

The type of automation system can be determined based on these information, as discussed in the lesson.

B. For what kind of a factory would you recommend computer integrated manufacturing and why?

Ans: For large systems producing sophisticated and expensive products in large volumes having many subunits to be integrated in complex ways.

C. What kind of automation would you recommend for manufacturing

a. Light bulbs

Ans: Fixed

b. Garments

Ans: Flexible

c. Textile

Ans: Programmable

d. Cement

Ans: Programmable

e. Printing

Ans: Flexible

f. Pharmaceuticals

Ans: Flexible

g. Toys

Ans: Flexible

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