ARCHITECTURE OF INDUSTRIAL AUTOMATION SYSTEMS

Abdu Idris Omer
Taleb M.M., PhD
Majmaah University, Kingdom of Saudia Arabia

Abstract

   This article is aimed to name the levels of industrial automation, describes the hierarchical structure of industrial automation systems, (what information one accept from another, what information can be given from one to another), describes essential functions of each level, and mentions the differences between automatic control and supervisory control. Moreover, the article provides an exposure to the technologies that enable operation and control of modern industrial machines and systems.

Keywords: Automation, sensors, Actuators, supervisory control

Introduction

   If you go to a factory, you will likely encounter a set of machines. You will see many equipment such as sensors, operating display, a various cabinet containing hardware, all these together make a factory works as orchestra.

   How complex systems are organized? What are the various elements of the system? How do they relate to each other?. How do they interact with each other?. What are the roles they perform?. These things define the architecture. Whenever you discuss a technology, such thing includes user view i.e. to know how things work, how things put together, how to design and make these machines, even to explain the application oriented as well as to illustrate the existing technologies with trends. Industrial automation and control is an Interdisciplinary: not only electrical engineering but chemical and mechanical engineering.

1.1 Definition of Industrial Automation

   From Etymology, industry is a systematic activity that includes manufacture, services or trade (Benjamin,2003).

Industrial automation is defined as a set of technologies that results in operations of industrial machines and systems without significant human intervention and achieve performance superior to manual operation.

1.1.1 Industrial communication system

Here is a brief description of the various levels of the industrial automation.

Level 0 is a sensor and actuator that directly interact with the process of the machine. Level 1 is an automatic control and Level 2 is a supervisory control. Level 3 production control which is responsible for maintenance, production, quality, inventory, etc. Level 4 enterprise is mainly concerned with management functions, sales, marketing, etc. See Figure 1.
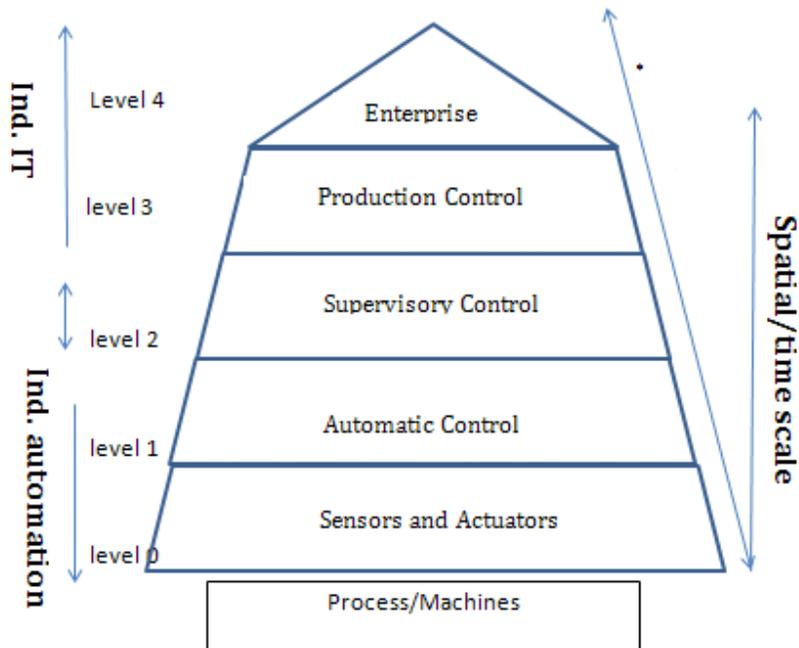

Figure 1: Industrial automation and control levels

The question that arises is why these functionalities are necessary for the overall control of a factory? However, not all these layers are perfectly automated.

From level 2 upward, it is not true that you have computer based automation for functioning the performing on that level, some functions may be done by human being, for example, if you go to a power plant or if you go to a big refinery, you will find that in the shop floor, there is a control room. If you enter the control room, you will likely find large computer monitors, and there are a group of people sitting around these monitors and constantly

looking at them. However, some functions could be automated, and others are manually operated (Benjamin,2003).

At the level of production control, most of the operations are performed by humans with the aid of tools that help people to perform the production control functions. At Level 4, you will have managers who use tools for performing their functions.

Let us again look at these levels and their nature with certain some more details.

Why it is a pyramid? This is because as you go up the pyramid, the spatial scale and time scale of a given system at that level increase. For example, consider one sensor system measures one process variable in the whole machine, look only at that variable, in that sense, its spatial scale is very limited. In the whole shop floor, there are several machines, and in each machine there are several process variables at the sensor (level zero), so in that sense, its scope is very limited, but its interaction is over very small time scale (sampling time) it gives to the controller, each value represents the variable over a very short time in that sense each value which comes from a sensor has a very short time scale.

As you go up for example, if you go to the automatic control, the latter also watches the sampling level, it computes control input for the plant at each sample time. Sometimes considerations are made of large duration. For example, when you say that the settling time should be low. When considering setting time you are considering that if you make change from one operating time to another, how the output reach from one level to another. So you are typically concerning about duration of time. If you go to supervisory control level (Headquarters, Department of the army,2006) one of the major function of this level is to change a set point. The set points change is not made every moment. Control input changes affects the plant every sample time. But set points changes are not made every sample time, Let us say some hours.

If you take the power system boiler, for example, so at 3 o`clock pm, it may be operating at 10% load, and at 7 o`clock am, it may be operating at 25% load. At 9:30 am also, then huge amount of load come into the system because all offices are open at that time. Again, between 9:30 am and 11 o`clock am, it will ramp up significantly from 30% to 90% load perhaps,

The 90% load will maintain till again say 5 o`clock pm. After 5 o`clock pm, people will switch on lighting loads, then you get the evening period. Only the load will significantly increase when boiler operating point may change.

So the operating point of a boiler typically gets changed say 7-stim, 10 times over a day. Its change is also based on the decision taken based on period per hour. So in that sense, it's a larger spatial scale. Because one

sensor looks at one signal. One automatic controller may take control action over several sensors into account. In that sense, its spatial scale increases. One supervisory controller will typically look after a number of automatically control loops and typically looks after one piece of equipment, like a boiler, a refinery or distillation column. Typically, there will have many automatic controlling loops. Similarly, a shop floor may be made of several set units of machines, so the production control is done typically at the shop level. While the enterprise control is done at overall enterprise level, so as you go up, the time scale will increase and the spatial scale will also increase. That is why it is a pyramid is not a cylinder.

Having clarifying that let us look at the nature of technology which is used for automation at these various levels.

At the lowest level, where sensors and actuators, have hardware. They are actually sensing elements, electronic circuits or microprocessors. They are generally very hardware oriented. Also you have software elements because software is much closed to hardware in the sense that they interact much closed to hardware. so you have a lot of embedded technology at this level. This because the sensor is supposed to be embedded to the machine. This technology uses hardware and software.

If you go to the automatic control level, in many cases it is a separate hardware, it is not embedded into the machine, it is a separate real time deeply software hardware. The software is generally generic, thus it is not very special purpose, but it runs on special purpose hardware like PLC, industrial PCs, etc. But the software is a real time in the sense that the output must be generated with a given amount of time. Because during every sampling time, you have to generate the control input to the plant, so you have real time software. The hardware is special purpose or general purpose.

At the supervisory control, the hardware is mostly a general purpose; it is general purpose computers with strong data interface. Because many channels data from the whole process are connected to the supervisory control.

The software is still online. Because a piece of software will be online if it interacts with the external world, the acquired data continuously streaming in from the processor using sensors and various communication channels. However, it is not very hard real time because software application is called hard real time when the execution must be finished within dead line time, if it does not finish then serious consequences may occur and the system may fail. Hardware is general purpose but the software is very special purpose. For example, supervisory control software for a refinery is completely different from that of a power plant. It is very specific to the machine (Headquarters, Department of the army,2006).

Production control is not a powerful machine as such. It takes abstract view of a factory, how many pieces of equipment have been produced per hour, whether functional or not functional. The software is generally offline; it is not concerned with the machine itself. Similarly, for enterprise level. At these levels we are not so much closed to the hardware. We look at the process as if it is abstract identity. We take the decision about them, we analyze their performance, and we also monitor them. In that sense, the layers up to, from some parts of the supervisory control as well as production control and enterprise control could be tuned as industrial information technology rather than industrial automation technology (Figure2). Because automation has a kind of hardware and software flavor. On the other hand, information technology (IT) has also a lot of technology, optimization technology but they are not concerned about hardware. It is not real time technology.
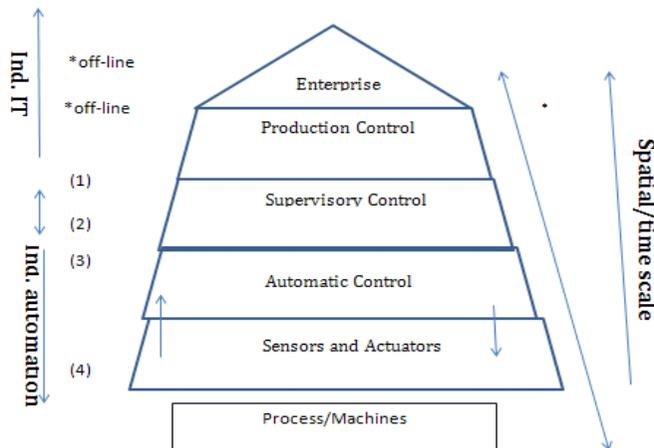

Figure 2: Industrial automation and control levels and their nature

(1) On-line, soft real time
(2) General purpose
(3) Real time S/W special h/w
(4) Embedded h/w, s/w

Here we will focus on the first three layers. Sensors continuously collect samples of measurement which pass over to the automatic controller. Similarly, the automatic controller continuously computes the control input which passes over to the actuator. Similarly, the information that the automatic controller receives from the sensor part of it pass to the supervisory controller to see whether the control is working satisfactory, or whether something a check point is needed or some sensors are failed and the process output is going out. In which case the supervisory controller must take some action so it can either change the set point or there are two sensors

it can switch from a one to the other. So it gives commands, this means that there are continuous information flow from the lower level to the upper one and from the upper level to the lower. As information goes up because of the spatial and time scale, information continuously gets aggregated up. So as you go higher and higher you get more and more time averaging information over part of the factory and as you go lower and lower you get detailed information about smaller and smaller part of the machine. So as you go up, information gets aggregated and as you come down information gets resolved. How does information flow up and down physically? How do they transmit?. Nowadays lot of stresses is put on.

There are usually communication systems which actually connect all these devices so that they can exchange information, send results, and do a lot of configuration management. Now let us look more details at these various levels.

2. The Elements of Industrial Control

What is basically done in the control? Why do we control? We control because we want the output that from a process variable which could be temperature, pressure, etc... We want them to be within certain way we desire. We want to achieve such purpose. We want the temperature to ramp up in a certain overtime then be held constant then after certain time ramp down. We can achieve this by comparing the output with whatever we want. To feel down that is done by a sensor. When we compare we see the error (see Figure 3). You give the error to the controller, then the controller knows what the controller input to be minimized, the controller is actually a computer system. The input to the controller is a logical input not a physical input. The job of the actuator is to produce a physical change which is proportional to the logic change. So if the physical change occurs, then the plant output will change in such a manner that the error will be reduced. This is the job of control(BenjaminC.Kuo,2010).
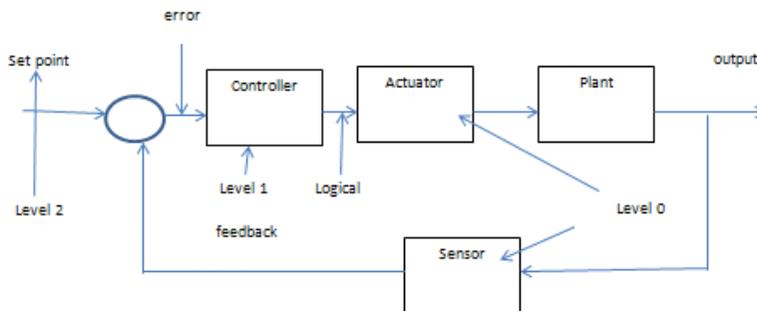

Figure 3: the structural elements of industrial control

Here we identify the major elements of industrial control; the sensor, actuator and controller. We get the desired value (set point) from level 2. While the sensor and actuator from level 0 and the controller from level 1. Let us see each of these levels.

First look at the sensor. The function of the sensor is to produce information which accurately represents a physical variable. So obviously there is some variable conversion required.

Generally, information is obtained in electrical form and that thing can be converted into digital using digital electronics. So you need something to convert the physical medium for example, temperature into some other form so some electrical signal can be generated. Here the sensing element will change the temperature change into resistance change, the resistance change still is not an electrical signal that can be manipulated therefor, and you need a signal conditioning, so you put this resistor into some bridge and produce a voltage which is proportional to the resistor change. The temperature is proportional to the resistance and the resistance is proportional to the voltage and finally the voltage is proportional the temperature. The voltage may contain some noise so some processing element is required to get more accurate voltage. At this point you get the information form. It is no longer a process variable neither an electrical variable. It became information, this information can be displayed or can be transmitted to a controller or it can be stored in some data base. Finally, you have to use this or it can be a network card or it can be a disk, (Figure4).
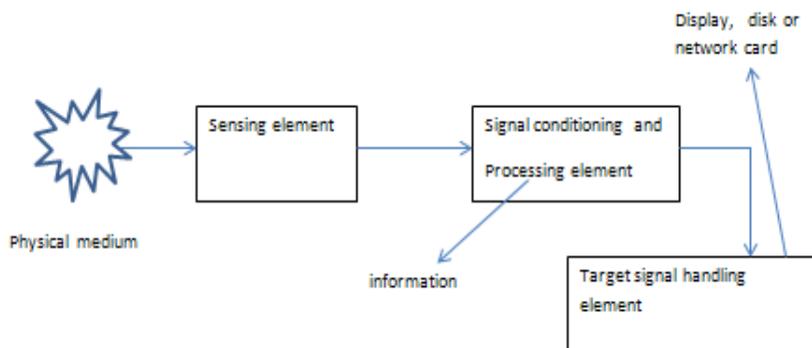

Figure 4:Sensor System

2.1 Level 0 (Sensing and Actuation)

Industrial Sensor System includes two major elements; the sensing element and the actuator. The sensing element is in its simple form, is

actually a signal conditioning and processing. Generally, a signal conditioning and processing composes the following items:
- Analog electronic signal conditioning followed by
- Digital processing
- Diagnostics/calibration/configuration
- Communication
- Signal protection and transmission

The second element of the industrial sensor system is the actuator which takes the logic information from the controller and then converts it to a physical plant input. The logic is no longer powerful. So it requires doing a lot of power amplification.

In summary, the actuator does two main functions; one function is the variable conversion, and the second function is a big amount of power amplification.

Because it is required a precise control, a feedback is needed. The actuator is actually a feedback control device.

An actuator has its own sensor. It has a controller and sometimes it has an analog signal processing and some power amplification (small hydraulic can handle a lot of power in small volume). The control valve in Figure5 is to be open or be closed, so it is required something to move it. So the hydraulic is used to move the stem. The sensor in figure 5 senses a position.
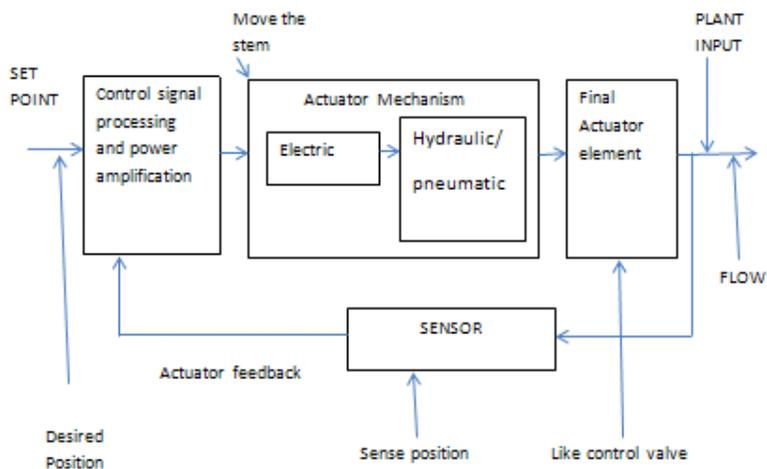

Figure 5: Actuator System

The total closed loop valve of the actuator shown in figure 5 controls the flow of the plant.

2.1.1 Industrial Actuator Systems

The industrial actuator systems (Figure 6) contained the following elements(BenjaminC.Kuo,2010):

- Electronic signal processing
- Electrical power amplification
- Electro-hydraulic/pneumatic/mechanical
- Feedback control for precision
- Auxiliaries for lubrication/cooling/filtering
- Remote operation and safety (operating circuit breaker which is a powerful machine)
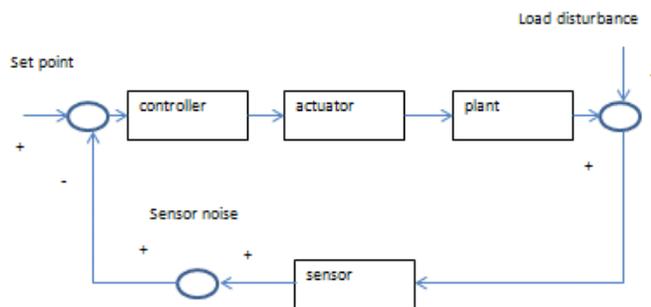- Energy optimization

Figure 6: Automatic Control Loop

2.2 Level 1: Automatic Control

Because the set point may change due to disturbance, so the automatic control loop maintains the set point.

Automatic control can be two types; continuous variable control (temperature is a continuous variable overtime) and Sequence/discrete event control. Moreover, the continuous variable control includes the followings:

- Controls analog continuous process variables
- closed loop control
- Track/hold set point/ (follow the set point). The set point is not constant it should hold it)
- Reject disturbance
- Generic PID/special purpose
- Tunable
- Dedicated digital RTS (microprocessor based system)
- Comparatively inexpensive

The second type of the automatic control is the sequence/discrete event control.

- Control of discrete valued process variables (ON/OFF or High/ Medium/Low).

You control the sequence; what happens after what? Or control timing i.e. when exactly the valve should be closed, for example, (5 minutes after valve is closed).

- Discrete sensing: limit switch/pressure switch/plant switch.
- Interlock, alarm
- PLC/industrial PCs, dedicated processor based
- No tuning is needed
- Status/sequencing/timing control

2.3 Level 2: Supervisory Control

The automatic control maintain a set of temperature for example, it does not know what temperature to maintain.

The supervisory control gives commands and a set point.

There is something which is very important, it is not necessary to use the same controller that you may use when the time plant start- up or the plant shutdown. Totally two different controllers.

So there are many controllers being used. If you want to start up, you use one controller and if you want to shut down, you use another controller. Also if you use normal operation you can use other controller, (Figure 7).

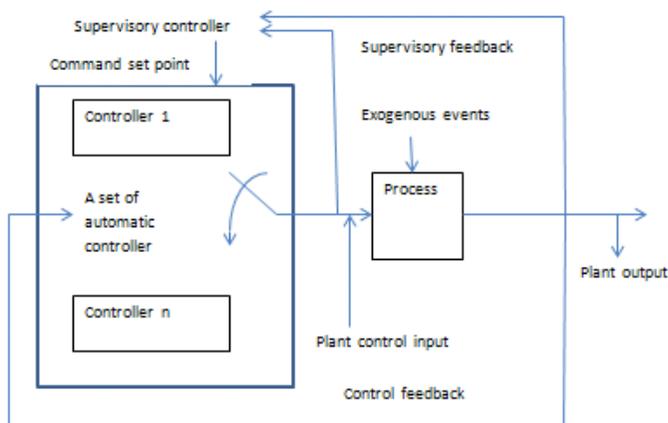You must give a command which controller to use and when.

Figure 7: supervisory controller operation

Based on the process of input/output, the supervisory controller does a lot of calculations to check always whether the system is working nicely. If it finds some problems, it immediately gives various commands to ensure which controller to use and when. The supervisory controller manages a number of automatic controllers.

The supervisory controller does the following jobs:

a- Set point computation (Impact on energy, quality, production volume)
b- Start up, shutdown, emergency operations
c- Control reconfiguration/tuning
d- Performance monitoring/diagnostics
e- Operator interface
f- Domain dependent (physical model based
g- Hard/soft real time
h- Expensive

2.4 Level 3 production Control

The production control has the following jobs and characteristics
a- Process scheduling
b- Material handling
c- Maintenance management
d- Inventory management
e- Quality management
f- Resource optimization technology
g- On-line non-real time

3. Conclusion

The article has explained the role of automation systems in industry. It focused mainly on the architecture of industrial automation systems. It described the scope and nature of the industrial automation. Moreover, the article has defined the industrial automation. It compared automation with control. It described the major roles of automation in the industry. The article provided industrial examples to illustrate all points being highlighted.

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