INSTRUMENTATION SYSTEMS

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Contents

Summary

The term "system" refers to a set of components that are connected to form and act as an entire unit. An *instrumentation system* is collection of instruments used to measure, monitor, and control a process. There are many applications of instrumentation systems, within technological areas as large as those associated with communications, defense, transportation, education, industrial manufacturing and research and development, and chemical and other process industries.

Developing and building instrumentation systems involves numerous scientific and technical disciplines, such as electronic, electrical, control, mechanical, chemical, metallurgical, and industrial engineering. In recent years many factors—such as the development of advanced mathematical theories, improvements in information and communication systems, and developments in sensors, measurement technology, computers, digital systems, Internet technology, and human–machine interactions—

have made the widespread application of instrumentation systems possible. Instrumentation systems have became the main cutting edge of technology, leading to higher productivity and thus becoming a major factor in deciding the competitiveness or survival of many businesses.

Modern instruments and instrumentation systems are largely based on digital technology. Digital instruments are developed by using dedicated ICs, microcontrollers and microprocessors that give them flexibility in information handling, networking and data communications. In manufacturing industry, processing plants, control and automation, and in other industrial applications, many instruments are used together to form very large instrumentation systems. These large systems can only be handled by a computer, or a number of computers. This article discusses microprocessor- and computer-based instrumentation systems. Therefore, a large proportion is dedicated to the basic principles of digital systems and digital process controllers. Many examples are given.

1. Introduction

Today, many advanced instrumentation systems are available, mainly directed at improving the productivity of industry and product quality. In many applications, instrumentation systems are custom-designed to meet specific process requirements. At the same time, instrumentation systems may have high initial costs, and in some cases they may lead to a loss of flexibility in production. Since the mid-1980s, many large firms have invested heavily in the procurement of hardware and software, creating extensive demand and accelerating research and development related to instrumentation and instrumentation systems. Furthermore, publicly-funded programs such as the Automated Manufacturing Research Facility (AMRF) have led to collaboration between industry and government. As a result, these efforts have shifted instrumentation systems from the stage of being general concepts to widespread implementation.

Although instrumentation systems can be used in any continuous process, they may largely be categorized into two main divisions: *process instrumentation* and *automation*. Advances in computing have played a major role in the development and implementation of these systems. In industry, computers form the core of *direct digital control* (DDC), *supervisory control*, *distributed control systems* (DCS), *hybrid control systems*, and *supervisory control and data acquisition* (SCADA), as well as simple systems such as single-loop controllers. SCADA, for example, allows reliable communication between devices located in remote sites using communication techniques such as microwave signal transmission and telemetry. Instrumentation systems constitute the heart of many operation systems, such as remote aircraft and satellite control, automated vehicle and transport systems, and fully-automated manufacturing plants and processes.

Advanced developments in instrumentation systems are supported by many secondary concepts such as *computer-aided design* (CAD) and *computer-aided engineering* (CAE). Automation is integrated with management concepts in the *computer-aided manufacturing* (CAM), *computer-integrated manufacturing* (CIM), *just-in-time* (JIT) type inventory management, and *flexible manufacturing systems* (FMS).

2. Instruments and Instrumentation Systems

Instrumentation systems are designed by taking the following factors into consideration:

- user requirements or specifications;
- functional design specifications;
- complete system design and structure;
- the test specification (for example, codes and integrated testing);
- the warranty, and other support such as training; and
- health and safety issues.

Instrumentation systems perform the following major functions:

- on-line mathematics, which establishes the monitoring and controlling process variables that cannot be measured directly but may be computed from other measurable variables;
- determining set points, and setting limits for variables and signals representing variables;
- selecting variables, and performing programmed operations for control and decision-making purposes; and
- logical and conditional moves.

In the next section an overview of instruments will be given. Further information can be obtained in the instruments and instrumentation section of this encyclopedia.

2.1. Instruments

Instruments are devices that monitor and measure physical variables. The physical parameters under investigation are known as *measurands*. The primary elements of instruments are sensors and transducers. Once the sensors generate signals in response to physical variables, the type of signal processing involved depends on the information that is required. In many applications, the outputs of the sensors are initially processed in analog form and then converted into digital representations, as shown in Figure 1.

Figure 1. Block diagram of a typical digital instrument

There may be a diverse range of sensors and transducers that can be selected to meet the measurement requirements. For example, there are many different sensors and transducers available for use in position or motion sensing, including capacitive sensors, inductive sensors, and optical sensors. The measurements themselves may be *static* or *dynamic*. Static measurements (for example, fixed dimensions and weights) are relatively easy, since the physical quantity being measured does not change over time. If the physical quantity does change, however, as is often the case, the measurement is said to be dynamic. In this case, the steady state and transient behavior of the physical variable must be analyzed and matched with the dynamic behavior of the instrument itself.

The topic of sensors and transducers, instruments, and measurements is a vast area, which cannot be covered in detail here. Interested readers can refer to the articles on the specific topic of instrumentation in this encyclopedia and references given in the Bibliography. Suffice to say that sensors and transducers are the fundamental components of instrumentation systems.

2.2. Instrumentation of Large Systems

Modern instrumentation systems are based primarily on digital techniques. In instrumentation systems, digital systems, computers, microprocessors, and other ICs are essential to almost all types of applications. Digital systems are widely accepted since they offer many advantages, including improved sensitivity, system flexibility, ease in information transmission, and so on. Most of the equipment associated with a digital instrumentation system can be divided into a number of major areas, such as sensing and controlling instruments, interface devices, input and output facilities, communication devices, main information processing equipment, and human–machine interface applications, as illustrated in Figure 2.

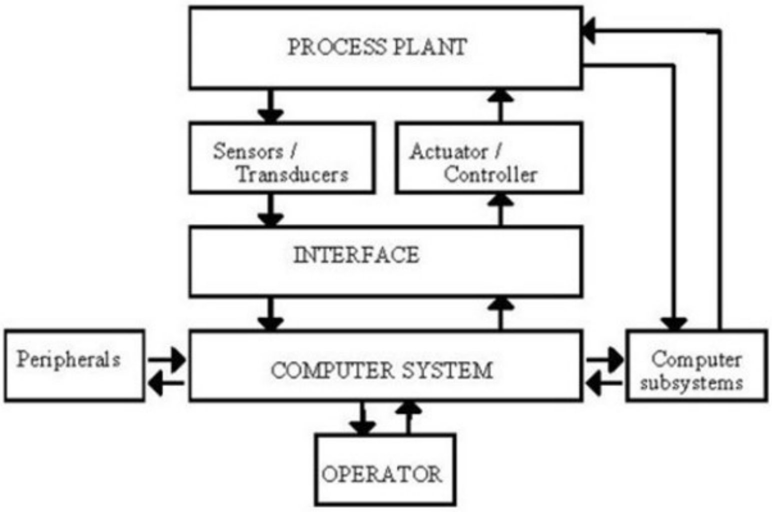

Figure 2. A computer control system

The computers in many large instrumentation systems may be arranged in a centralized, distributed, or hierarchical manner, and networked together using one of the available technologies. In a centralized computer control system all information is gathered by a central computer, which makes and implements decisions. Typical examples of such centralized computer control systems are the MDC 85 and PCS 8000. These are not general-purpose computers running control software, but are designed and manufactured for specific applications.

A modern industrial instrumentation system is usually a *distributed control system* (DCS). A DCS has three main components: the *data highway*, the *operator stations*, and the *microprocessor-based controllers*. The data highway handles information flow between components. The microprocessor controllers are responsible for effective control of the process, and are configured to work as multi-loop or single-loop controllers. The operator stations allow control commands to be given, the system database to be maintained, and process information to be displayed, For instance, the displays can be arranged as group, detail, trend, or alarm-broadcast displays. Operator consoles can handle large number of loops (up to 10,000). Nevertheless, DCS can have limitations in areas such as user orientation, communications, capacity, sequencing, speed, and reliability. Some of these problems may be eased by faster and improved communication highways, more powerful microprocessors, more effective database management, improvements in programming languages, greater data storage capacity, and other enhancements.

There are many distributed digital systems in the marketplace, such as the TDC series (Honeywell) and the TOSDIC series (Toshiba). The multi-task functions of a centralized computer system are divided between independent, dedicated functional units. Spatial distribution of the modules is made possible by the use of data highways. All distributed systems have a *control layer*, a *communication layer*, and a *process interface layer*, as illustrated in Figure 3.

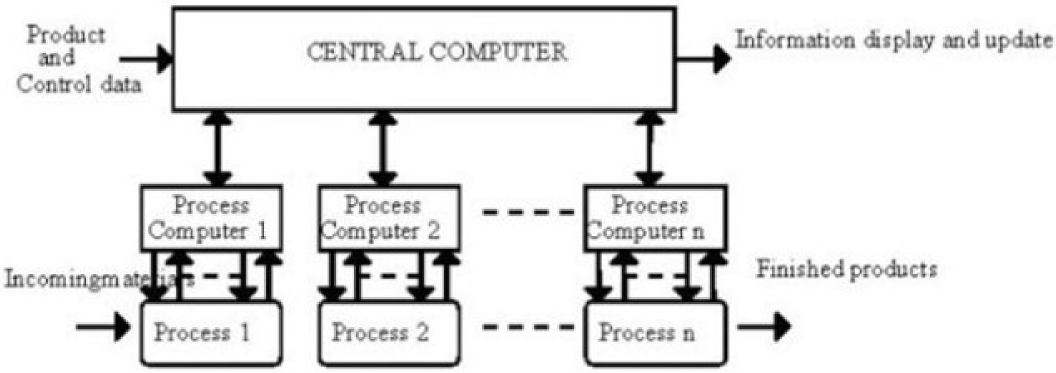

Figure 3. A hierarchical arrangement of computers in an instrumentation system

A hierarchical control system is a combination of centralized and distributed control systems. It has two layers of computers: one of these is dedicated to *in situ* process control, while the other contains a central computer responsible for the management of the total plant. In this system, all the computers work together by a communication network such as a *local area network* (LAN) or a *wide area network* (WAN).

Irrespective of the computers systems selected, the digital data communication needs to obey software protocols to ensure effective and efficient data flow. The protocols are managed by international standard organizations, such as the IEEE (Institute of Electrical and Electronic Engineers) and International Organization for Standardization (ISO). The communication protocols have number of layers, as illustrated in Table 1.

No.	**Layer**	**Application**	**Protocols**
1	Physical	Electrical, mechanical, process. Functional control of data circuits.	ISO/IEEE802.4, phase coherent carrier, broadband 10Mbs, *etc*.
2	Link	Transmission of data in LAN. Establish, maintain and release data links, error and	IEEE 802.4 token bus, IEEE

		flow information.	802.2 Type 1 connections.
3	Network	Routing, segmenting, blocking, flow control, error recovery, addressing, and relaying.	ISO DIS 8473, network services, ISO DAD 8073 (IS).
4	Transport	Data transfer, multiplexing, movement of data in network elements, mapping.	ISO Transport, Class 4. ISO8073 (IS).
5	Session	Communication and transaction management, synchronization, administering control.	ISO Session Kernel. ISO 8237 (IS).
6	Presentation	Transformation of information (*eg*. file transfer. Data interpretation, format and code transformation.	Null/MAP transfer. ISO 8823 (DP).
7	Application	Common application service elements (CASE); manufacturing message services (MMS); network management.	ISO 8650/2 (DP), RS-511, ISO 8571 (DP), IEEE802.1.

Table 1. The ISO reference model

2.3. Automation

Full understanding and careful study of systems control is crucial to modern instrumentation systems. Often the process is monitored continuously, and the data acquired from sensors and actuators that are operating during the process. Once the data has been collected, the process control strategy can be implemented. Therefore, modern process control is based largely on the measurement and control of process variables, the transmission of information, signal conditioning, and decision-making. Today, highly advanced measuring devices exist to monitor process variables, and various sizes and types of computer, microprocessor, and microcontroller are used in information-gathering, decision-making, and decision implementation.

The control function is not limited to the software in a computer, but resides in an entire loop that includes various instruments and elements. A fundamental element is that represented by the instruments, including sensors, transducers, and other measuring systems. Instrumentation forms part of the process involving the choice of measurement method and deciding on the use of the output information. Advances in sensor technology have provided a vast array of measuring devices that can be used as components of the larger system. These devices include high-sensitivity electromechanical sensors, optical scanners, machine vision devices, and others. In all applications, choosing a reliable and effective way of measuring the process variables is essential, so that further decisions concerning the overall system may be taken.

In automation, the characteristics of the signal conversion and transmission processes can affect the overall accuracy of the system, due to the possibility of losses and interference. Losses can take place due to electrical or mechanical interference, noise, cabling arrangements, power supplies, and other factors. Therefore, careful selection of communication technologies and equipment is of the utmost importance.

3. Digital Systems, Microprocessors, and Computers

Applications of microprocessors and computers in instrumentation systems can be categorized in terms of the following roles:

- *Data handling.* Data acquisition, signal conditioning, information extraction and data compression, interpretation, recording, storage, and communication.
- *Instrumentation control.* Includes on/off control of sensors, actuators, system resources, and process controls.
- *Human–machine interface.* One of the significant roles of computer systems in instrumentation systems is providing operators with a meaningful user interface to display control information ergonomically.
- *Experimentation and procedural development.* This involves commissioning, testing, and general prototyping of the targeted system.
- *Reporting and documentation.* An important role, involving data recording and maintaining records of operational procedures.

It is important to understand the basic architecture of computers in order to appreciate their functionality in instrumentation systems. Microprocessors are integrated circuits that handle and process data in binary format. In other words, a general-purpose microprocessor is used as the *central processing unit* (CPU) in a computer. The most significant manufacturers of microprocessors are Intel, Motorola, NEC, Fujitsu, Texas Instruments, Hitachi, Sony, IBM, AMD, and Zilog. By contrast, microprocessors that have built-in memory and interface circuits are called "microcontrollers." Due to their small size, simplicity, and low cost, microcontrollers are used in many applications in automation and instrumentation, as well as in consumer products. Typical families of microcontroller are the Motorola MC68HC11 and the PIC microcontroller.

Basic architectures of microcontrollers and computers are given in Figure 4 and Figure 5 respectively.

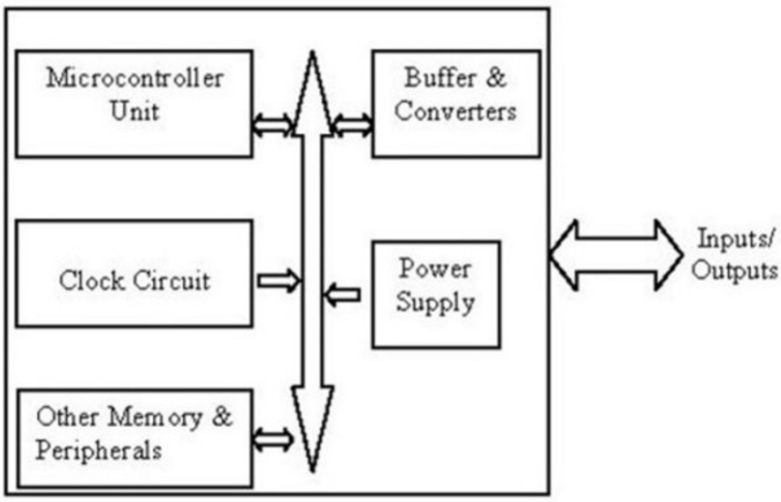

Figure 4. Block diagram of a microcontroller

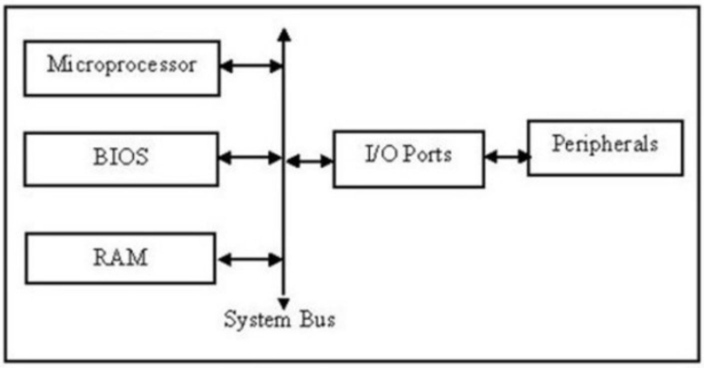

Figure 5. Block diagram of a computer

Microcontrollers and computers are both used extensively in instrumentation systems. They play an important role in data-acquisition, processing and control. A typical computer-based instrumentation system involves the subsystems shown in Figure 6.

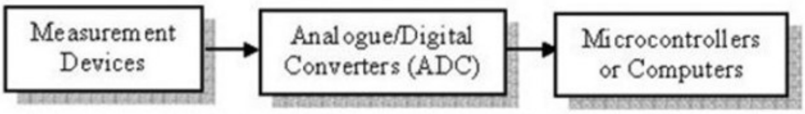

Figure 6. Block diagram of an instrumentation system

The microcontrollers and computers used most commonly in instrumentation systems can be categorized into two basic types: *embedded controllers* and *dedicated computers*.

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Biographical Sketches

Dr. Halit Eren received the B.Eng. degree in 1973, the M.Eng. degree in electrical engineering in 1975, and a Ph.D. in control engineering from the University of Sheffield, UK. Recently he has obtained an MBA from Curtin University of Technology.
Dr. Eren has been lecturing at the Curtin University of Technology since 1983, first in Kalgoorlie School of Mines and then at the School of Electrical and Computer Engineering, Perth, WA. He served as the Head of Department of Electronic and Communication for some time. His areas of expertise are control systems; instruments, instrumentation and networking; mineral processing; signal processing; and engineering mathematics. His principle areas of research are ultrasonic and infrared techniques, density and flow measurements, moisture measurements, fieldbuses, telemetry, telecontrollers, mobile robots, hydrocyclones, and Artificial Intelligence applications . He serves as a consultant to a number of industrial establishments. He has written numerous articles in books published by the CRC Press and Wiley and Sons.

Dr C.C. Fung completed his Ph.D. at the University of Western Australia in 1994. Prior to this, he received his B.Sc. in Maritime Technology with First Class Honors and an M.Eng. from the Institute of Science and Technology, University of Wales, in 1981 and 1982, respectively. Currently he is lecturing in the School of Electrical and Computer Engineering, Curtin University of Technology. His research concentrates on the application of computational intelligence to engineering problems, including autonomous robot control, remotely-operated underwater vehicle control, speech recognition, hydrocyclone parameter identification and control, hybrid energy systems, and well-log data analysis.