General Higher Education the 13th Five-Year Planning Teaching Materials

普通高等教育“十三五”规划教材

Control Network Technology

控制网络技术

李 擎 刘 艳 李江昀 张维存 编著

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Abstract

This book mainly describes the networking technology in the production process of integrated automation systems. The main contents include the layered structure of integrated automation systems and an overview of control networks, the foundation of data communication and computer networks, concepts and functions of the OSI reference model, and information on a typical control network named Profinet. As an entity network standard, Profinet focuses on application and practice, and integrates network equipment and its use.

It is suitable as a textbook for relevant courses in colleges and universities and as a reference book for automation engineers and technicians in the field.

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Preface

The content of "Control Network Technology" can be summarized as "Computer Networks + Fieldbus". The background of writing this book is threefold: First, the background of the era in which the automation industry is located. Since human society entered into the twenty-first century, a new chapter has been launched in the information revolution based on computers and the Internet. The emergence of new technologies and concepts such as the Internet of things, cloud computing and Internet + has made the top-level design of the information revolution more clear and concrete. All aspects of human society are permeated by these elements, including the fields and industries radiated by the automation industry. The second is the technology reserve accumulated by advanced control systems. The four levels of integrated automation in modern industrial enterprises, namely, basic automation, process control system, manufacturing execution system and enterprise resource planning, have gradually changed from conception to reality. All of these four levels rely on network connection: at the bottom is fieldbus, and at the top is computer networks. Thirdly, the future expectation of upgrading the control field to intelligent control in an all-round way. With the introduction of German Industry 4.0 and Chinese Manufacturing 2025, the networking of control systems will be deeper and more popular. In such an era and professional background, automation engineering practice for professionals requires not only familiarity with fieldbus, but also sufficient knowledge of computer networks.

This book combines the technology of "computer network" and "fieldbus", deletes any content on computer networks which has little relevance to the practice of automation engineering, and integrates the knowledge of the two parts organically to make it more complete and systematic. It is suitable as a textbook for relevant courses in colleges and universities and as a reference book for automation engineers and technicians in the field.

The book is divided into eight chapters. Chapter 1 is an introduction which mainly

describes the composition of enterprise integrated production systems, computer networks, and fieldbus. Chapter 2 covers data communication and introduces basic theories of data communication, such as signal transmission modes, channels, data coding, transmission media, etc. Chapter 3 introduces major concepts related to computer networks, including computer network topology, computer network hardware and software, the Internet composition and computer network performance indexes. Chapters 4, 5, 6 and 7 describe the data link layer, media access control sublayer, network layer and transport layer of OSI reference model respectively. Chapter 8 is about Profinet, a typical integrated network of field bus and computer networks, and introduces industrial ethernet, Profinet, network equipment, VLAN, VPN and so on. Chapter 1 is written by Li Jiangyun; Chapters 2 and 3 by Li Qing and Liu Yan; Chapters 4 and 5 by Li Qing and Li Jiangyun; Chapters 6 and 7 by Liu Yan and Li Jiangyun; Chapter 8 by Liu Yan and Zhang Weicun. The compilation process was also supported by postgraduate students from the School of Automation & Electrical Engineering, University of Science and Technology Beijing, such as Zuo Lei, Geng Jiahui, Su Zhenfeng, Wang Yaoping and Li Rui. The responsible editors of this book have also paid a lot of hard work for its publication. On the occasion of the official publication of this book, I would like to express my heartfelt thanks to them.

This textbook has been included in the school-level planning textbook of University of Science and Technology Beijing. The compilation and publication of the textbook have been funded by the teaching material development funds of University of Science and Technology Beijing.

Since my work background as well as the authors' level of expertise is limited, shortcomings and mistakes are inevitable. I hereby urge readers to criticize and correct.

Editor

Beijing, December 2018

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1 Introduction

Goal:

(1) Understand the concept of control network.

(2) Master enterprise integrated automation system.

(3) Master the concept of computer networks and fieldbus.

1.1 Enterprise integrated automation system

In modern enterprises, computers have taken on more and more tasks in automatic control, office automation, business management, and marketing. Enterprise networks will be an important infrastructure for connecting the various workshops and departments, as well as exchanging information with the outside world. In the market economy and the information society, the networks play an important role in the comprehensive competitiveness of enterprises.

Fieldbus is a popular topic in the field of industrial control. The control network discussed in this book is a broader concept and technology comprising fieldbus. The control network generally refers to a computer network system that is characterized by the control of objects. Control network originates from computer network technology and has much in common with general information networks, but there are also differences. For instance, in an enterprise automation system, a single user is dispersed into a system by means of control network, usually with broadcast or multicast as the communication method. However, in information network, an autonomous system generally adopts a one-to-one communication with another autonomous system.

1.1.1 A layered architecture

With the development of enterprise integrated automation systems, it is necessary to closely link business decision-making, management, planning, scheduling, process optimization, fault diagnosis and field control. According to market demand, we should conduct comprehensive information processing to produce new products in the shortest time and with lower resource energy

consumption. In addition, all levels of computers such as automatic control, office automation, business management, and marketing must be interconnected into network to achieve information communication and data sharing. Therefore, the information in the enterprise network is multi-layered.

Figure 1-1 is a schematic diagram of an enterprise network system based on a control network. The system is divided into the following four levels according to the functional structure: Enterprise resource planning (ERP), Manufacturing execution system (MES), Process control system (PCS) and Field control system (FCS). A complete enterprise network system is formed through network connection and information exchange between layers.

The early structure of the enterprise network system is complex and has many functional levels, including control, monitoring, scheduling, planning, management, and business decision-making. With the development and popularization of Internet technology, the structural level of enterprise network systems tends to be flat. At the same time, the division of functional levels is also more simplified. The lower layer is the FCS layer where the fieldbus is located. The top layer is the ERP layer. The information from the industrial site is controlled, optimally calculated and displayed in the PCS layer. The part of the multiple control management functions is interspersed in the middle of MES layer.

ERP and EMS functional layers mostly use Ethernet technology to form an information network. Therefore, the network integration between them and, the information interaction with the external Internet are better solved, and its information integration is relatively easy.

In Figure 1-1, the fieldbus network segments (H1, PROFIBUS, and LonWorks) are connected to the factory field devices. The foundation of an enterprise network is the FCS layer. At present, there are many types of control networks used in the FCS layer. The communication consistency within this layer network is very poor, except Distributed control system (DCS), Programmable logic controller (PLC), Supervisory control and data acquisition (SCADA), etc. The control network is quite different from the data network in several aspects, such as the communication protocol and the network node type. It is difficult to exchange information between control networks and between control networks and external internet networks. There are many obstacles to achieving interconnection and interoperability. Therefore, it is necessary to improve the data integration and exchange capabilities of the control network from the aspects of communication consistency and data exchange technology.

Figure 1-2 is the functional model and the hierarchical structure of an enterprise information system. The top layer is the decision-making layer; the bottom layer is the field control layer; and the bottom-up middle layers are the monitoring optimization layer, the scheduling layer, the planning layer, the management layer and the decision-making layer. Each functional module runs under the support of computer network and database. According to the internal and external information of the enterprise, the enterprise decision-making system provides decision support for the medium-term/

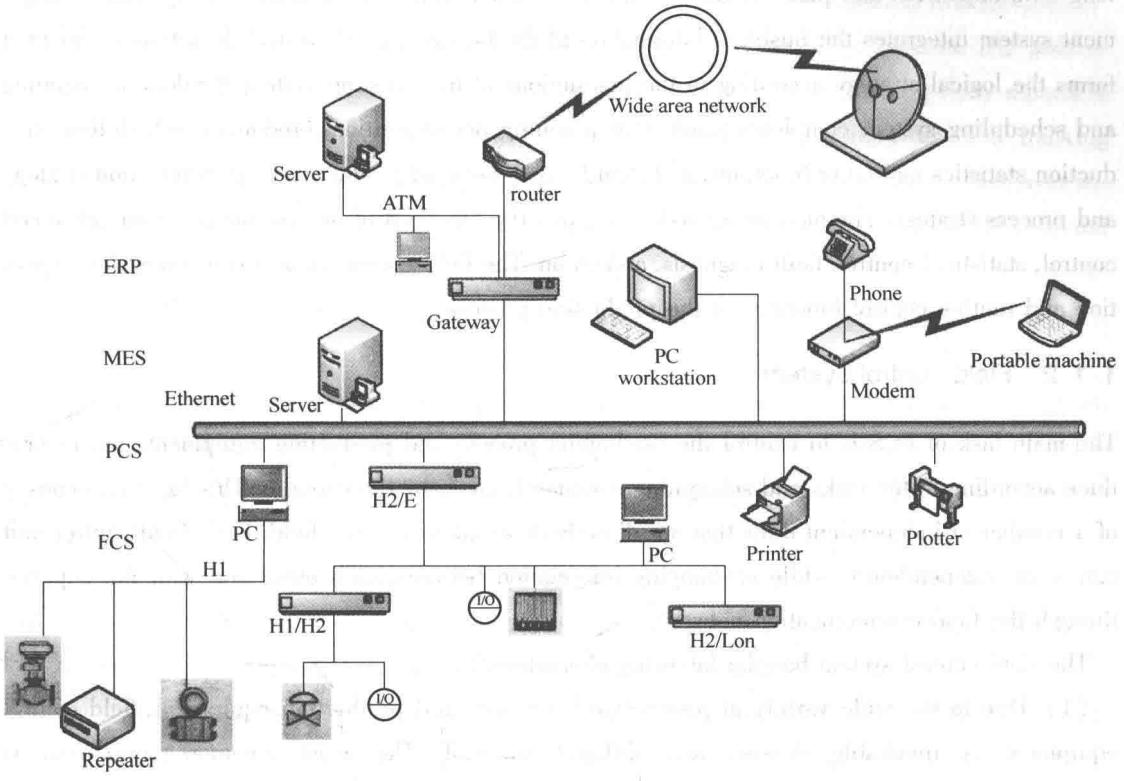

Figure 1-1 A schematic diagram of an enterprise network system based on a control network

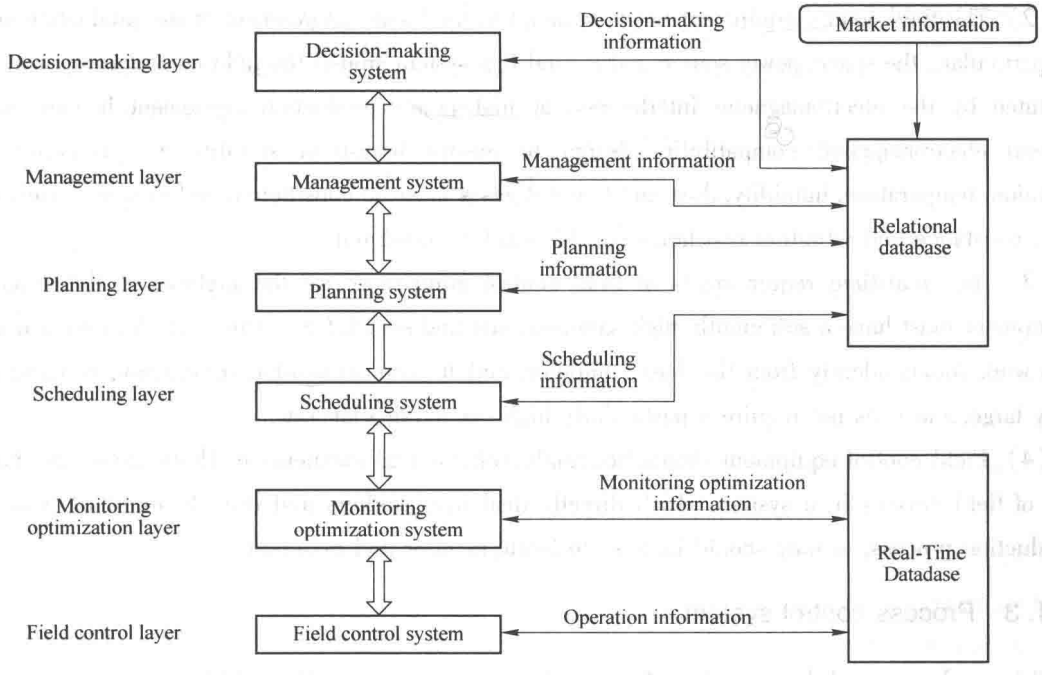

Figure 1-2 Function model and hierarchy structure of enterprise information system

long-term objectives and plans of the enterprise's management and product strategy. The management system integrates the business information of the factory, workshop and department, and then forms the logical strategy according to the instructions of the decision system. Production planning and scheduling system completes production planning decomposition, production scheduling, production statistics and other functions, and then forms a detailed production plan, production strategy and process strategy. The monitoring system realizes the functions of process optimization, advanced control, statistical control, fault diagnosis, and so on. The field control system completes the inspection and routine control functions of the production process.

1.1.2 Field control system

The main task of FCS is to control the production process and production equipment, and to produce according to the tasks and scheduling commands given by the superior. This layer can consist of a number of independent units that are directly distributed near the field. Each field control unit can work independently, while exchanging information between each other and with the superior through the field communication network.

The field control system has the following characteristics:

(1) Due to the wide variety of production processes and production equipment, field control equipment is inevitably diverse and difficult to unify. The most common equipment is programmable controllers, single-loop regulators, multi-loop regulators, industrial controllers, various distributed I/O devices, and various fieldbuses.

(2) The field control equipment needs to adapt to the harsh environment of the production site. In particular, the space, power source and ground line system around the field control equipment are polluted by the electromagnetic interference of high-power production equipment. It must have careful electromagnetic compatibility design to ensure long-term stability and reliability. In addition, temperature, humidity, dust and harmful gases must be considered, and in some cases, impact resistance and vibration resistance should also be considered.

(3) The real-time requirements of field control equipment are the highest, so field control equipment must have a sufficiently high sampling rate and speed. Generally, each field control unit can work independently from the host computer, and its communication information is often not very large, and does not require a particularly high communication rate.

(4) Field control equipment should be simple, reliable and inexpensive. There are a large number of field devices in a system, which directly deal with workers and directly interface with the production process, so they should be easy to learn, monitor and maintain.

1.1.3 Process control system

PCS is used to control the operation of the production equipment at the field layer, collect the main parameters and status of the production process, and report anomalies. At the same time, the neces-

sary commands are issued to the field control unit, such as setting the set value, so that the production equipment can work in coordination and ensure the best control of the process. The process control system also has to undertake part of the management work, such as forming daily reports of each workshop, displaying trend curves and statistical charts of key parameters, and tracking product quality, so that the management of the workers on the workshop is scientific. This layer includes multiple monitoring hosts. These hosts communicate with superiors and subordinates, and also communicate with each other over the network.

PCS has the following characteristics:

(1) The process control system is composed of some process monitoring stations. Each station governs a portion of the field control unit equipment. There is also a requirement to establish certain communication links between stations and stations, especially where fault-tolerant support is required. If there is a management level above, the process control station must also be able to communicate with it.

(2) Process control system includes many functions such as system functions, operator functions and engineer functions. System functions are related to both operators and engineers. Operator functions are used while operating the plant. Engineer functions are used during the setup, commissioning, maintenance and management of the system. The process monitoring station displays the on-site process and field device information to the operator in real time. It displays this information intuitively and vividly by integrating graphics, text, data, tables and colors into one screen. The displayed content is not only the window for monitoring, but also the basis for guiding the operation.

(3) The process control station has a rich configuration function. This is necessary for building, adding, subtracting and changing systems, and makes it easy for engineers and operators to define and modify various parameters of the system.

1.1.4 Manufacturing execution system

MES is a production information management system for the manufacturing floor of the manufacturing enterprise. MES provides many management modules such as manufacturing data management, planned scheduling management, production scheduling management, inventory management, quality management, human resource management, work center/equipment management, tool tooling management, procurement management, cost management, project board management, production process control, underlying data integration analysis and upper layer data integration decomposition.

Today MES can offer real-time applications. They generate current and even historical maps for production equipment and can thus be used as a basis for optimization processes. As early as the beginning of the 1980s, work started on methods of this kind which were then known as production data acquisition or machine data collection. But while the main emphasis in the past was on achieving improvements in machine utilization, today the concern is predominantly to obtain

real-time mapping of the value stream.

MES monitors the entire production process, starting with raw materials entering the factory and ending up with products entering storage. It records the materials and equipment used in the production process, the data results of the product inspection, and personnel in each production process. The collection of the information can be analyzed by the MES system, and the production schedule, target achievement status, product quality status, utilization status of the produced people, machines and materials can be presented in real time through the system report, so that the entire production site is completely transparent. Whenever you are in the office, the management of the company can see the status of the production site clearly through the Internet. The boss at the headquarters can also manage information through MES. Customers who are far away from abroad can also look over progress and product quality of their order.

The benefits of the MES system for the factory are as follows:

(1) Optimizing the production management mode of the enterprise, strengthening process management and control, and achieving refined management objectives.

(2) Strengthening the collaborative office capacity of each production department, improving work efficiency and reducing production costs.

(3) Improving the timeliness and accuracy of statistical analysis of production data, avoiding human interference and promoting the standardization of enterprise management.

(4) Providing effective and standardized management support for quality inspection of products, intermediate products and raw materials.

(5) Real-time control of information such as planning, scheduling, quality, process, and equipment operation, so that relevant departments can find problems and solve problems timely.

(6) The MES system can be used to establish a standardized production management information platform, so that the information between the internal control layer and the management layer can be interconnected, and then the core competitiveness of the enterprise is improved.

MES optimizes the management of the manufacturing process through feedback. It is mainly responsible for workshop production management and scheduling execution. A well-designed MES system can integrate management functions such as production scheduling, product tracking, quality control, equipment failure analysis, and network reporting on a unified platform. The system uses a unified database and network connection to provide workshop management information services for production departments, quality inspection departments, technology departments, logistics departments, etc. The system helps companies implement complete closed-loop production by emphasizing the overall optimization of the manufacturing process.

1.1.5 Enterprise resource planning

ERP is information systems that integrate processes in an organization using a common database