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ADVANCED INDUSTRIAL CONTROL TECHNOLOGY

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Advanced Industrial Control Technology

Preface

The first book of mine, entitled Industrial Control Technology: A Handbook for Engineers and Researchers, was published in June of 2008. A large number of engineers and researchers working in the processing, chemical and manufacturing industries think that the book is an applicable, implemental reference for modern real-time and distributed industrial control technologies - due to its comprehensive coverage, sophisticated explanation, and detailed content. That book also attracts great interest in universities and colleges around the world, which encouraged me to develop a book to be used for training professional engineers and teaching diploma courses in the field of industrial process control and production automation.

Nowadays, global industries find it more and more necessary to recruit engineers and graduates who have obtained solid training in technical skills and engineering expertise, rather than just the theory and strategy of industrial controls from universities or colleges. To offer this professional training and diploma courses, worldwide universities and colleges seem to urgently need an excellent book which provides full coverage of industrial control technologies suitable for the implementation of modern industrial control engineering. This book, Advanced Industrial Control Technology, aims at meeting this need.

This book fully covers industrial control technical topics with the intention of documenting all the key technologies applicable for various industrial control systems and engineering; after completing the courses within this book, engineers and students should be capable of implementing most control systems and engineering in different industrial applications.

This book provides a full series of the industrial control technologies traced through industrial control developments, including the traditional control techniques; and modern control techniques using real-time, distributed, robotic, embedded, computer and wireless control technologies.

This book gives a complete profile of these technologies from the field layer and the control layer to the operator layer for industrial control systems. This book includes all the interfaces in industrial control systems: the interfaces between controllers and systems; the interfaces between different layers; the interfaces between operators and systems. It is very noteworthy that this book not only describes the details of both real-time operating systems and distributed operating systems, but also of the microprocessor boot code, which seems beyond the scope of most industrial control books.

For the components, devices and hardware circuits, this book emphasizes the technical issues together with their working principles and physical mechanisms. The technical issues include the specification parameters, installation procedures, and calibration and configuration methodologies, etc. For the software packages, this book gives the programing methods in additional to their semantics and rationales.

Therefore for all industrial control and automation technologies, this book can serve equally as a textbook for postgraduates and undergraduates; as a guidebook for engineering and technical training; and as a handbook for practical engineers and researchers.

BACKGROUND

In the nineteenth century during the Industrial Revolution in Great Britain, machines were invented to replace human hands in the production of things such as textiles and tools. Industry emerged in the world as an important sector within human society. Accordingly, production and motion processes gradually began to be carried out by means of machines rather than human hands. Thereafter, to free human eyes and brains as much as possible from operating and monitoring various machine processes, Industrial Control and Automation was generated as a special technology used in industry. In 1910, Henry Ford achieved automation in his automobile assembly plant. Then, Allen Rogers and Arthur D. Little in America put forward the "Unit Operation" concept and the technique led to continuous chemical processing and extensive automation during the 1920s. With these pioneering works, "Industrial Control and Automation" came to be more and more used in various industries, and thus underwent significant development from the early part of the twentieth century.

In the 1930s, Harry Nyquist put forward a stability criterion by expanding the mathematical dynamic system and stability theory of Alexander Lyapunov, which initiated control theory. Thereafter in World War II, as an approach to fire control, airplane guidance, and large-scale chemical production control, the "system" concept was introduced to industrial control and automation, which led control theory to a higher level.

In 1947, the first generation of modern programed electronic computers was built in America. In 1968, a digital computer was produced to compete with electromechanical systems then under development for the main flight control computer in the US Navy. Based on computer technology, control engineers developed programable controllers and embedded systems. The first recognizably modern embedded system was the Apollo Guidance Computer, developed by Charles Stark Draper at the MIT Instrumental Laboratory.

In the 1970s, a great technical revolution occurred in the electronic and semiconductor industries, in which the integrated circuits were generated. By means of large-scale integrated circuit technologies, all the central-processing functions of a computer could be built on a single semiconductor chipset called a microprocessor or microcontroller.

Since the 1970s, Intel, IBM and other super-corporations have kept advancing the techniques of microprocessors to make their bit capacity increase from 4-bit, 8-bit, 16-bit to 32-bit in 1979. The highest capacities of microprocessor at present are 64-bit and 128-bit, developed by the AMD and Cyrix corporations, respectively, in the early 1990s. Nowadays, the single microprocessor has been extended into the multi-core microprocessor using parallelism and shared mechanisms.

- With the enhancement of the capacities and speeds of microprocessors, a widespread use of embedded control became feasible in the world from the mid-1990s. Accordingly, an important standard of industrial control was created, which is real-time control.
- Another high-technology achievement of the twentieth century is computer communication networks, which were developed in the 1980s. Inspired by the computer communication networks, distributed control was developed as another powerful control technique.

After World War II, high technology advanced throughout the world, and created many technical miracles such as programable integrated circuits, supercomputers and computer networks, etc. As a result, automatic controls in many vehicles, such as in aircraft, ships and cars, have greatly increased their scope; production automation in many industries, for example, in coal mines, steel plants and chemical factories, reached a higher level. Furthermore, more and more countries in the world are capable of making advanced space vehicles such as satellites and spacecraft that have very high requirements of the automatic controls inside them.

After decades of development, industrial control has formed a complete category with two aspects: industrial control theory and industrial control technology.

- Industrial control theory is the design guide for industrial control engineering. Industrial control theory includes the basic mathematical theory, control system theory, control models, control algorithms, and control strategies.
- Industrial control technology is the implemental guide for industrial control engineering. Industrial control technology includes field-level devices, embedded controllers and computer hardware, the components and protocols of industrial networks, and the software, mainly composed of real-time operating systems, distributed operating systems, embedded application software and control system routines.

Overall, with more than two centuries' development and evolution, industrial control and automation technologies have so advanced that they benefit us in all aspects of our life and in all kinds of production systems; they are closely integrated with computer hardware and software, network devices and communication technologies; they are faithfully based on modern results in the mathematical and physical sciences.

ORGANIZATION

This book has been structured into parts, chapters, sections, subsections and titled paragraphs, etc. There are eight parts in this book. Each part comprises several chapters. In total, this book consists of nineteen chapters within these eight parts. Each chapter in this book is dedicated to one special topic, and contains a number of sections explaining an aspect of this topic. Every chapter has two appended lists: one is a list of Problems and the other is Further Reading. The problem lists provide readers with questions for reviewing the knowledge included in the chapter. The Further Reading points readers to further sources related to the chapter.

Part 1 is titled "Industrial control fundamentals". This part contains two chapters: Chapter 1 is "Industrial control systems", and Chapter 2 is "Industrial control engineering". Modern control systems fall into three types described in Chapter 1: embedded control systems refer to a special relationship of control system to controlled system; real-time control systems are those control systems which satisfy the temporal standard for control operations; distributed control systems describe control systems that have special architectures and rationales in delivering control functions. In industry, the subjects of control applications can be processes such as a chemical reaction or an electrical transmission, a motion such as a car's motion or an aircraft's motion, a production such as making a machine or producing clothes, etc. Chapter 2 discusses the three types of modern industrial control engineering: process control, motion control and production automation.

Part 2, entitled "Field elements of industrial control systems", includes Chapters 3 and 4. In industrial control systems, the field level means the lowest level where control agents directly detect, measure, drive, and apply forces to the controlled objects. Chapter 3, entitled "Sensors and actuators", describes the sensors and actuators of the field-level elements, including optical sensors, temperature and distance sensors, and measurement sensors; and electric, magnetic, pneumatic, hydraulic and piezoelectric actuators. Chapter 4, entitled "Transducers and valves", describes transducers and valves including limited switches, photoelectric switches, proximity switches, ultrasonic transducers, linear and rotary motors, control valves, solenoid valves, and float and flow valves.

Part 3 of this book is entitled "Embedded hardware in industrial control systems". This part provides a detailed list of the types of microelectronic components used in control systems. These are the "Microprocessors" in Chapter 5, and the "Programmable-logic and application-specific integrated circuits (PLASIC)" in Chapter 6. Chapter 5 describes both single-core microprocessor and multi-core microprocessor units, emphasizing the multi-core microprocessors because this type of microelectronic architecture is much more powerful than single-core for performing real-time and distributed controls due to their parallelism and the shared mechanism. Chapter 6 introduces the three main types of ASICs: FPGA, MPGA and PLD. In this chapter, several typical ASIC devices are described, including programmable peripheral I/O ports, programmable interrupt controllers, programmable timers, and CMOS and DMA controllers.

Part 4 is entitled "Controllers and computers for industrial controls". Each of the controllers discussed in this part, similar to computers, is a system with its own hardware and software so that it is able to independently perform control functions. In Chapter 7, it explains the industrial intelligent controllers that are necessary for both industrial production control and industrial process control; these are PLC controllers, CNC controllers, and fuzzy-logic controllers. In Chapter 8, it explains some industrial process controllers, including PID controllers, batch process controllers and servo motion controllers. Industrial computers are specially architectured computers used in industrial control systems playing similar functions to the controllers. Chapter 9 of this book is on "Industrial computers" and explains industrial motherboards, industrial personal computers (PC), and some computer peripherals and accessories.

The device networks in industrial control systems are basically fieldbus-based multiple-node networks that intelligently connect field elements, controllers, computers and control subsystems for applying process, motion or production controls to industrial and enterprise systems. These networks demand interoperability of control functions at different hierarchical levels with digital data communications. Part 5 of this book is dedicated to "Embedded networks in industrial control systems". In this part, Chapter 10 introduces the layer model, architectures, components, functions and applications of several primary industrial control networks: CAN, SCADA, Ethernet, DeviceNet, LAN, and other enterprise networks. Chapter 11 of this part deals with networking devices, including networking hubs, switches, routers, bridges, gateways and repeaters. This chapter also provides some key techniques used in these networking devices.

Part 6 is on "Interfaces in industrial control systems". This part describes three types of interfaces; field interfaces in Chapter 12, human–machine interfaces in Chapter 13, and data transmission interfaces in Chapter 14. These three types of interfaces basically cover all the interface devices and technologies existing in the various industrial control systems. The actuator-sensor interface locates at the front or rear of the actuator-sensor level to bridge the gap between this level and the controllers. The HART was a traditional field subsystem but is still popular at present because it integrates digital signals with analogue communication channels. Fieldbuses, such as Foundation and Profibus, are actually dedicated embedded networks at the field level. The data transmission interfaces include the transmission control and I/O devices that are used for connecting and communicating with controllers. The human–machine interfaces contain both the tools and technologies to provide humans with easy and comfortable use of the technology.

The title of Part 7 is "Embedded industrial control software". Modern control technology features computer hardware, communication networks and embedded software. Embedded software for control purpose includes three key components: the "Microprocessor boot code" in Chapter 15, the "Real-time operating systems" in Chapter 16, and the "Distributed operating systems" in Chapter 17. These chapters provide the basic rationale, semantics, principles, work sequence and program structures for each of these three components. Chapter 15 explains the firmware of a microprocessor chipset. Chapter 16 gives all the details of real-time operating systems, which are the platforms needed for a control system to satisfy real-time criteria. Chapter 17 explains the necessary platform for distributed control systems, which is the distributed operating system.

Part 8 is for the profound topic of "Industrial control system routines". This part is dedicated to system routines that make the control systems more efficient, more user-friendly and safe to operate. Chapter 18 explains industrial system operation routines, including the self-test routines at power-on and power-down, installation and configuration routines, diagnostic routines, and calibration routines. Chapter 19, the last chapter of this book, is on industrial control system simulation routines, which are process modeling and simulation routines, manufacture modeling and simulation routines, and the simulator, toolkits and toolboxes for implementing simulation. In Chapter 19, the identification principles and techniques for model-based control are also discussed.

SUGGESTIONS

This book is an engineering- and implement-oriented technical textbook, guidebook and handbook, which hence requires not only classrooms but also laboratories. Field practices, including field experiments and implementations, are necessary for learning the material in this book. In places where conditions are ready, the training in each part of this book should be based on one or several prototype industrial systems. For example, the following industrial systems and networks can provide the background for studying this book: manufacturing industries, including the makers of machines, motors, vehicles, cars, aircrafts, ships, and so on; chemistry production industries, including the producers of medicine, plastics, fibers, and so on; energy industries, including electric power production and transmission, crude oil fields, coal mines, and so on; transport industries, including railways, underground transport, city roads, inner-river shipping, and so on; food production industries, including the makers of breads, sugar, beers, wines, and so on; device makers for industrial control networks such as industrial Ethernet, Fieldbuses, industrial computers; industrial control system interfaces such as actuator-sensor interfaces, human–machine interfaces, and data transmission interfaces, etc.

This book contains so much that it could take one and a half academic years to complete the study. Therefore, depending on your requirements, selection of which contents and topics in this book to read is very feasible. Because this book consists of eight parts, each part can be used for a specific area of study, such as: industrial control systems and engineering fundamentals; sensors, actuators, transducers and valves in industrial control systems and engineering; embedded hardware in industrial control engineering: single-core and multi-core microprocessors; Application-specific integrated circuits (ASIC) and programmable intelligent devices; digital controllers in industrial control systems; industrial computers; industrial control networks: architectures and components and interfaces;

industrial control networks: communication protocols and software; the buses and routers in industrial control networks; real-time operating systems; distributed operating systems; microprocessor boot code; industrial control system routines; industrial processes and systems modeling; simulating the industrial control system; etc.

SOURCES

Writing this book has involved reference to a myriad of sources including academic and technical books, journal articles, lecture notes, and in particular industry technical manuals, device specifications and company introductory or demonstration documents etc. displayed on websites of various dates and locations. The number and the scale of the sources are so huge that it would be practically impossible to acknowledge each source individually in the body of the book. The sources for each chapter of this book are therefore placed at the end of each chapter. This method has two benefits. It enables the author to acknowledge the contribution of other individuals, institutions and companies whose scholarship or products have been referred to in this book; and it provides help for the reader who wishes to read further on the subject.

Acknowledgments

My most sincere thanks go to my family: to my wife Minghua Zhao, and my son Huzhi Zhang, for their unwavering understanding and support.

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