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Edited by M. Thoma and A. Wyner

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Author
Prof. Ming Rao
Intelligence Engineering Laboratory
Dept. of Chemical Engineering
University of Alberta
Edmonton, Alberta
Canada T6G 2G6

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intelligent process control (Chapter 6), intelligent maintenance support system for air-traffic control (Chapter 7), and integrated intelligent software environment for gear manufacturing system (Chapter 8). The new knowledge, which is generated form building intelligent control systems and may complement the knowledge of both AI technique and application domains, is covered in Chapter 9. The conclusions are summarized in Chapter 10.

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PREFACE

Intelligent control is a new interdisciplinary field which extensively applies the knowledge of computer science, artificial intelligence, electrical engineering as well as system science to industrial automation processes.

A new integration architecture for implementing real-time distributed intelligent control systems is also developed. The construction of intelligent systems is one of the most important techniques among artificial intelligence research tasks. My goal is to develop an integrated intelligent system to accomplish the real-time control of industrial processes. An integrated intelligent system is a large knowledge integration environment that consists of several symbolic reasoning systems (expert systems) and numerical computation packages. These software programs are controlled by a meta-system, which manages the selection, operation and communication of these programs. This new architecture can serve as a universal configuration to develop high-performance distributed intelligent systems for many complicated applications in real-world domains. The configuration of the integrated intelligent system has attracted significant attention from both industry and academia, and is expected to lead to a new era for the application of AI techniques to real-world chemical intelligent process control problems.

My experience from developing intelligent process control systems also indicates that new knowledge may be generated from the process of developing knowledge-based systems, which may complement the knowledge of both artificial intelligence techniques and the related application domains.

Chapter 1 introduces the background of intelligent control system, its current state, and future development. A knowledge-based systems for process control design, namely IDSCA (Intelligent Direction Selector for the Controller's Action in multiloop control systems), is presented in Chapter 2. The integrated intelligent system is described in Chapter 3. Its implementation in OPS5 environment and C environment is presented the following chapter, while the implementation with TURBO-PROLOG is presented in Chapter 8 with application to an intelligent gear manufacturing system. Several applications based on the integrated intelligent system are developed, such as intelligent optimal control system (Chapter 5), pulp and paper

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1 Introduction

1.1 Intelligent control for industrial processes

The growing complexity of industrial processes and the need for higher efficiency, greater flexibility, better product quality, and lower cost have changed the face of industrial practice. Meanwhile, the application of computers has allowed the implementation of more advanced techniques. For example, chemical process control is the science and technology of automation in chemical industries. As shown in Figure 1.1, chemical process control is interdisciplinary in nature, and allows the application of knowledge from system science and computer science to be extensively applied.

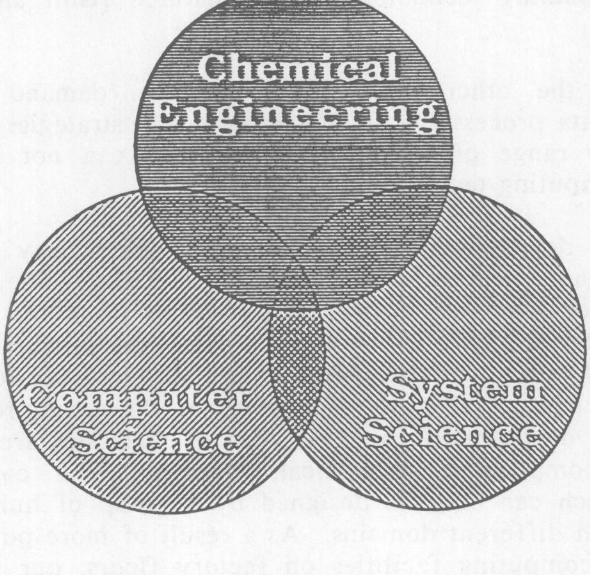

Figure 1.1 Field interaction

It has been widely recognized that quality control and process automation are the key elements to make modern industries stay competitive internationally. Recently, the chemical companies have begun to recognize the importance of process control in order to have a successfully functioning manufacturing facility [Astrom, 1985]. With the advent of microcomputer technology, process control developed rapidly during the past 10 years. The chemical process industries have historically recognized the importance of process control in order to have a successfully functioning manufacturing facility. It can safely be said that chemical processing in the future will require that operators have considerable process control knowledge and experience.

For a long time, computers have been used for control and monitoring in process industries. With the advent of microcomputer technology, process control developed rapidly. The application of more powerful computers has allowed us to implement more advanced control concepts. The systematic knowledge of process operation has created an environment facilitating the introduction of expert systems. Existing hardware and programming technologies have matured [Ishii and Hayami, 1988].

On the other hand, the increasing demand for more effective data processing methods and control strategies to be used in a wider range of industrial applications can not be met by current computing techniques.

The development of industry automation may be divided into four stages in term of automation [Lu, 1989]. The first stage, namely labor-intensive stage, mainly relies on skills of human operators on simple non-automatic machines, which can be designed by individual designer. At the second stage (equipment-intensive), automatic equipment plays a dominant role in the competition of productivity. This kind of machines are associated with the complicated mechanical, electronic and computerized devices which can only be designed by a group of human design experts from different domains. As a result of more powerful and affordable computing facilities on factory floors, our industry is now moving into the third stage (data-intensive), which stimulates the development of Flexible Manufacturing System (FMS). At this stage, automation is realized at the level of data processing, and CAD is the key technology for design tasks. The next challenge is decision-making automation for knowledge-intensive industry, such as Computer Integrated Manufacturing Systems (CIMS) which integrates CAD, CAM, CAPP (Computer-Aided Production Planning) and CAT (Computer-Aided Testing) to accomplish various production tasks, such as taking order, production planning, design, manufacturing, testing, sales and management. This high-performance automation does not allow too much intervention from human experts within the operation process.

The technological advances in automatic control have addressed the research interests of intelligent control, which encompasses the theory and applications of both artificial intelligence (AI) and automatic control (Figure 1.2). Intelligent process control is developed for implementing process automation, improving product quality, enhancing industrial productivity, preventing environmental and hazardous risks, and ensuring operational safety. Two objectives of intelligent control are.

1. enhancing product quality through automation, and
2. improving efficiency through AI techniques.

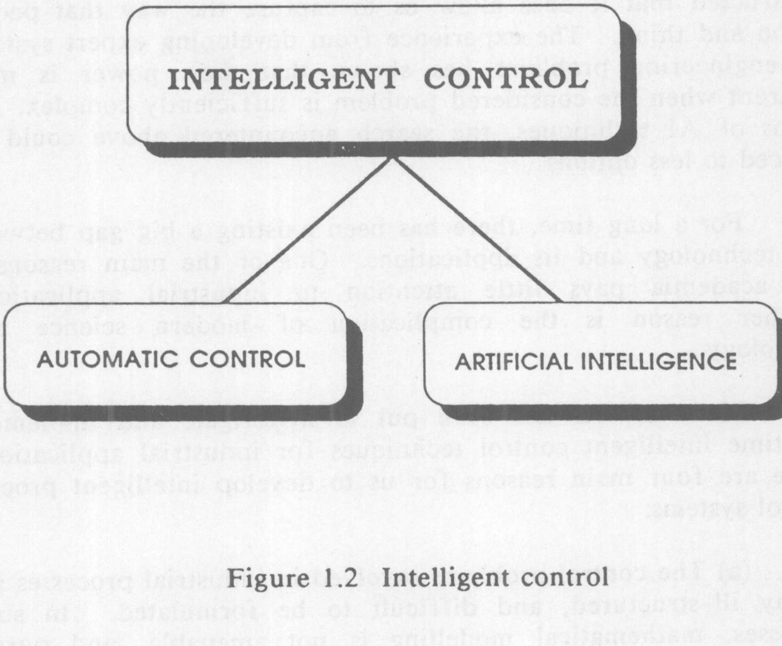

Figure 1.2 Intelligent control

Currently, computers have been widely used in engineering applications, but the use has been limited almost exclusively to purely algorithmic solution. In fact, many engineering problems are not amenable to purely algorithmic computation. They are usually ill-structured problems that deal with non-numerical or non-algorithmic information and are suitable for the use of AI techniques, especially expert systems [Weise and Kulikowski, 1984].

As a new advanced technology frontier, AI has been widely applied to various disciplines, including control engineering. This study aims at processing non-numerical information, using heuristics and simulating human being's capability in problem-solving. In fact, a much better terminology for this field was suggested as "complex information processing system", rather than "artificial intelligence". Today, instead of continuing arguing which terminology is better, we concentrate on investigating the use of powerful computation technology in AI research.

An expert system is also a computer program that acquires the knowledge of human experts and applies it to make inference for the user with less training or experience in solving various problems. Expert systems provide programming methodology for solving ill-structured engineering problems which are difficult to be handled by purely algorithmic methods. An expert system is so constructed that it does allow us to capture the way that people reason and think. The experience from developing expert systems for engineering problems has shown that their power is most apparent when the considered problem is sufficiently complex. By means of AI techniques, the search encountered above could be reduced to less options.

For a long time, there has been existing a big gap between new technology and its applications. One of the main reasons is that academia pays little attention to industrial applications. Another reason is the complication of modern science and technology.

Many efforts has been put to investigate and implement real-time intelligent control techniques for industrial applications. There are four main reasons for us to develop intelligent process control systems:

(a) The control problems involved in industrial processes are usually ill-structured, and difficult to be formulated. In such processes, mathematical modelling is not amenable, and purely algorithmic methods are difficult to use. However, AI techniques provide programming methodology for solving these ill-formulated engineering problems.

(b) In industrial manufacturing processes, operating conditions are frequently changed based on different production criteria. There exist many periodic operation procedures. Intelligent systems are suitable for use in such an environment.

(c) The stochastic occurrence of operational faults requires emergency handling in manufacturing processes. Past experience has shown that intelligent fault diagnosis systems are very powerful in dealing with such complex situations.

(d) Industrial process control always deals with the uncertain and fuzzy information. The conventional control systems fail to process such information. However, intelligent systems can process the imprecise information.

(e) Intelligent control is a new technological challenge, which may change the methodology of process control.

In the design of intelligent control system, knowledge processing techniques, including knowledge acquisition, representation, integration, management and utilization, are the main research topics of intelligence engineering which is a new engineering and technology research field.

Traditionally, expert system development mainly relied on the knowledge engineer who, by the definition, was a computer scientist and had the knowledge of artificial intelligence and computer programming. Knowledge engineers interviewed domain experts to acquire the knowledge, then built the expert systems. With the much powerful hardware platforms and more user-friendly programming environment, the increased computation capability of our control engineers, a new era of AI applications is coming to enable engineers to program the expert systems to handle their problems at hand. As we know, during the development of expert systems, knowledge acquisition is the most important but difficult task. Even with the help from knowledge engineers, some private knowledge (such as heuristics and personal experience as well as the role of thumb) may still be difficult to transfer. A new generation of engineers, namely intelligence engineers, are to be trained to meet the needs in this subject. The name of intelligence engineer was set to distinguish the knowledge engineer. An intelligence engineer is a domain engineer, (for instance, a control engineer), who has the certain domain knowledge in the related application area. Through a comparatively short period of training process, she/he learns the basic AI techniques, gets the hand-on experience on programming expert systems. Then, the intelligence engineer could build up much better expert system to solve her/his domain problem, and extend AI applications successfully. Intelligence engineering involves applying artificial intelligence techniques to engineering problems, and investigating artificial intelligence theoretical fundamentals and techniques based on engineering methodology. Figure 1.3 demonstrates the objectives of intelligence engineering. Distinguished from knowledge engineering, intelligence engineering emphasizes on integrating knowledge from different application domains to solve the real world engineering problems.

In the process of building expert systems, acquisition and representation of knowledge are two of the most important steps. The methodology used in this process is different from that in the prototype problem or in the related quantitative simulation program. In the process of developing an expert system, some new methods to solve the problem may be generated, which may complement the solver of the prototype problem [Weise and Kulikowski, 1984; Rao, Jiang and Tsai, 1988]. As usual, the new technique of programming expert systems is sought to guarantee the realization of new algorithms for this problem. This indicates that building an expert system is not just a translation from the existing expertise knowledge into a computer program; it is the production process in which new expertise knowledge can be acquired.

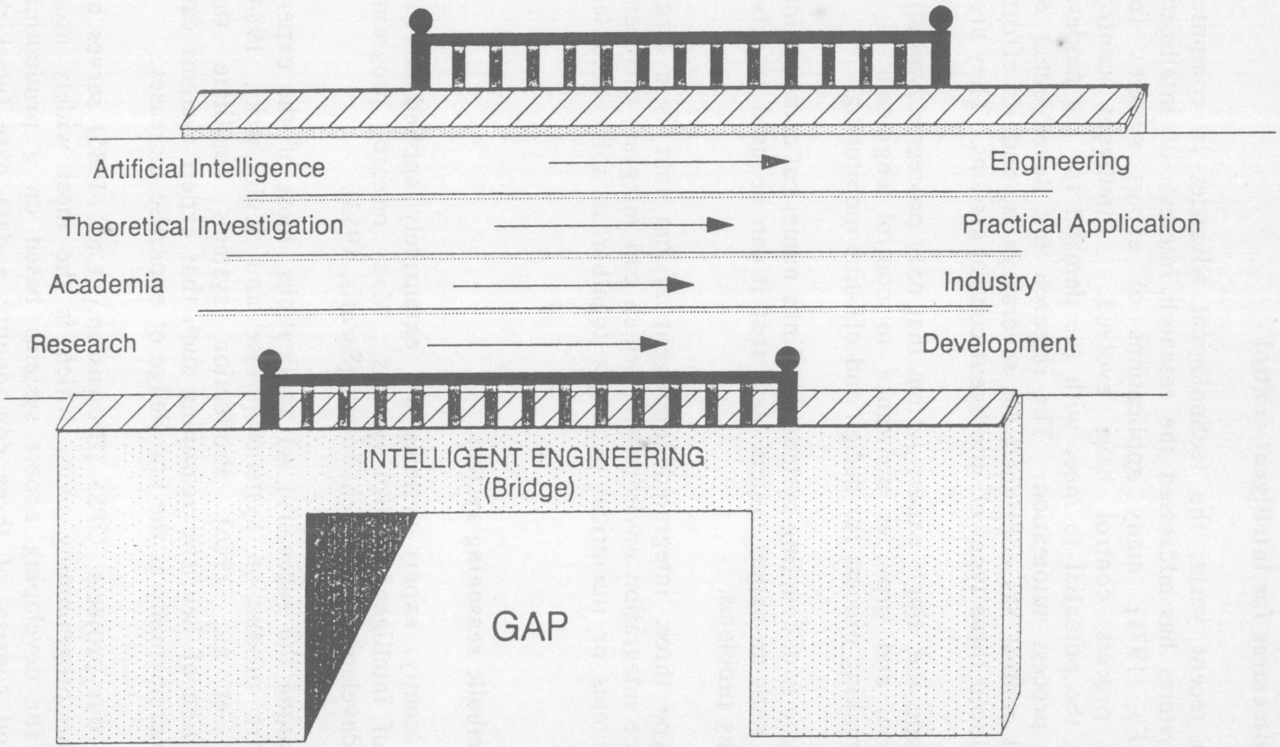

Figure 1.3 Intelligence engineering as a bridge

1.2 Architectures for intelligent control

In recent years, the technological advances in computer control systems has addressed the research interests of intelligent control [Fu, 1971]. many applications of expert systems for advanced process control have evolved. Intelligent control highlights the potential to meet with the demand for the modern industrial process automation. The research and development of intelligent control has continued for several years, and its efforts have produced three types of intelligent control systems. They are:

Type one: single expert system that only processes symbolic information, and provides assistance to control engineers in a decision-making process for design and off-line monitoring.

Type two: coupling system that links numerical computation programs with an expert system such that it can be used to solve engineering problems.

Type three: integrated intelligent system that is a large intelligence integration environment, which can integrate different expert systems or numerical packages together to solve complex problems.

1.2.1 Symbolic reasoning system

Presently, expert systems are extensively applied in the research of intelligent control systems. Many research programs focus on developing intelligent robots [Saridis, 1983].

Among the successful AI applications, most of the expert systems are production systems [Weise and Kulikowski, 1984; Talukdar, et al., 1986]. Production systems facilitate the representation of heuristic reasoning such that expert systems can be built incrementally as the knowledge of expertise increases.

In our projects, OPS5 (Brownston, et al., 1985) serves as one of the programming tools, which is the most widely used language for developing expert systems based on a production system, and consists of three components: a data base (working memory), a knowledge base (production memory) and an inference engine as shown in Figure 1.4. Working memory is a special buffer-like data structure and holds the knowledge that is accessible to the entire system. Each unit of working memory is an attribute-value element. Any attribute that is not assigned a value for a particular instance is given the default value designated as "nil".

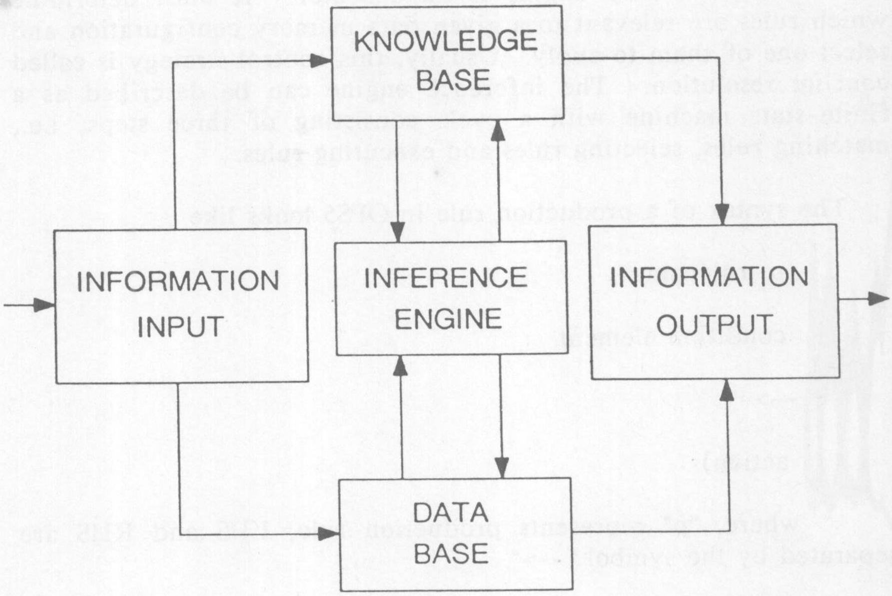

Figure 1.4 Structure of expert system