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INTELLIGENT CONTROL SYSTEMS

An Introduction with Examples

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by

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Acknowledgments

With the high popularity and expectations of intelligent control systems in our minds, we felt a great challenge to come up with a textbook in intelligent control systems. That is why we are particularly grateful for all those who have encouraged us to get through: our colleagues, students and families.

The material is based on our intelligent control course for 4th and 5th year information engineers in the University of Veszprém (Hungary) which has been taught successfully for 5 years for more than 100 students. The support of the University, our colleagues and students is gratefully acknowledged.

The inspiring and friendly atmosphere at the Department of Computer Science at the University of Veszprém and that of the Systems and Control Laboratory of the Computer and Automation Research Institute has also contributed to the writing of this book.

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Preface

Disciplines are diverging and converging. That is a natural process of science. Diverging is the deeply penetrating characteristic of science, opening knowledge about new phenomena and creating new methods. Convergence emerges by the interaction of disciplines, it serves as a relevant driving force towards new more effective syntheses. Convergence is evoked by the subject itself, i.e. by science-supported solving of practical tasks.

Control of industrial processes is the best example. Physics, chemistry and mechanics join the control of dynamically changing processes and control methods as a result of mathematical system theory. We can enumerate several further relations, economy and sociology, the whole world of the process and the applying human being.

Here stops the university educator in writing a textbook: What are the constituents of the basic knowledge for an engineer to be prepared for intelligent control? What are easily digestible, stemming from earlier courses? Where should his/her own course be ended, hoping that the further studies and especially the diligence and practice of the student enhances all these for enabling to complete the realistic, highly complex tasks of intelligent process modeling, design and control? That means the thorough and, on the other hand, general knowledge of system requirements.

The underlying textbook is the result of several years teaching experience and could not be based on similar course books in the field. The reason is evident: dynamic system analysis and synthesis applied ideas of artificial intelligence in the past few years only. These methods relate to the general methods of representation functional dynamics, e.g. Petri-nets; different methods of handling uncertainty, especially in cases where statistics is not sufficient but human experience has a relevant role, e.g. fuzzy concept. The description of dynamics is more meaningful by

qualitative methods due to discrete changes in the status and consistence of the materials concerned. Basic is the application of rules and logical reasoning in the analysis of phenomena and control operation. Special tools, such as programming languages dedicated for logical reasoning, shells for creating consultation systems in a special field, i.e. expert systems should be added, too.

The convergence of disciplines open a very suitable pedagogical means for examples related to the real life phenomena of those procedures where the student is familiar. By this way the reader receives much better insight into the subject, can understand theoretical concepts by his/her own personal impression that enables the stimulation of further steps outlined a little bit above.

I wish success for the textbook and to the students, started with this initiative!

Tibor Vámos
Member of the Hungarian Academy of Sciences
Computer and Automation Research Institute
Budapest, 21th June, 2001

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Chapter 1

GETTING STARTED

Intelligent control is a rapidly developing, complex and challenging field with great practical importance and potential. It emerged as an interdisciplinary field of computer controlled systems and artificial intelligence (AI) in the late seventies or early eighties when the necessary technical and theoretical infrastructure in both computer science and real-time computation techniques became available.

A great deal of interest has been shown in learning more about intelligent control by a wide audience. It has been a challenging and popular course subject for both graduate and undergraduate students of various engineering disciplines. At the same time there is a growing need amongst industrial practitioners to have textbook material on the subject readily to hand.

Because of the rapidly developing and interdisciplinary nature of the subject, the information available is mainly found in research papers, intelligent control system manuals and – last but not least – in the minds of practitioners, of engineers and technicians in various fields. There are a few edited volumes consisting of research papers on intelligent control systems [1], [2]. Little is known and published about the *fundamentals and the general know–how in designing, implementing and operating intelligent control systems.* Therefore, the subject is suitable mainly for elective courses on an advanced level where both the material and the presentation could and should be flexible: a core basic material is supplemented with variable parts dealing with the special tools and techniques depending on the interest and background of the participants.

1. INTELLIGENT CONTROL: WHAT DOES IT MEAN?

The notion of intelligent control systems is based on a joint understanding of the notions of "control systems" and "intelligent systems". Both of the above notions have undergone a strong development and have been the subject of disputes and discussions (see e.g. [3]). Therefore we shall restrict ourselves to practical, engineering type definitions of both, in describing the subject matter of this book.

Control systems assume the existence of a dynamic system to be controlled, that is an object the behaviour of which is time-dependent behaviour and which responds to the influences of its environment described by the so called input signals by output signals. The control system then senses both input and output and designs an input that achieves a predefined control aim.

Control systems are most often realized using computers, and in these cases we talk about *computer-controlled systems.* A computer-controlled system is by nature a real-time software system. Its software architecture contains standard data structures and tasks operating thereon. These include the following:

- *data structures:* raw measured data, measured data, events, etc.
- *tasks:* measurement device handling, primary processing, event handling, etc.

Appendix A gives a detailed description of the most important terms and notions in systems and control theory, as well as the software structure of a computer controlled system.

The notion of *intelligence* in the sense of *artificial intelligence* [4]-[8] is the other ingredient in the term "intelligent control systems". The notion of *intelligence* in itself has been a subject of permanent discussion for a long time and *artificial intelligence* is understood as "computer-aided intelligence", that is intelligence produced by computers.

The engineering type definition of artificial intelligence can be best understood if one recalls the elements of a problem for which we think we need a clever or "intelligent" solution. It is intuitively clear that easy or trivial tasks do not need a clever solution, just – perhaps – hard work. On the other hand, clever or intelligent solutions exhibit at least some non-trivial, surprising or unusual element, approach or other ingredient [9]. Therefore, one may say that an *intelligent method solves*

- *a difficult (non-trivial, complex, unusually large or complicated) problem*

- *in a non-trivial, human-like way.*

Furthermore, we can identify another basic characteristic of intelligent methods if we follow the idea of the engineering type definition above. The basic difference between the human and the machine way of solving difficult problems is that humans prefer to use clever heuristics over mechanistic exhaustive "brute force" approaches. The presence of *heuristics* is one of the key characteristics of intelligent methods.

To summarize we can say that *intelligent control systems are computer-controlled systems where at least part of the control tasks performed require intelligent methods.*

2. COMPONENTS OF INTELLIGENT CONTROL SYSTEMS

Every object with some kind of intelligence exhibits a quite complex and sophisticated structure: think of the biological structure of our nervous system controlled by our brain. Similarly, intelligent control systems have special components which are necessary to carry out control in an intelligent way. Most of the software elements of an intelligent control system perform its control function but some special elements serve its users, who come from various backgrounds and have varying academic qualifications.

2.1 SOFTWARE ELEMENTS

As we have already seen before, intelligent control systems are computer controlled systems with intelligent element(s) [10]. This implies that Neuman's principle applies to these systems: they have separate elements for the inherently passive, *data type* part and the active, *program type* part.

In traditional software systems, like in computer controlled systems, the data type elements are usually organized in a *database* while the active elements are *real-time tasks.* Tasks share the data in the database and a special task, the *database manager* is responsible for the resource management and the consistency of the data base.

This separation is clearly visible on the software structure of a computer controlled system described in details in section 5. in Appendix A.

Clearly not every intelligent system obeys Neuman's principle. Our brain, for example, works in a distributed manner, where every neuron has processing functions and stores data as well by connecting to other neurons.

The intelligent software systems that obey Neuman's principle are called *knowledge-based* systems. In intelligent software systems one can also find elements of the data and program type, therefore they are all knowledge-based systems. These elements, however, are given other special names as compared to traditional software systems.

The basic elements of a knowledge-based system are depicted in Fig. 1.1.

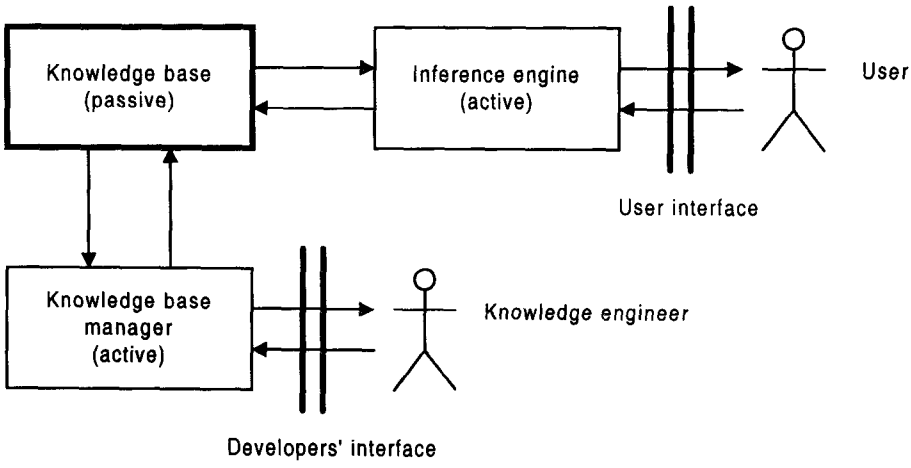

Figure 1.1. The structure of knowledge-based systems

We can see the following active and passive elements:

1. *Knowledge base*
   The database of a knowledge-based system is called the knowledge base. There is, however, a substantial difference between a database with data entirely passive and a knowledge base where the relationships between the individual data elements are much more important. We shall learn more about the similarities and differences between data and knowledge bases in Chapter 2.

2. *Inference engine*
   The inference engine of a knowledge-based system is its processing (program) element. It uses the content of the knowledge base to derive new knowledge items using the process of *reasoning*. Reasoning in rule-based expert systems is the subject of a separate chapter, Chapter 3.

There can be more than one inference engine in a knowledge-based system, in the same way as there are multitasking traditional software systems.

3. *Knowledge base manager*
   Similarly to the database manager, the knowledge base manager of a knowledge-based system performs the resource and consistency management of the knowledge base. However, this task is much more difficult than that of the database manager's, because the relationships between knowledge items are much more complex. As it is shown in Chapter 4 even checking the completeness and contradiction freeness of a rule-based knowledge base is computationally hard.

There is a special, important and widely used special type of knowledge-based systems where the knowledge is collected from an expert in a specific application domain. Such a knowledge-based system in a specific domain is called an *expert system.* If , in addition, the knowledge base contains data items and logical relationships between them expressed in the form of *rules* we speak about a *rule-based expert system* [11].

2.2 USERS

There are two principally different types of users in any knowledge-based system and their roles, qualification and user privileges are different.

1. *Knowledge engineer*
   A knowledge engineer is a person with a degree in computing, software engineering, programming or alike with specialization in intelligent systems. The design, implementation, verification and validation of a knowledge-based system is done by knowledge engineers. Ideally, they should have an interdisciplinary background knowing both knowledge-based systems technology and the application field in which the knowledge-based system is being used. In the case of intelligent control systems, a knowledge engineer should be familiar with the basic notions and principles of computer controlled systems as well.

   Knowledge engineers use the so called *developers´ interface* which is designed to work directly with the knowledge base manager of the knowledge-based system. Through this interface high privilege tasks, such as changing the structure and content of the knowledge base and other knowledge base management tasks can be carried out.

2. *User*
   A knowledge-based system is most often used via the so called *user*