KNOWLEDGE-BASED AND LEARNING CONTROL SYSTEMS

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Contents

Summary

This chapter presents a class of uncertain intelligent control systems in which the control decisions are based on a knowledge representation. The knowledge representation may be considered as an extension of a classical mathematical model in traditional control systems. In knowledge-based learning control systems the current control decisions are based on *step by step* knowledge validation and updating. Then, the learning process may be considered as an extension of a process of adaptation in traditional control systems.

The first concepts and methods for the knowledge-based and learning control systems were elaborated around the 1960s as the result of the applications of general artificial intelligence tools to control problems. The main development of this kind of control systems during the 1980s and 1990s is closely connected with the progress in the field of general knowledge-based and intelligent systems. There exists a large variety of definitions, approaches and ideas in the area of knowledge-based and learning systems.

Consequently, the problems of the systems under consideration are not so precisely defined and well composed as those of the classical control systems. This situation is typical for relatively new and rapidly developing areas. In this chapter basic ideas will be presented in a short and unified form which makes it possible to study related or

quite different individual concepts described in the literature and not presented here. After presenting the general concepts and specific features of the knowledge-based control, two basic forms of the knowledge representation and the corresponding control problems are reviewed. Then the different concepts of learning control systems are described.

1. Introduction

In traditional control systems the formulation of control problems and the determination of control algorithms are based on the exact and precise knowledge of the deterministic control plant. This knowledge is usually presented in the form of mathematical formulas which are called a mathematical model of the plant. In a function describing the relationship between the input and the output for a static plant or in differential (or difference) equations describing a dynamical plant some parameters may be unknown.

Then we may apply the concept of the feed-back control satisfying the stability conditions for which the exact knowledge of the parameters is not required or we may use the initial *a priori* knowledge of the parameters, e.g. in the form of their probability distributions if the unknown values of the parameters are assumed to be the values of random variables. This situation may be considered as a first level of uncertainty in the control system.

In many practical situations however the uncertainty concerning the plant may be much higher than the incomplete or imperfect knowledge of the parameters in the traditional mathematical model. In general, the plant may be nondeterministic, the classical forms of the mathematical models may not be adequate to its behavior and/or the knowledge of the plant given by an expert may be imperfect or incomplete. Anyway, in many practical cases this knowledge (sometimes having a linguistic form only, without any variables and formulas) may be presented in a precise form satisfying some principles and rules which makes it possible to formulate the control problem and to solve it by a computer.

Such a form is usually called a *knowledge representation* and the control system under consideration from the methodological point of view belongs to a class of uncertain control systems. On the other hand, the computer control system in our case may be considered as a specific form of a Decision Support System (DSS) which is usually called an Expert Control System.

Generally speaking, in a knowledge-based expert system it is necessary to determine the knowledge representation of the problem to be solved and to develop the algorithm of the knowledge-based problem solving. The knowledge-based expert control systems have their specific features which will be shortly described in Section 3, following the presentation of general ideas of the knowledge-based and learning control systems in Section 2. In the next sections the forms of the knowledge representations, the knowledge-based control problems and the basic concepts of learning in the knowledge-based control systems will be described.

At the end of this introduction let us note that knowledge-based control systems have numerous practical applications in different areas: in the control of complex technological and manufacturing processes, in so called flexible manufacturing systems with robots and manipulators, in the management and control of economical processes, project management, computer-aided medical therapy using a knowledge-based diagnosis, for the control of biotechnological processes and ecological systems.

Shortly speaking, knowledge-based control finds application in every situation where the exact mathematical models of the plant must and can be replaced by an expert knowledge, and the exact traditional control algorithms must and can be replaced by knowledge-based control rules executed by a computer expert system. Such a computer expert replacing the traditional controller should contain a knowledge base, a program generating the control decisions, and additional blocks for the interconnections with a user (human operator) and with a control plant.

2. General Concepts of Knowledge-Based and Learning Control Systems

The general idea of the knowledge-based control is illustrated in Figure 1. The control algorithm generates control decisions based on the knowledge representation and some external information containing the requirements concerning the plant, the purpose of decision making, the constraints etc.

Usually the knowledge representation describes the knowledge of a class of the plants under consideration. So it cooperates with the traditional data base containing the specific knowledge (e.g. the numerical values of the parameters) of the particular plant to be controlled. During the control process the control algorithm uses as its inputs the results of current observations of the disturbances and/or the effects of the control (feed-back). The structure of the knowledge-based control system may be more complicated and may contain additional blocks for the knowledge acquisition, the selection of the particular decision from the set of possible decisions determined by a basic part of the control algorithm and blocks representing the learning process in the learning control system which will be considered in Section 6.

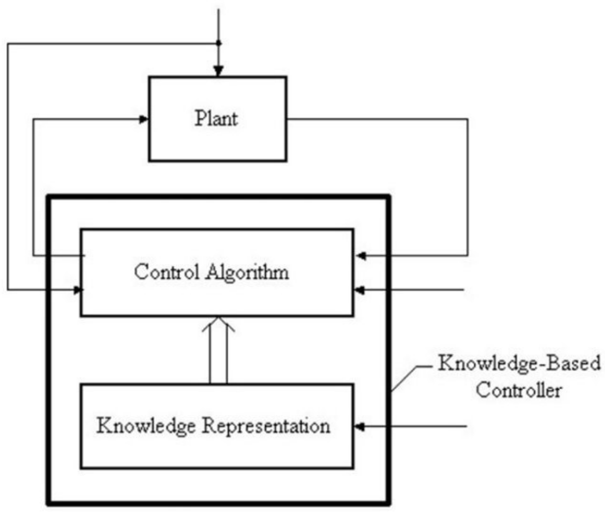

Figure 1. The basic scheme of knowledge-based control system

In the knowledge-based control system the following questions should be cleared up and solved:

1. How to formulate the knowledge representation and the control problem.
2. How to determine the algorithm generating the control decisions or the set of possible control decisions.
3. How to describe uncertainties in the knowledge representation and use it for the statement and solution of the control problem.
4. How to improve or increase the initial knowledge using the results of current observations of the plant and current evaluations of the control quality, if possible.
5. How to use the current knowledge updating in step by step improving of the control decision making, i.e. in the learning process.

The solutions of the problems listed above should be presented in a precise form sufficient and suitable for computer implementation. The learning process consists here in *step by step* knowledge evaluation and updating, and in using the results for the determination of the current control decisions. Then, the learning process in the knowledge-based control system may be considered as an extension of the adaptation in traditional control systems, based on the results of the current *identification of the control plant*. (see *Identification for control*, *Adaptive Control*, *Model Based Predictive Control for Linear Systems*).

It is important to note that we can consider two kinds of knowledge given by an expert and used in our system:

(i) The knowledge of the plant.
(ii) The knowledge of the control.

The expert describes the relationships concerning the plant in the first case, and describes his (her) knowledge of how to control in the second case. The knowledge representation has a declarative character in the first case and a procedural character in the second case. Consequently, the determination of the final form of the control decisions may be based on the knowledge of the plant (*a descriptive approach*) or directly on the knowledge of the decision making (*a prescriptive approach*).

In the second case a designer of the system should determine the algorithm generating the precise final control decisions which may be put at the input of the particular plant to be controlled, based on the general knowledge given by an expert for a class of plants. Such an approach is applied in the concept of so called fuzzy controllers (see *Fuzzy Control Systems*). These two kinds of the knowledge are also considered in the learning control system.

In the prescriptive approach the current improving of the knowledge about the decision making may be considered as an extension of the idea of adaptation in traditional control systems, consisting in self-adjusting of the parameters in the controller. The form of the controller may not be based on the plant model which is unknown, but can be assumed *a priori* as a model of a human operator. If this model has unknown parameters then two versions of the adaptation may be applied:

I. Direct self-adjusting of the parameters in the model of the human operator, using the current observations of the control quality.

II. Step by step evaluation of the parameters in the model, using the current observations of the human operator, i.e. adaptation via the identification of the human operator. In the prescriptive approach for the knowledge-based control system, two versions listed above are more complicated. The traditional form of the human operator model is replaced by the knowledge representation given by an expert, and in general this representation differs from the final form of the control algorithm which should be determined by a designer. Then, in the first version the learning process consists in the direct improving of the control algorithm and in the second version it consists in the updating of the knowledge of the control and consequently, improving the control algorithm based on this knowledge.

Let us note that the descriptive and prescriptive approaches are not specific for the knowledge-based control systems but they are used in different cases of knowledge-based systems and in common sense for informal practical situations concerning a knowledge and learning. We can describe and improve the knowledge about "*how it is*" (e.g. to learn about how a computer is built) or about "*how to operate*" (e.g. to learn how to operate with a computer).

3. Specific Features of the Knowledge-Based Control Systems

As already said, the knowledge-based control may be considered as a special case of the knowledge-based problem solving, and the knowledge-based control systems form a special class of knowledge-based decision making systems. The specific properties and problems connected with the control are the following:

1. The knowledge-based decision making concerns a control plant, i.e. the real object which is to be controlled. The control plant is a source of data obtained as the result of observations and measurements, and is a subject of the current decisions which should be introduced at its input. In many practical cases it is not possible to obtain the exact values of the measured variables (or the observations have not a numerical character), and the results of observations take the form of knowledge about the current state of the plant. Then an additional block representing the acquisition of the current knowledge is required.

2. The knowledge-based control systems are as a rule *real time* systems. This is a typical property of control systems which means that the observation and the decision making are performed in the moments determined *a priori* or by a current situation (event systems). Consequently, the expert system working as a controller should be a real-time computer system with special additional input-output devices and an operating system supervising the data acquisition and the determination of the control decisions in real time.

3. The knowledge representation of the plant or of the control may have a special form. For example, it may describe the relationships in a complex of operations which should be controlled, including the current situation concerning the group of robots and other executors of production operations. The knowledge about the control may contain specific rules, typical for operations which are necessary to perform the control. As a rule, the control plant is a dynamical system, i.e. its current state depends on the former state and the former decision. Consequently, the control process is *a multi-stage decision making* process. The description of the dynamical knowledge representation and the determination of a sequence of decisions based on the dynamical knowledge representation involve new difficult problems, specific for the knowledge-based control.

4. In the case of the control we may say about two kinds of the knowledge in the same situation: the knowledge of the plant and the knowledge of the control. Then we can compare two approaches: the generating of the control decisions based on the knowledge of the plant (a descriptive approach) or based directly on the initial and not precise knowledge of the control (a prescriptive approach).

5. We may say about two kinds of expert systems for the control: an expert system supporting the designer of a control system and an expert system acting as a controller. In the first case only *a priori* knowledge of the plant, requirements, constraints etc. is introduced into the knowledge representation. In the second case the current knowledge and/or the knowledge of the control (in a prescriptive approach) should be introduced and a computer expert should be designed as a real-time knowledge-based system. In adaptive and learning control system both kinds of systems cooperate in real-time: an expert-designer improves the work of an expert-controller. In such a case we can say about an expert-designer on the higher level who designs the learning system under consideration.

6. In many practical applications the control plant is a complex system, i.e. it is the composition of interconnected parts (subsystems). Consequently, we have the problem of decision making based on the distributed knowledge. On the other hand, even the description of a simple plant may be composed of two parts: a traditional mathematical model with a classical data base and a knowledge representation. Then, the control system is *a hybrid knowledge-based system* (Figure 2). Another form of the complex system may be obtained as a result of the decomposition of the control which may be based on the auxiliary results of identification or pattern recognition. Then the direct control decisions are generated using the results obtained from the knowledge-based identification and recognition systems.

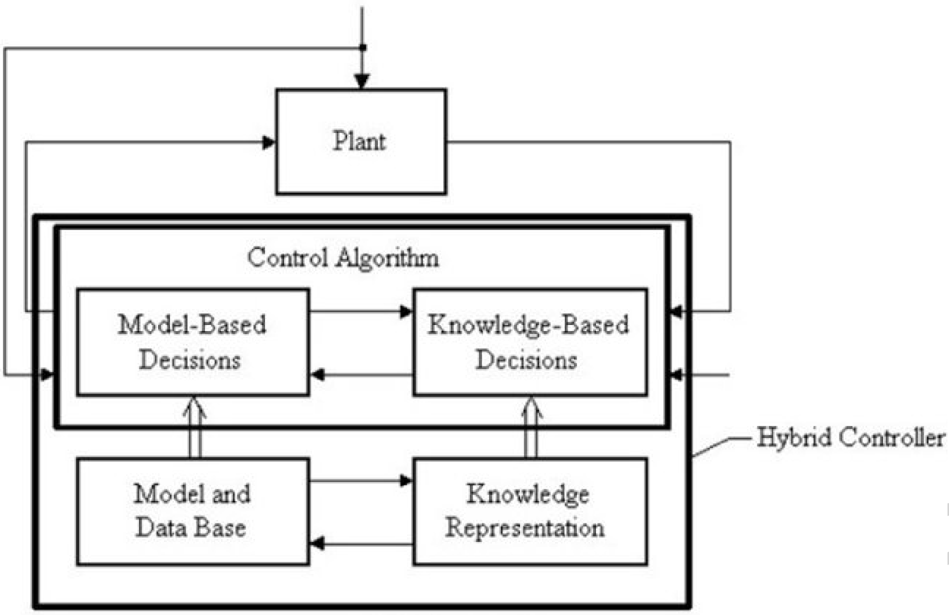

Figure2. Hybrid control system

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Biographical Sketch

Zdzislaw Bubnicki received the Ph.D. and Dr. Sci. degrees from Wroclaw University of Technology, Wroclaw, Poland, in 1964 and 1967, respectively. He was a Full Professor of control and information systems and the Director of the Institute of Control and Systems Engineering at Wroclaw University of Technology. His research interests included artificial intelligence, intelligent and knowledge-based systems, learning and operation systems. He authored of over 200 papers and seven books, among others: *Identification of Control Plants* published by Elsevier and *Uncertain Logics, Variables and Systems* published by Springer. He was the Editor-in-Chief of the journal *Systems Science* and the Associate Editor of the journals *Control and Intelligent Systems, Artificial Life and Robotics* and *Systems Analysis Modeling Simulation*.

Professor Bubnicki was a senior member of the Polish Academy of Sciences, President of the Polish Committee of Automation, Polish Representative in the International Federation for Information Processing (IFIP) General Assembly, and a member of technical committees in IFIP and the International Federation for Automatic Control (IFAC). He was an honorary member of World Organisation of Systems and Cybernetics (WOSC). He passed away on 12th March 2006.