Fuzzy Algorithms for Control

FUZZY ALGORITHMS FOR CONTROL

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FUZZY ALGORITHMS FOR CONTROL

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Preface

This edited book gives an overview of the work performed by a number of European research groups, that worked together in a consortium called Falcon (Fuzzy Algorithms for Control) under the umbrella of the European Community program to stimulate activities in this rapidly developing field. New results of analysis and design and some new applications have been included as well to show the progress that has been made in the years after the formal termination of the working group. As a result of the Falcon activities, new research and information dissemination programs have been initiated by the European Community in which the participants of the Falcon consortium still play a leading role.

After the seminal work of Zadeh in the sixties, it took a long time before fuzzy sets and fuzzy logic were accepted by the academia and the industry. Fuzzy sets and fuzzy logic caused a major paradigm shift that influenced many scientific, technical and non-technical areas. This is one of the reasons why this new theory had to face severe criticism from some scientific areas, which felt that their carefully built positions were attacked. Control engineering is one of the fields in which fuzzy logic was introduced early in the seventies. European researchers, such as Mamdani in the UK, Holmblad and Østergaard in Denmark and van Nauta Lemke in the Netherlands took the lead in this area. A general acceptance in the control engineering community could not be obtained before the nineties, however, after a breakthrough of fuzzy logic applications in consumer goods and in other areas, which was stimulated by a powerful research program in Japan.

In 1992, prof. H.-J. Zimmermann took the initiative to form a European consortium to promote the research and the application of fuzzy sets and fuzzy logic. A working group on fuzzy algorithms for control (Falcon) was set up by research teams from Germany, France, the United Kingdom, Belgium, the Netherlands, Italy and Spain. This group was subsidized by the European Community. Later on, partners from Sweden and Finland became associated members and also researchers from Russia were involved in the working group. At the same time, a major European Congress on Intelligent Techniques and Soft Computing (EUFIT) was organized, and again Zimmermann was the initiator of this event. This conference is annually held in Aachen and attracts about 600 participants, both from the academia and the industry.

This book contains 12 chapters clustered into three parts, which each contains four chapters. Most of the chapters could have been included in at least two parts of the book, but by using fuzzy clustering techniques in an intuitive way, we came to the current division of the chapters.

Chapters in Part I address the position of fuzzy systems in systems and control engineering. It took a long time before fuzzy modeling and control techniques were accepted by the control community. However, it has been shown that these techniques can provide solutions to problems that would remain unsolved or yield unsatisfactory results with conventional methods. Fuzzy control also faces some criticism from the AI community. In many cases, fuzzy sets and fuzzy logic are used to approximate a nonlinear mapping between input and output signals, rather than that human experience and reasoning are used along the seminal ideas of fuzzy sets and systems.

The first chapter by Verbruggen and Bruijn gives an overview of areas where fuzzy modeling and control can be beneficial for control engineering. It describes general issues in control engineering problems which should be solved and compares the fuzzy-system approach to conventional and advanced approaches based on analytical descriptions of the problem. It shortly comments on why fuzzy control is still to some extent a controversial subject and cautions that fuzzy control is not a panacea for all unsolved problems.

The second chapter by Årzén, Johansson and Babuška starts with a short overview of the basic concepts of fuzzy control systems, such as the structure of the controller (including prefiltering and postfiltering blocks). A comparison with the commonly used industrial controllers is presented and some nonlinear fuzzy control structures are described.

The application of fuzzy models can play an important role in nonlinear control. Construction of transparent fuzzy models from data is the subject of Chapter 3 by Babuška and Setnes. It is shown that fuzzy models extracted from data in an automatic manner are to some degree redundant and thus can be simplified. Similarity measures are used to achieve this simplification and to provide transparent models. This approach is demonstrated on the modeling and control of an air-conditioning system.

The fourth chapter by Dubois, Prade and Ughetto analyses the coherence between fuzzy-control methodologies and the field of approximate reasoning. It is shown that discrepancies exist between the two fields and that the pragmatic engineering approach based on a nonlinear mapping of input and output signals, which is now mostly used in fuzzy control, could benefit from a more formal approach based on knowledge representation. It is also shown that the notion of gradual rules makes it possible to recover the concept of interpolation as a special case of fuzzy-logic inference.

Part II, which also contains four chapters, is concerned with several analysis and design issues in fuzzy control systems. The control theory community built up an elegant and nearly complete framework for the analysis and design of linear control systems. Moreover, many concepts have been developed for nonlinear systems, but a complete framework for these systems does not exist. It is clear that in order to compete with the approach presented hitherto in the control community, fuzzy control must incorporate some of the major concepts of control theory, such as stability and performance evaluation.

In Chapter 5, Perfilieva introduces fuzzy logic normal forms for the representation of control laws. The chapter also addresses using fuzzy-logic control models as universal approximators. Fuzzy logic normal forms are introduced for the uniform algebraic representation of these models. It is shown that a class of real-valued functions can be characterized by a certain fuzzy logic form.

In control engineering, the concept of stability of nonlinear systems is very important and it is clear that stability analysis should be an important tool for analyzing the nonlinear behavior of fuzzy control systems. In Chapter 6, Ollero, Marin, García-Cerezo and Cuesta present a thorough overview of the stability analysis of fuzzy control loops. The chapter first reviews the basic stability concepts. Then, two different approaches are considered in more detail: input-output stability and Lyapunov stability. The relation between the two approaches is also highlighted.

Although stability is a basic condition for a control system, in order to achieve the desired performance, a number of design specifications should be fulfilled. This is the subject of Chapter 7 by Sousa, Kaymak and Verbruggen. The main objectives to be fulfilled are related to the performance specifications with regard to the speed and accuracy of the control system and the ability to handle disturbances and model-plant mismatch (robustness of the overall system). It is shown that fuzzy decision-making algorithms are able to translate the objectives and constraints derived from the control-design goals in a transparent way.

In many applications in modern process-industry and manufacturing systems, the control problem cannot be divided into a number of single-input, single-output (SISO) systems and the interaction between variables in these systems has to be considered. The number of rules in such a MIMO system is large, as it is an exponential function of the number of input variables and the number of linguistic terms. The complexity of multivariable fuzzy rule-based systems is the central topic of Chapter 8 by Setnes, Lacrose and Titli. This chapter gives a survey of methods to reduce the complexity in fuzzy systems by pruning insignificant rules, or by using decentralized and hierarchical structures. It is shown that the methods presented in this chapter can reduce the complexity of the system considerably and can provide the user or designer with more insight in the system.

In the third part of the book, a number of applications of fuzzy control are presented. Only those application areas are covered in which the Falcon group members were most active or where an approach is presented which is different from those presented elsewhere.

Chapter 9 by Zimmermann, Angstenbergen and Weber is to a certain extent related to the previous chapter. Advanced data-analysis techniques can be applied to reduce the complexity of large amounts of data. The overall goal is to find structure in these data by partitioning them into relatively few classes of similar objects described by some attributes. A number of methods for fuzzy data analysis is described. In data analysis, it is not a priori clear which method should be applied to get the desired solution. Therefore, it is very important to pre-process the data before they become input to the data-analysis method. A software tool for data analysis, called DataEngine, is described in more detail. The relation between fuzzy data analysis and fuzzy control is considered and, finally, an industrial application is presented of a blast-furnace process.

Modern process industry presents many challenges for the design of control systems. Because of the customer-driven approach, the minimization of energy consumption and waste of material and because of the restrictions set by environmental regulations, a complex control setting must be considered. One has to cope with problems such as process nonlinearity, time-varying characteristics, incomplete process knowledge, etc. Chapter 10 by Juuso describes some of the problems in the process industry which can be solved by fuzzy control. To handle fuzzy control, a linguistic equation approach has been developed. Fuzzy modeling based on expert knowledge is used, resulting in a compact linguistic equations type of model and it is shown how these models can be used in a fuzzy-control configuration. The benefits of the presented method are demonstrated in two real applications: a solar-plant control system and a lime kiln plant. The chapter concludes with an overview of tools available for the implementation of fuzzy controllers in the process industry.

A number of challenging problems in which fuzzy logic can play an important role can be found in mobile robotics. Fuzzy logic has been used to consider the inaccuracy of the sensors and, in general, the uncertainties due to the limitations of the robot's perception system. It is also useful to express control commands and navigation strategies in a qualitative form. However, the complexity of the system becomes very high and requires a large number of rules to express behaviors of the complete mobile-robot system. The reactive navigation problem is addressed by applying the concept of virtual sensors in order to reduce the complexity and to add some flexibility to the implementation of the behaviors. Next, obstacle avoidance, map building, localization and planning problems are treated. Applications of fuzzy control to a mobile robot and a wheelchair for disabled people are presented.

The last chapter of the book, by Schram, Aznar and Verbruggen, is concerned with the enhancement of flight control by means of fuzzy logic. In aeronautical systems, fuzzy logic can reduce the extensive efforts in the design of control systems for new aircraft. Moreover, unexpected situations, such as changing weather conditions and system failures, can be handled by fuzzy systems to a certain extent. It is expected that in the near future, problems with the certification of fuzzy-control applications in aircraft will be solved. The chapter first describes the design of a fuzzy MIMO controller for the lateral and longitudinal flight path. A comparison is made with conventional controllers. Next, the problem of flight safety is considered and possible solutions using fuzzy logic are presented. Two examples are given. First, a control reconfiguration is described, for a situation where an engine failure occurs; the induced moment and the decreased force must be compensated by the remaining actuators and control surfaces. The second example concerns the microburst phenomenon, an unexpected vertical displacement of air that is radiated outward as it reaches the ground. A recovery strategy has been developed which can be readily implemented in a fuzzy flight-control framework.

It was not an easy task to complete the final text of this edited book. The authors are involved in many projects concerning fuzzy and conventional control systems and little time was available for most of them to write chapters on research, which is, in some cases, still going on. Fuzzy control has finally become an accepted and respected method in the control-engineering community and this is at least partly the result of the efforts of the Falcon-group members. We wish to thank the authors for their contributions and for reviewing chapters of their colleagues.

Finally, we want to thank Magne Setnes and Stanimir Mollov, Ph.D. students of the Control Laboratory of the Delft University of Technology, for their excellent job to produce in a short period a revised version of the chapters complying with the requirements of the publisher.

HENK B. VERBRUGGEN

HANS-JÜRGEN ZIMMERMANN

ROBERT BABUŠKA

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1 FUZZY SYSTEMS IN CONTROL ENGINEERING

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1.1 INTRODUCTION

Classical control methods have shown their applicability in many practical control problems in industry. It is shown, however, that still unanswered questions remain, which can probably be solved with the fuzzy system approach. Modern production methods and modern production units require increased flexibility, resulting in highly nonlinear system behavior of partly unknown systems. Advanced control methods developed by system and control theorists are only partly able to satisfy the demands. It is in this area that fuzzy modeling and control methods can play an important role, because available qualitative operator and design knowledge can easily be implemented. In this chapter, the possible role of fuzzy systems in low level control and in more advanced control is indicated. The introduction of fuzzy methods has been a controversial subject and has resulted in many misunderstandings. This chapter tries to clarify this situation and to emphasize the possible cooperation between the various players in the game: conventional control theory, fuzzy control, the AI community, and last but not least the end users.