Preface

Since the idea of the fuzzy set was proposed in 1965, many developments have occurred in this area. Applications have been made in such diverse areas as medicine, engineering, management, behavioral science, just to mention some. The application of the fuzzy sets involves different technologies, such as fuzzy clustering on image processing, classification, identification and fault detection, fuzzy controllers to map expert knowledge into control systems, fuzzy modeling combining expert knowledge, fuzzy optimization to solve design problems.

Fuzzy systems are used in the area of artificial intelligence as a way to represent knowledge. This representation belongs to the paradigm of behavioral representation in opposition to the structural representation (neural networks). The foundation of this paradigm is that intelligent behavior can be obtained by the use of structures that not necessarily resemble the human brain.

A very interesting characteristic of the fuzzy systems is their capability to handle in the same framework numeric and linguistic information. This characteristic made these systems very useful to handle expert control tasks.

This book is divided in two parts. The first part is devoted to the construction of static and dynamic fuzzy models from numerical information. Such models are important in areas such as data mining and control of dynamical systems. The second part shows how to exploit these models to design control systems. The book is organized into 8 chapters and 5 appendices.

Chapter 1 is entirely dedicated to the problem of function approximation and modeling. The first part of the chapter shows the approximation capabilities of fuzzy systems with triangular, polynomial and Gaussian membership functions. In this part, this book presents an analytical study of the approximation capabilities of the different types of membership functions.

Chapter 2 describes different techniques to construct fuzzy models from input–output data. Gradient descent techniques, clustering and evolutionary techniques are explained in this chapter. Some gradient expressions are derived to illustrate the expressions used to adjust the fuzzy models. This section is complemented with the Appendix B where the main clustering techniques used in modeling are explained. In the second part of the chapter the problems of generalization and consequence estimation are studied. An initialization and training method for the consequences is one of the highlights of this chapter. The method improves the generalization capabilities of the fuzzy models. It is illustrated by means of a graphical example.

Chapter 3 introduces the concept of linguistic integrity and presents an algorithm to build fuzzy models with linguistic meaning. This algorithm is especially important in tasks such as knowledge discovery and data mining. The contributed algorithm is named AFRELI (Autonomous Fuzzy Rule Extractor with Linguistic Integrity). This algorithm is complemented with an algorithm to reduce the complexity of the fuzzy models (FuZion algorithm). Several examples are presented where complex nonlinear functions, chaotic nonlinear systems and industrial processes are modeled using this algorithm.

Chapter 4 is devoted to the problem of nonlinear identification of dynamic systems using fuzzy models. In this chapter the tools developed in previous chapters are used to develop a framework for system identification using fuzzy models. The chapter begins by formulating the problem of system identification using fuzzy models. The chapter includes an analysis of the structure of the fuzzy models, which are more suitable to be applied in system identification. Thereafter the chapter studies the problem of experiment design and proposes types of signals that are considered to deliver "sufficient excitation" to guarantee the reliable construction of the model. The regressors selection is considered a complex problem also analyzed in this book. The main methods are reviewed and the advantages and disadvantages of the methods are analyzed. The possible structures of the models for nonlinear systems are enumerated and a short analysis of the applicability of some of these structures to identification using fuzzy models is included. Parameter calculations for different type of structures are studied under the assumption that gradient descent methods are used in this calculation. The issue of dynamic calculation of the gradients is emphasized, and Appendix C includes the derived expressions of these gradients. The chapter closes with a short discussion of the validation issues. This discussion points out the fact that fuzzy models can be validated using not only quantitative criteria but also qualitative criteria based on the information given by the linguistic rules. The chapter presents an example of identification of a gas furnace process proposed by Box and Jenkins [1]. In this example, most of the elements presented in the chapter are included.

Chapter 5 presents an overview of different techniques that have been designed to construct fuzzy controllers. The chapter starts by making a classification of the different methods where fuzzy sets are applied to control. The chapter explains some of the methods starting with the first early ideas employing pure expert knowledge. Then the discussion focuses on a very practical method, which is the design of PID-like fuzzy controllers. This section is complemented with the theorem presented in Appendix D. This contributed theorem guarantees that any discrete linear controller can be copied exactly by a fuzzy system. This property is exploited to initialize fuzzy controllers such that their initial performance (before tuning) at least equals the performance of a given linear controller. Then, the overview presented in this chapter focus on the adaptive control techniques based on fuzzy models. Inverse learning and direct learning are the two methods studied in this section. The chapter then pays attention to methods based on direct synthesis, and the method of feedback linearization is proposed where the models used to linearize the affine system are fuzzy models. The main drawbacks of this method are analyzed and the sliding mode fuzzy control method is explained as an alternative. Finally, the chapter is completed by a description of the fuzzy gain scheduling method. The advantages of the method, including the existence of methods to directly design stable controllers and test controllers for stability, are studied and discussed. The section is complemented with an industrial example presented in Appendix E where a stable fuzzy scheduling controller is designed for an automotive application a continuous variable transmission (CVT) system.

Chapters 6 and 7 are devoted to the construction of predictive controllers based on fuzzy models. Chapter 6 begins with the simplest idea of unconstrained predictive fuzzy control. The problem is formulated and a method to reduce the problem to a quadratic program is presented. The method includes the formulation of a predictor based on the concept of free and forced response; the estimation of the forced response is improved by a method proposed in this chapter. The chapter includes an application example where the control strategy is applied to a continuous stirred tank reactor (CSTR). In this example, the strategy is shown to perform quite similarly to the most optimal strategy. The second part of Chapter 6 studies the constrained predictive control problem. This part shows three different algorithms that exploit the information provided by the different types of dynamic fuzzy models. The chapter closes with an example where the control methods are applied to a steam generator model of a power plant and a gas-phase polymerization reactor for the production of polyethylene. The strategies are compared with classical linear predictive control strategies, and the improvement in performance can be clearly observed.

Chapter 7 presents a novel extension to the concepts presented in Chapter 6. This chapter, studies the problem of robust nonlinear predictive control based on fuzzy models. The chapter begins with the formulation of the problem. Then the problem is reduced to a robust quadratic program. The robust quadratic program is written as a second-order cone program using a new formulation presented in this book. Advantages of the use of these algorithms are mentioned including the computational complexity. The use of this robust optimization technique guarantees a minimum performance despite the mismatch of the models or the linearization errors introduced by the control algorithm. The chapter is completed with a list of possible ways to describe the uncertainty of the models.

Finally, Chapter 8 condenses the main contributions of the book and proposes new challenges for researchers.

The book also includes five appendices. The first two appendices show the fundamentals of fuzzy set operations and clustering. The last three are extensions to the content of the chapters.

The reader will be guided by summary boxes that contain the main ideas of the different sections, facilitating the comprehension and the goals of each section of the book.

The book is written at a level suitable for use in a graduate course on applications of fuzzy systems in data mining and nonlinear modeling and control. The book discusses novel ideas and provides a new insight into the studied topics. For this reason, the book is a valuable source for researchers in the areas of artificial intelligence, data mining, modeling and control. The realistic examples also provide a good opportunity to people in industry to evaluate these new technologies, which have been applied with success especially in the areas of monitoring and control of chemical processes and in oil exploitation.

Leuven, Belgium
January 2004

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http://www.springer.com/978-1-85233-828-2

Fuzzy Logic, Identification and Predictive Control
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2005, XX, 264 p., Hardcover
ISBN: 978-1-85233-828-2