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Ying Bai, Hanqi Zhuang and Dali Wang (Eds.)

# Advanced Fuzzy Logic Technologies in Industrial Applications

With 220 Figures

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# Series Editors' Foreword

The series *Advances in Industrial Control* aims to report and encourage technology transfer in control engineering. The rapid development of control technology has an impact on all areas of the control discipline. New theory, new controllers, actuators, sensors, new industrial processes, computer methods, new applications, new philosophies…, new challenges. Much of this development work resides in industrial reports, feasibility study papers and the reports of advanced collaborative projects. The series offers an opportunity for researchers to present an extended exposition of such new work in all aspects of industrial control for wider and rapid dissemination.

In the mid-1960s and contemporary with Kalman's pioneering papers on state-space models and optimal control, L.A. Zadeh began publishing papers on "fuzzy sets". It took another decade before the fuzzy-logic controller due to Mamdani and Assilion was reported in the literature (ca. 1974), and now the fuzzy-logic control paradigm is entering its fifth decade of development and application. Thus, this new *Advances in Industrial Control* monograph edited by Ying Bai, Hanqi Zhuang and Dali Wang on fuzzy-logic control and its practical application comes as a timely reminder of the wide range of problems that can be solved by this continually evolving methodology.

The volume can be considered in two parts, Chapters 1 to 5 cover a range of fundamental issues and then Chapters 6 to 21 range across a number of application studies. A cast of authors originating from the US, Mexico, Spain, P.R. China, Estonia, United Kingdom, Taiwan and Chile has contributed these 21 chapters. These diverse contributions have been melded together by editors Ying Bai, Hanqi Zhuang and Dali Wang to provide a systematic review of recent fuzzy-logic control applications.

The opening group of chapters examines a number of fundamental issues in constructing and applying fuzzy-logic controllers. The basic constructs of fuzzy-logic namely fuzzy sets, fuzzy rules and the defuzzification procedure are outlined in Chapter 2. Chapter 3 follows this basic material with a look at how fuzzy-logic controllers are implemented. A most interesting distinction between a static fuzzy-logic controller design and a dynamic (or adaptive) fuzzy-logic controller design is made in these chapters. This is one design route to enhancing the performance of fuzzy-logic controllers. Another route to performance enhancement is to extend the internal architecture of the fuzzy-logic controller by using "fine" and "coarse"

lookup tables and this modification is covered in Chapter 2. Also of considerable interest to the industrial engineer will be the material in Chapter 3 relating to the implementation of software and hardware fuzzy-logic controller solutions. Methods to ease the tuning of fuzzy-logic controllers are presented in Chapters 4 and 5. Tuning is a problem because fuzzy-logic controller performance can be tuned using scaled control gains, modifications to the membership functions, changes to the controller rule base or by adjusting entries to the inherent lookup table of the controller. None of these looks particularly simple and Chapters 4 and 5 make contributions to the tuning task.

A particular strength of this new volume in the *Advances in Industrial Control* series is the set of reports from a wide range of application studies, some 16 contributions in total, and these are found in Chapters 6 to 21. The subject areas are as follows:

*Manufacturing and Business Processes*

- Laser tracking system ~ Chapter 6
- Data mining ~ Chapter 17
- Manufacturing robot calibration ~ Chapter 20
- Plastic injection moulding ~ Chapter 21

*Image Processing*

- Visual image processing ~ Chapter 7
- Medical image processing ~ Chapter 8

*Vehicle Control Systems*

- Aspects of automobile control ~ Chapters 9, 10 and 11
- Mobile robot vehicles ~ Chapter 12
- Unmanned aerial vehicle control ~ Chapter 15 and 16

*Power System Control*

- Power distribution ~ Chapter 18
- Power generation ~ Chapter 19

This is quite a wide range of industrial areas and includes some non-control applications; for example, image processing and the survey chapter on fuzzy-logic applied to data-mining (Chapter 17). An interesting feature of the control problems is that some of them involve the control of "soft" variables like the distance between cars in the context of traffic control or the need for obstacle avoidance in the mobile-robotic-vehicle-control problem. These more relaxed control problems are thought to be more suited to the flexible approaches of fuzzy-logic control. Of the 16 application chapters, one is a survey chapter, eight demonstrate practical results using computer-simulated models and seven involve results from hardware prototypes, hardware experimental laboratory-scale rigs and some field trials. Consequently the volume has a healthy proportion of chapters with results from practical implementations of fuzzy-logic control.

This volume will be of considerable interest to all those involved in the development and application of the fuzzy-logic controller field. Industrial engineers and academic researchers should find the volume a useful indicator of the maturity of the fuzzy-logic controller paradigm and a valuable resource for exploring the potential of these controllers for industrial applications.

M.J. Grimble and M.A. Johnson
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# Preface

Over the past four decades, the theory of Fuzzy Logic Control (FLC) and its applications have been widely developed and implemented in almost all aspects of our modern society, including education and research, manufacturing, medicine, and commercial applications. Application of the FLC technology leads to a revolution in modern control and intelligent control in our time. To help readers to understand and apply this technology in the real world, newer, updated information about fuzzy logic control and its applications is needed. This book intends to provide readers with advanced materials of the FLC technology applied to today's industrial settings. For this purpose, we invited authors, who are among the leaders in the related application fields, to contribute their experience and expertise to this book.

The book provides both adequate theoretical background and rich practical implementation examples on FLC in industrial applications. Compared with other similar books, up-to-date and advanced practical implementation of fuzzy onlogic controllers on in industrial applications, such as on-line dynamic control FLC, fuzzy interpolation methods, and various new tuning techniques, are presented. Many of these new techniques have been successfully tested in industrial environments, which can be critical for actual implementations, improve greatly performance of controllers, and save developers' time and energy.

The fuzzy inference technology discussed in most of the current books belongs to the category of static fuzzy inference systems, which means that both fuzzy membership functions and control rules are pre-determined prior to the implementation of a fuzzy logic controller for a plant. This approach is also called 'off-line' fuzzy inference system. The major disadvantage of this technique is that each output of a lookup table, derived from membership functions and control rules, is calculated based on a pre-assumed input range, which may not be accurate enough to real inputs as this fuzzy inference system is applied to an actual control system. Another drawback of this approach is that it makes a control parameter tuning process more difficult because of its 'off-line' nature.

To design a fuzzy logic controller that gives superior performance in a real system, the above-mentioned issue needs to be adequately addressed. To this end, a dynamic or 'on-line' fuzzy inference system is introduced and discussed in this

book. In the dynamic fuzzy inference system, membership functions and control rules are not determined until the fuzzy inference system is applied to a physical plant and each output of the lookup table is calculated based on the current inputs to the fuzzy inference system. This possesses the potential of not only greatly improving the control performance of the fuzzy inference system but also facilitating the parameter tuning process.

Another important contribution on the implementation of fuzzy control in the book is that some of new tuning techniques are discussed in a great detail. As everyone knows, the most difficult stage in a fuzzy control application is its tuning phase. How to efficiently tune a fuzzy control system and make it a perfect controller for a real system is a challenging task. Most existing books did not provide much information for such a tuning process. A few of books presented some, but those tuning techniques tend to be out of date and may not improve greatly the control performance of the system involved. New tuning methods, such as the μ-law technique, the histogram equalization algorithm and the Bezier-based method are discussed in detail in this book. With these tuning techniques, a tuning process can be significantly simplified and the control performance of the system can be greatly improved.

Compared with other similar books on the subject, this book provides more up-to-date and advanced fuzzy control application techniques and examples in different fields, such as laser tracking and control, robot calibration, image processing and pattern recognition, medical engineering, autonomous underwater vehicles, audio systems, and data mining. These application examples will benefit practitioners from various industrial sectors.

The book is written to be easily understood by readers who may have no special knowledge in fuzzy logic and intelligent controls. The targeted readers of this book include a wide variety of people, from design engineers, application engineers and project managers working in industrial controls to undergraduate students, graduate students and faculty members in universities and scientific research laboratories.

Totally twenty chapters are included in this book. Chapter 1 provides basic knowledge of control technologies such as linear control , non-linear control and FLC. The fundamentals of FLC are presented in chapter 2. Chapters 3, 4 and 5 discuss the dynamic or 'on-line' fuzzy control systems and knowledge-based tuning procedures. Beginning in Chapter 6, various fuzzy control applications implemented in different industrial fields are provided. These application fields include:

- Laser tracking system
- Image processing and pattern recognition
- Medical engineering
- Guiding of the transportations
- Automobiles control
- Autonomous mobile robots control
- Autonomous underwater vehicles control
- Fight control
- Path tracking and obstacles avoidance of UAVs

- Data mining control
- Power networks control
- Predictive control of a solar power plant
- Robots calibration
- Manufacturing welding systems control

Special thanks should be given to all chapter authors and those who have made valuable contributions to this book. This book could not be published without these indispensable contributions.

March 2006

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