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FUZZY MODELING FOR CONTROL

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to Dana, Michaela, and *Markéta*

Contents

Preface xi
Acknowledgments xiii

1. INTRODUCTION 1
   1.1 Modeling and Identification of Complex Systems 1
   1.2 Different Modeling Paradigms 2
   1.3 Fuzzy Modeling 3
   1.4 Fuzzy Identification 4
   1.5 Control Design Based on Fuzzy Models 6
   1.6 Outline of the Book 6

2. FUZZY MODELING 9
   2.1 Linguistic Fuzzy Models 10
      2.1.1 Linguistic Terms and Variables 11
      2.1.2 Antecedent Propositions 12
      2.1.3 Linguistic Hedges 13
      2.1.4 Inference in the Linguistic Model 14
      2.1.5 Defuzzification 20
      2.1.6 Fuzzy Implication versus Mamdani Inference 21
      2.1.7 Rule Chaining 23
      2.1.8 Singleton Model 24
   2.2 Fuzzy Relational Models 25
   2.3 Takagi–Sugeno Models 29
      2.3.1 Inference in the TS Model 30
      2.3.2 Analysis of the TS Inference 32
      2.3.3 Alternative Interpolation Scheme for the TS Model 36
   2.4 Constructing Fuzzy Models 39
      2.4.1 Knowledge-based Approach 41
      2.4.2 Data-driven Methods 42
   2.5 Summary and Concluding Remarks 46

3. FUZZY CLUSTERING ALGORITHMS 49
   3.1 Cluster Analysis 50
      3.1.1 The Data 50

3.1.2 What Are Clusters? 50
3.1.3 Clustering Methods 51
3.2 Hard and Fuzzy Partitions 52
3.2.1 Hard Partition 52
3.2.2 Fuzzy Partition 54
3.2.3 Possibilistic Partition 55
3.3 Fuzzy c-Means Clustering 55
3.3.1 The Fuzzy c-Means Functional 56
3.3.2 The Fuzzy c-Means Algorithm 56
3.3.3 Inner-product Norms 58
3.4 Clustering with Fuzzy Covariance Matrix 60
3.4.1 Gustafson–Kessel Algorithm 60
3.4.2 Fuzzy Maximum Likelihood Estimates Clustering 63
3.5 Clustering with Linear Prototypes 64
3.5.1 Fuzzy c-Varieties 66
3.5.2 Fuzzy c-Elliptotypes 66
3.5.3 Fuzzy c-Regression Models 68
3.6 Possibilistic Clustering 69
3.7 Determining the Number of Clusters 72
3.8 Data Normalization 72
3.9 Summary and Concluding Remarks 74

4. PRODUCT-SPACE CLUSTERING FOR IDENTIFICATION 75
4.1 Outline of the Approach 75
4.2 Structure Selection 77
4.2.1 The Nonlinear Regression Problem 78
4.2.2 Input–output Black-box Models 79
4.2.3 State-space Framework 82
4.2.4 Semi-mechanistic Modeling 82
4.3 Identification by Product-space Clustering 83
4.4 Choice of Clustering Algorithms 88
4.4.1 Clustering with Adaptive Distance Measure 88
4.4.2 Fuzzy c-lines and c-elliptotypes 91
4.4.3 Fuzzy c-regression Models 93
4.5 Determining the Number of Clusters 94
4.5.1 Cluster Validity Measures 94
4.5.2 Compatible Cluster Merging 98
4.6 Summary and Concluding Remarks 107

5. CONSTRUCTING FUZZY MODELS FROM PARTITIONS 109
5.1 Takagi–Sugeno Fuzzy Models 109
5.1.1 Generating Antecedent Membership Functions 110
5.1.2 Estimating Consequent Parameters 118
5.1.3 Rule Base Simplification 129
5.1.4 Linguistic Approximation 134
5.1.5 Examples 135
5.1.6 Practical Considerations 142

5.2 Linguistic and Relational Models 144
5.2.1 Extraction of Antecedent Membership Functions 145
5.2.2 Estimation of Consequent Parameters 146
5.2.3 Convertion of Singleton Model into Relational Model 148
5.2.4 Estimation of Fuzzy Relations from Data 150
5.3 Low-level Fuzzy Relational Models 153
5.4 Summary and Concluding Remarks 160

6. FUZZY MODELS IN NONLINEAR CONTROL 161
6.1 Control by Inverting Fuzzy Models 162
6.1.1 Singleton Model 162
6.1.2 Inversion of the Singleton Model 164
6.1.3 Compensation of Disturbances and Modeling Errors 171
6.2 Predictive Control 173
6.2.1 Basic Concepts 174
6.2.2 Fuzzy Models in MBPC 176
6.2.3 Predictive Control with Fuzzy Objective Function 183
6.3 Example: Heat Transfer Process 186
6.3.1 Fuzzy Modeling 186
6.3.2 Inverse Model Control 187
6.3.3 Predictive Control 188
6.3.4 Adaptive Predictive Control 191
6.4 Example: pH Control 192
6.5 Summary and Concluding Remarks 193

7. APPLICATIONS 197
7.1 Performance Prediction of a Rock-cutting Trencher 198
7.1.1 The Trencher and Its Performance 198
7.1.2 Knowledge-based Fuzzy Model 198
7.1.3 Applied Methods and Algorithms 203
7.1.4 Model Validation and Results 205
7.1.5 Discussion 206
7.2 Pressure Modeling and Control 208
7.2.1 Process Description 208
7.2.2 Data Collection 209
7.2.3 SISO Fuzzy Model 209
7.2.4 MISO Fuzzy Model 212
7.2.5 Predictive Control Based on the Fuzzy Model 213
7.2.6 Discussion 214
7.3 Fuzzy Modeling of Enzymatic Penicillin–G Conversion 216
7.3.1 Introduction 216
7.3.2 Process Description 218
7.3.3 Experimental Set-up 220
7.3.4 Fuzzy Modeling 220
7.3.5 Semi-mechanistic Model 224
7.3.6 Discussion 224
7.4 Summary and Concluding Remarks 225

Appendices 226
A– Basic Concepts of Fuzzy Set Theory 227
A.1 Fuzzy Sets 227
A.2 Membership Functions 227
A.3 Basic Definitions 228
A.4 Operations on Fuzzy Sets 229
A.5 Fuzzy Relations 230
A.6 Projections and Cylindrical Extensions 230
B– Fuzzy Modeling and Identification Toolbox for MATLAB 233
B.1 Toolbox Structure 233
B.2 Identification of MIMO Dynamic Systems 233
B.3 Matlab implementation 234
C– Symbols and Abbreviations 239
References 243
Author Index 253
Subject Index 257

Preface

Since its introduction in 1965, fuzzy set theory has found applications in a wide variety of disciplines. Modeling and control of dynamic systems belong to the fields in which fuzzy set techniques have received considerable attention, not only from the scientific community but also from industry. Many systems are not amenable to conventional modeling approaches due to the lack of precise, formal knowledge about the system, due to strongly nonlinear behavior, due to the high degree of uncertainty, or due to the time varying characteristics. Fuzzy modeling along with other related techniques such as neural networks have been recognized as powerful tools which can facilitate the effective development of models. One of the reasons for this is the capability of fuzzy systems to integrate information from different sources, such as physical laws, empirical models, or measurements and heuristics.

Fuzzy models can be seen as logical models which use "if–then" rules to establish qualitative relationships among the variables in the model. Fuzzy sets serve as a smooth interface between the qualitative variables involved in the rules and the numerical data at the inputs and outputs of the model. The rule-based nature of fuzzy models allows the use of information expressed in the form of natural language statements and consequently makes the models transparent to interpretation and analysis. At the computational level, fuzzy models can be regarded as flexible mathematical structures, similar to neural networks, that can approximate a large class of complex nonlinear systems to a desired degree of accuracy.

Recently, a great deal of research activity has focused on the development of methods to build or update fuzzy models from numerical data. Most approaches are based on neuro-fuzzy systems, which exploit the functional similarity between fuzzy reasoning systems and neural networks. This "marriage" of fuzzy systems and neural networks enables a more effective use of optimization techniques for building fuzzy systems, especially with regard to their approximation accuracy. However, the aspects related to the transparency and interpretation tend to receive considerably less attention. Consequently, most neuro-fuzzy models can be regarded as black-box models which provide little insight to help understand the underlying process.

The approach adopted in this book aims at the development of transparent rule-based fuzzy models which can accurately predict the quantities of interest, and at the

same time provide insight into the system that generated the data. Attention is paid to the selection of appropriate model structures in terms of the dynamic properties, as well as the internal structure of the fuzzy rules (linguistic, relational, or Takagi–Sugeno type). From the system identification point of view, a fuzzy model is regarded as a composition of local submodels. Fuzzy sets naturally provide smooth transitions between the submodels, and enable the integration of various types of knowledge within a common framework.

In order to automatically generate fuzzy models from measurements, a comprehensive methodology is developed. It employs fuzzy clustering techniques to partition the available data into subsets characterized by a linear behavior. The relationships between the presented identification method and linear regression are exploited, allowing for the combination of fuzzy logic techniques with standard system identification tools. Attention is paid to the aspects of accuracy and transparency of the obtained fuzzy models.

Using the concepts of model-based predictive control and internal model control with an inverted fuzzy model, the control design based on a fuzzy model of a nonlinear dynamic process is addressed. To this end, methods which exactly invert specific types of fuzzy models are presented. In the context of predictive control, branch-and-bound optimization is applied. Attention is paid to algorithmic solutions of the control problem, mainly with regard to real-time control aspects.

The orientation of the book is towards methodologies that in the author's experience proved to be practically useful. The presentation reflects theoretical and practical issues in a balanced way, aiming at readership from the academic world and also from industrial practice. Simulation examples are given throughout the text and three selected real-world applications are presented in detail. In addition, an implementation in a MATLAB toolbox of the techniques presented is described. This toolbox can be obtained from the author.

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