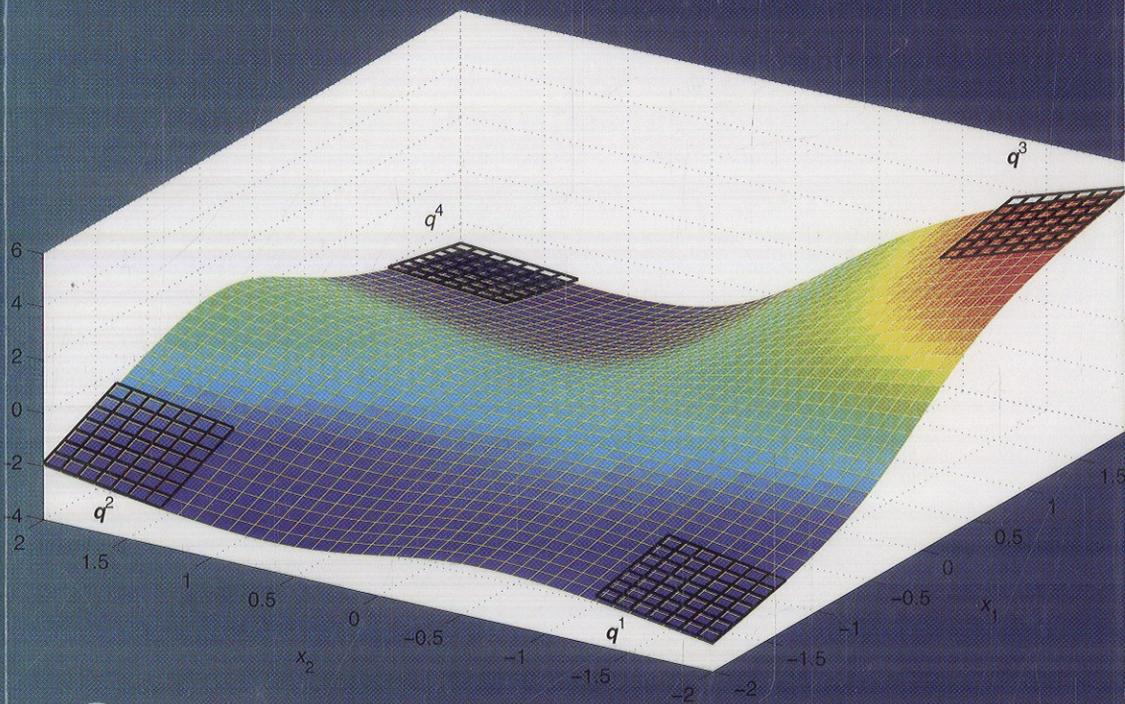


Fuzzy Control and Identification

John H. Lilly



 WILEY

TABLE OF CONTENTS

PREFACE

xi

CHAPTER 1 INTRODUCTION

1

- 1.1 Fuzzy Systems 1
- 1.2 Expert Knowledge 3
- 1.3 When and When Not to Use Fuzzy Control 3
- 1.4 Control 4
- 1.5 Interconnection of Several Subsystems 6
- 1.6 Identification and Adaptive Control 8
- 1.7 Summary 9
- Exercises 10

CHAPTER 2 BASIC CONCEPTS OF FUZZY SETS

11

- 2.1 Fuzzy Sets 11
- 2.2 Useful Concepts for Fuzzy Sets 15
- 2.3 Some Set Theoretic and Logical Operations on Fuzzy Sets 16
- 2.4 Example 18
- 2.5 Singleton Fuzzy Sets 22
- 2.6 Summary 23
- Exercises 24

CHAPTER 3 MAMDANI FUZZY SYSTEMS

27

- 3.1 If-Then Rules and Rule Base 27
- 3.2 Fuzzy Systems 29
- 3.3 Fuzzification 29
- 3.4 Inference 30
- 3.5 Defuzzification 30
 - 3.5.1 Center of Gravity (COG) Defuzzification 31
 - 3.5.2 Center Average (CA) Defuzzification 31
- 3.6 Example: Fuzzy System for Wind Chill 31
 - 3.6.1 Wind Chill Calculation, *Minimum* T-Norm, COG Defuzzification 35
 - 3.6.2 Wind Chill Calculation, *Minimum* T-Norm, CA Defuzzification 38
 - 3.6.3 Wind Chill Calculation, *Product* T-Norm, COG Defuzzification 38
 - 3.6.4 Wind Chill Calculation, *Product* T-Norm, CA Defuzzification 41
 - 3.6.5 Wind Chill Calculation, Singleton Output Fuzzy Sets, *Product* T-Norm, CA Defuzzification 41
- 3.7 Summary 42
- Exercises 43

CHAPTER 4 FUZZY CONTROL WITH MAMDANI SYSTEMS 46

-
- 4.1 Tracking Control with a Mamdani Fuzzy Cascade Compensator 46
 - 4.1.1 Initial Fuzzy Compensator Design: Ball and Beam Plant 47
 - 4.1.2 Rule Base Determination: Ball and Beam Plant 50
 - 4.1.3 Inference: Ball and Beam Plant 52
 - 4.1.4 Defuzzification: Ball and Beam Plant 53
 - 4.2 Tuning for Improved Performance by Adjusting Scaling Gains 53
 - 4.3 Effect of Input Membership Function Shapes 56
 - 4.4 Conversion of PID Controllers into Fuzzy Controllers 59
 - 4.4.1 Redesign for Increased Robustness 64
 - 4.5 Incremental Fuzzy Control 66
 - 4.6 Summary 69
 - Exercises 69

CHAPTER 5 MODELING AND CONTROL METHODS USEFUL FOR FUZZY CONTROL 71

-
- 5.1 Continuous-Time Model Forms 71
 - 5.1.1 Nonlinear Time-Invariant Continuous-Time State-Space Models 71
 - 5.1.2 Linear Time-Invariant Continuous-Time State-Space Models 74
 - 5.2 Model Forms for Discrete-Time Systems 75
 - 5.2.1 Input-Output Difference Equation Model for Linear Discrete-Time Systems 76
 - 5.2.2 Linear Time-Invariant Discrete-Time State-Space Models 76
 - 5.3 Some Conventional Control Methods Useful in Fuzzy Control 78
 - 5.3.1 Pole Placement Control 79
 - 5.3.2 Tracking Control 81
 - 5.3.3 Model Reference Control 82
 - 5.3.4 Feedback Linearization 84
 - 5.4 Summary 85
 - Exercises 86

CHAPTER 6 TAKAGI-SUGENO FUZZY SYSTEMS 88

-
- 6.1 Takagi-Sugeno Fuzzy Systems as Interpolators between Memoryless Functions 88
 - 6.2 Takagi-Sugeno Fuzzy Systems as Interpolators between Continuous-Time Linear State-Space Dynamic Systems 92
 - 6.3 Takagi-Sugeno Fuzzy Systems as Interpolators between Discrete-Time Linear State-Space Dynamic Systems 95
 - 6.4 Takagi-Sugeno Fuzzy Systems as Interpolators between Discrete-Time Dynamic Systems described by Input-Output Difference Equations 98
 - 6.5 Summary 101
 - Exercises 101

CHAPTER 7 PARALLEL DISTRIBUTED CONTROL WITH TAKAGI-SUGENO FUZZY SYSTEMS 106

-
- 7.1 Continuous-Time Systems 106
 - 7.2 Discrete-Time Systems 109
 - 7.3 Parallel Distributed Tracking Control 112
 - 7.4 Parallel Distributed Model Reference Control 116
 - 7.5 Summary 118
 - Exercises 119

CHAPTER 8	<i>ESTIMATION OF STATIC NONLINEAR FUNCTIONS FROM DATA</i>	121
8.1	Least-Squares Estimation	121
8.1.1	Batch Least Squares	122
8.1.2	Recursive Least Squares	123
8.2	Batch Least-Squares Fuzzy Estimation in Mamdani Form	124
8.3	Recursive Least-Squares Fuzzy Estimation in Mamdani Form	132
8.4	Least-Squares Fuzzy Estimation in Takagi–Sugeno Form	135
8.5	Gradient Fuzzy Estimation in Mamdani Form	136
8.6	Gradient Fuzzy Estimation in Takagi–Sugeno Form	145
8.7	Summary	146
	Exercises	147
CHAPTER 9	<i>MODELING OF DYNAMIC PLANTS AS FUZZY SYSTEMS</i>	149
9.1	Modeling Known Plants as Takagi–Sugeno Fuzzy Systems	149
9.2	Identification in Input–Output Difference Equation Form	154
9.2.1	Batch Least-Squares Identification in Difference Equation Form	154
9.2.2	Recursive Least-Squares Identification in Input–Output Difference Equation Form	159
9.2.3	Gradient Identification in Input–Output Difference Equation Form	160
9.3	Identification in Companion Form	163
9.3.1	Least-Squares Identification in Companion Form	163
9.3.2	Gradient Identification in Companion Form	165
9.4	Summary	167
	Exercises	168
CHAPTER 10	<i>ADAPTIVE FUZZY CONTROL</i>	169
10.1	Direct Adaptive Fuzzy Tracking Control	170
10.2	Direct Adaptive Fuzzy Model Reference Control	173
10.3	Indirect Adaptive Fuzzy Tracking Control	175
10.4	Indirect Adaptive Fuzzy Model Reference Control	179
10.5	Adaptive Feedback Linearization Control	184
10.6	Summary	187
	Exercises	188
REFERENCES		190
APPENDIX	<i>COMPUTER PROGRAMS</i>	192
INDEX		229