Table of Contents

Preface v

Part I Introduction

1. Hidden Markov Model Processing 3
1.1 Models, Objectives, and Methods 3
1.2 Book Outline 4

Part II Discrete-Time HMM Estimation

2. Discrete States and Discrete Observations 15
2.1 Introduction 15
2.2 Model 17
2.3 Change of Measure 20
2.4 Unnormalized Estimates and Bayes' Formula 27
2.5 A General Unnormalized Recursive Filter 29
2.6 States, Transitions, and Occupation Times 32
2.7 Parameter Reestimation 35
2.8 Recursive Parameter Estimation 40
2.9 Quantized Observations 42
2.10 The Dependent Case 45
2.11 Problems and Notes 55

3. Continuous-Range Observations 57
3.1 Introduction 57
3.2 State and Observation Processes 58
3.3 Conditional Expectations 58
3.4 Change of Measure 60
3.5 Recursive Estimation 62
3.6 States, Transitions, and Occupation Times 65
3.7 EM-Parameter Reestimation 68
3.8 Vector Observations 70
3.9 Zero Delay Observation Model 72
3.10 Recursive Parameter Estimation 73
3.11 HMMs with Colored Noise 76
3.12 Mixed-State HMM Estimation 79
3.13 Problems and Notes 80

4. Continuous-Range States and Observations 83
4.1 Introduction 83
4.2 Linear Dynamics and Parameters 83
4.3 The ARMAX Model 87
4.4 Nonlinear Dynamics 91
4.5 Kalman Filter 99
4.6 Problems and Notes 101

5. A General Recursive Filter 103
5.1 Introduction 103
5.2 Signal and Observations 103
5.3 Change of Measure 105
5.4 Recursive Estimates 106
5.5 Extended Kalman Filter 109
5.6 Parameter Identification and Tracking 110
5.7 Formulation in Terms of Transition Densities 114
5.8 Dependent Case 116
5.9 Recursive Prediction Error Estimation 121
5.10 Problems and Notes 123

6. Practical Recursive Filters 125
6.1 Introduction 125
6.2 Recursive Prediction Error HMM Algorithm 128
6.3 Example: Quadrature Amplitude Modulation 135
6.4 Example: Frequency Modulation 143
6.5 Coupled-Conditional Filters 152
6.6 Notes 160

Part III Continuous-Time HMM Estimation

7. Discrete-Range States and Observations 163
7.1 Introduction 163
7.2 Dynamics 163
7.3 A General Finite-Dimensional Filter 169
7.4 Parameter Estimation 176
7.5 Problems and Notes 178

8. Markov Chains in Brownian Motion 181
8.1 Introduction 181
8.2 The Model 182
8.3 A General Finite-Dimensional Filter 183
8.4 States, Transitions, and Occupation Times 185
8.5 Parameter Estimation 187
8.6 Finite-Dimensional Predictors 189
8.7 A Non-Markov Finite-Dimensional Filter 194
8.8 Problems and Notes 202

Part IV Two-Dimensional HMM Estimation

9. Hidden Markov Random Fields 207
9.1 Discrete Signal and Observations 207
9.2 HMRF Observed in Gaussian Noise 226
9.3 Continuous-State HMRF 232
9.4 Example: A Mixed HMRF 237
9.5 Problems and Notes 242

Part V HMM Optimal Control

10. Discrete-Time HMM Control 247
10.1 Control of Finite-State Processes 247
10.2 More General Processes 254
10.3 A Dependent Case 259
10.4 Problems and Notes 264

11. Risk-Sensitive Control of HMM 265
11.1 Introduction 265
11.2 The Risk-Sensitive Control Problem 266

11.3 Connection with H^∞ Control 272
11.4 Connection with H_2 or Risk-Neutral Control 274
11.5 A Finite-Dimensional Example 278
11.6 Risk-Sensitive LQG Control 285
11.7 Problems and Notes 288

12. Continuous-Time HMM Control 291
12.1 Introduction 291
12.2 Counting Observation Process Control 292
12.3 The Dependent Case 300
12.4 HMM Control in Gaussian Noise 312
12.5 Hybrid Conditionally Linear Process 318
12.6 Problems and Notes 327

Appendix A. Basic Probability Concepts 329
Appendix B. Continuous-Time Martingale Representation 337

Bibliography 343

Author Index 355

Subject Index 357