Chapter 1 Introduction

1.1 Why Stochastic Models, Estimation, and Control? 1
1.2 Overview of the Text 3
1.3 The Kalman Filter: An Introduction to Concepts 3
1.4 Basic Assumptions 7
1.5 A Simple Example 9
1.6 A Preview 15
General References 15
Appendix and Problems 16
References 23

Chapter 2 Deterministic system models

2.1 Introduction 25
2.2 Continuous-Time Dynamic Models 25
2.3 Solutions to State Differential Equations 37
2.4 Discrete-Time Measurements 42
2.5 Controllability and Observability 43
2.6 Summary 48
References 48
Problems 49

Chapter 3 Probability theory and static models

3.1 Introduction 59
3.2 Probability and Random Variables 60
3.3 Probability Distributions and Densities 70
3.4 Conditional Probability and Densities 76
### Chapter 6 Design and performance analysis of Kalman filters

6.1 Introduction 289  
6.2 The Requisite of Engineering Judgment 289  
6.3 Application of Kalman Filtering to Inertial Navigation Systems 291  
6.4 INS Aided by Position Data: A Simple Example 297  
6.5 Doppler-Aided INS 305  
6.6 INS Calibration and Alignment Using Direct Kalman Filter 317  
6.7 Generating Alternative Designs 322  
6.8 Performance (Sensitivity) Analysis 325  
6.9 Systematic Design Procedure 341  
6.10 INS Aided by Navigation Satellites 342  
6.11 Practical Aspects of Implementation 351  
6.12 Summary 358  
   References 359  
   Problems 362

### Chapter 7 Square root filtering

7.1 Introduction 368  
7.2 Matrix Square Roots 370  
7.3 Covariance Square Root Filter for Qa 0 373  
7.4 Vector-Valued Measurements 374  
7.5 Covariance Square Root Filter for Q~ IE 0 377  
7.6 Inverse Covariance Square Raw Filter 388  
7.7 U-D Covariance Factorization Filter 392  
7.8 Filter Performance and Requirements 399  
7.9 Summary 405  
   References 405  
   Problems 406

Index 411

### Volume 2

### Chapter 8 Optimal smoothing

8.1 Introduction 1  
8.2 Basic Structure 2  
8.3 Three Classes of Smoothing Problems 3  
8.4 Fixed-Interval Smoothing 5  
8.5 Fixed-Point Smoothing 15  
8.6 Faced-Lag Smoothing 16  
8.7 Summary 17  
   References 18  
   Problems 19
Chapter 9 Compensation of linear model inadequacies

9.1 Introduction 23
9.2 Pseudonoise Addition and Artificial Lower Bounding of P 24
9.3 Limiting Effective Filter Memory and Overweighting Most Recent Data 28
9.4 Finite Memory Filtering 33
9.5 Linearized and Extended Kalman Filters 39
9.6 Summary 59
References 59
Problems 62

Chapter 10 Parameter uncertainties and adaptive estimation

10.1 Introduction 68
10.2 Problem Formulation 70
10.3 Uncertainties in $\Phi$ and $B_d$: Likelihood Equations 74
10.4 Uncertainties in $\Phi$ and $B_d$: Full-Scale Estimator 80
10.5 Uncertainties in $\Phi$ and $B_d$: Performance Analysis 96
10.6 Uncertainties in $\Phi$ and $B_d$: Attaining Online Applicability 101
10.7 Uncertainties in $Q_a$ and $R$ 120
10.9 Bayesian and Multiple Model Filtering Algorithms 129
10.9 Correlation Methods for Self-Tuning: Residual “Whitening” 136
10.10 Covariance Matching and Other Techniques 141
10.11 Summary 143
References 144
Problems 151

Chapter 11 Nonlinear stochastic system models

11.1 Introduction 159
11.2 Extensions of Linear System Modeling 160
11.3 Markov Process Fundamentals 167
11.4 Itô Stochastic Integrals and Differentials 175
11.5 Itô Stochastic Differential Equations 181
11.6 Forward Kolmogorov Equation 192
11.7 Summary, 202
References 202
Problems 205

Chapter 12 Nonlinear estimation

12.1 Introduction 212
12.2 Nonlinear Filtering with Discrete-Time Measurements Conceptually 213
12.3 Conditional Moment Estimator, 215
12.4 Conditional Quasi-Moments and Hermite Polynomial Series 239
12.5 Conditional Mode Estimator 241
12.6 Statistically Linearized Filter 243
Volume 3

Chapter 13 Dynamic programming and stochastic control

13.1 Introduction 1
13.2 Basic Problem Formulation
13.3 Introduction to Concepts. Overview of Simple LQG Problem 9
13.4 The Backward Kolmogrov Equation 20
13.5 Optimal Stochastic Control with Perfect Knowledge of the State 24
13.6 Optimal Stochastic Control with Noise-Corrupted Measurements 45
13.7 Summary 58
Reference 60
Problems 62

Chapter 14 Linear stochastic controller design and performance analysis

14.1 Introduction 68
14.2 The LQG Stochastic Regulator 69
14.3 Stability 82
14.4 Stability of LQG Regulators 91
14.5 Stability Robustness of LQG Regulators 102
14.6 The LQG Synthesis of Trackers 114
14.7 Nonzero Setpoint Controllers 122
14.8 Rejection of Time Correlated Disturbances 126
14.9 the LQG Synthesis of PI Controllers 132
14.10 Command Generator Tracking 151
14.11 Performance Evaluation of Linear Sampled Data Controllers 166
14.12 Systematic Design Procedure 175
14.13 The LQG Controller for Continuous Time Measurements 184
14.14 Summary 190
References 193
Problems 202

Chapter 15 Nonlinear stochastic controllers

15.1 Introduction 223
15.2 Basic Problem Formulation and Controller Characteristics 223
15.3 Linear Perturbation Control Laws for Nonlinear System, Direct Application of LQG Synthesis 230
15.4 Assumed Certainty Equivalence Design 241
15.5 Closed Loop Law Approximations and Dual Effect 245
15.6 Stochastic Adaptive Control 247
15.7 Design Philosophy 256
15.8 Summary and Perspective 257
References 260
Problems 266

INDEX 271