

CONTENTS

Foreword v

Chapter 1 Introduction 1

Chapter 2 Review of Underlying Mathematical Techniques 10

2.1 Vectors, Matrices, and Least Squares 10

2.2 Probability and Random Processes 24

Chapter 3 Linear Dynamic Systems 51

3.1 State-Space Notation 51

3.2 Transition Matrix 57

3.3 Matrix Superposition Integral 63

3.4 Discrete Formulation 66

3.5 System Observability and Controllability 67

3.6 Covariance Matrix 72

3.7 Propagation of Errors 75

3.8 Modeling and State Vector Augmentation 78

3.9 Empirical Model Identification 84

Chapter 4 Optimal Linear Filtering 102

4.1 Recursive Filters 105

4.2 Discrete Kalman Filter 107

- 4.3 Continuous Kalman Filter 119
- 4.4 Intuitive Concepts 127
- 4.5 Correlated Measurement Errors 133
- 4.6 Solution of the Riccati Equation 136
- 4.7 Statistical Steady State – The Wiener Filter 142

Chapter 5 Optimal Linear Smoothing 156

- 5.1 Form of the Optimal Smoother 157
- 5.2 Optimal Fixed-Interval Smoother 160
- 5.3 Optimal Fixed-Point Smoother 170
- 5.4 Optimal Fixed-Lag Smoother 173

Chapter 6 Nonlinear Estimation 180

- 6.1 Nonlinear Minimum Variance Estimation 182
- 6.2 Nonlinear Estimation by Statistical Linearization 203
- 6.3 Nonlinear Least-Squares Estimation 214
- 6.4 Direct Statistical Analysis of Nonlinear Systems – CADET™ 216

Chapter 7 Suboptimal Filter Design and Sensitivity Analysis 229

- 7.1 Suboptimal Filter Design 230
- 7.2 Sensitivity Analysis: Kalman Filter 246
- 7.3 Sensitivity Analysis Examples 255
- 7.4 Developing an Error Budget 260
- 7.5 Sensitivity Analysis: Optimal Smoother 266
- 7.6 Organization of a Computer Program for Covariance Analysis 268

Chapter 8 Implementation Considerations 277

- 8.1 Modeling Problems 278
- 8.2 Constraints Imposed by the Computer 288
- 8.3 The Inherently Finite Nature of the Computer 292
- 8.4 Algorithms and Computer Loading Analysis 303

Chapter 9 Additional Topics 316

- 9.1 Adaptive Kalman Filtering 317
- 9.2 Observers 320
- 9.3 Stochastic Approximation 335
- 9.4 Real-Time Parameter Identification 348
- 9.5 Optimal Control of Linear Systems 356

Index 371