

Contents

Notation	xiii
1. Preliminaries	1
1.1 Matrix and Determinant Preliminaries	1
1.2 Probability Preliminaries	8
1.3 Least-Squares Preliminaries	15
Exercises	18
2. Kalman Filter: An Elementary Approach	20
2.1 The Model	20
2.2 Optimality Criterion	21
2.3 Prediction-Correction Formulation	23
2.4 Kalman Filtering Process	28
Exercises	29
3. Orthogonal Projection and Kalman Filter	33
3.1 Orthogonality Characterization of Optimal Estimates	33
3.2 Innovations Sequences	35
3.3 Minimum Variance Estimates	37
3.4 Kalman Filtering Equations	38
3.5 Real-Time Tracking	43
Exercises	45
4. Correlated System and Measurement Noise Processes	50
4.1 The Affine Model	50
4.2 Optimal Estimate Operators	52

4.3 Effect on Optimal Estimation with Additional Data	53
4.4 Derivation of Kalman Filtering Equations	56
4.5 Real-Time Applications	62
4.6 Linear Deterministic/Stochastic Systems	64
Exercises	66
 5. Colored Noise	 68
5.1 Outline of Procedure	68
5.2 Error Estimates	69
5.3 Kalman Filtering Process	71
5.4 White System Noise	74
5.5 Real-Time Applications	75
Exercises	76
 6. Limiting Kalman Filter	 78
6.1 Outline of Procedure	80
6.2 Preliminary Results	81
6.3 Geometric Convergence	90
6.4 Real-Time Applications	95
Exercises	97
 7. Sequential and Square-Root Algorithms	 99
7.1 Sequential Algorithm	99
7.2 Square-Root Algorithm	105
7.3 An Algorithm for Real-Time Applications	107
Exercises	109
 8. Extended Kalman Filter and System Identification	111
8.1 Extended Kalman Filter	111
8.2 Satellite Orbit Estimation	115
8.3 Adaptive System Identification	117
8.4 An Example of Parameter Identification	119
Exercises	122

9. Decoupling of Filtering Equations	125
9.1 Decoupling Formulas	125
9.2 Real-Time Tracking	128
9.3 The $\alpha - \beta - \gamma$ Tracker	130
9.4 An Example	133
Exercises	134
 10. Notes	 137
10.1 The Kalman Smoother	137
10.2 The $\alpha - \beta - \gamma - \theta$ Tracker	139
10.3 Adaptive Kalman Filtering	142
10.4 Adaptive Kalman Filtering Approach to Wiener Filtering	143
10.5 The Kalman-Bucy Filter	145
10.6 Stochastic Optimal Control	146
10.7 Square-Root Filtering and Systolic Array Implementation	147
10.8 Real-Time System Identification	150
 References	 153
 Answers and Hints to Exercises	 159
 Subject Index	 189