

Contents

1. Introduction

- 1.1 System models 1.1
- 1.2 Evolution of mathematical models 1.2
 - 1.2.1 Interpretative models 1.3
 - 1.2.2 Predictive models 1.4
 - 1.2.3 Models for filtering and state estimation 1.5
 - 1.2.4 Models for diagnosis 1.6
 - 1.2.5 Models for simulation 1.7
- 1.3 Models as approximations of reality 1.8
- 1.4 Model construction 1.9
 - 1.4.1 Deducing models from other models: physical modeling 1.9
 - 1.4.2 Deducing models from data: identification 1.9
- 1.5 Identification steps 1.10
- 1.6 Identifiability 1.11
- 1.7 Classes of models for identification 1.11
 - 1.7.1 Oriented and non oriented models 1.11
 - 1.7.2 Algebraic and dynamical models 1.12
 - 1.7.3 Causal and non causal models 1.12
 - 1.7.4 Purely dynamic and non purely dynamic models 1.12
 - 1.7.5 Lumped and distributed models 1.12
 - 1.7.6 Constant and time-varying models 1.13
 - 1.7.7 Linear and nonlinear models 1.13
 - 1.7.8 Deterministic and stochastic models 1.13

- 1.7.9 SISO, MISO and MIMO models 1.13
- 1.7.10 Parametric and non parametric models 1.13
- 1.7.11 Continuous and discrete models 1.14
- 1.7.12 Free and non free models 1.14
- 1.8 Structure of this book 1.14

2. Equation error identification

- 2.1 Equation error models 2.1
- 2.2 The identification problem 2.4
- 2.3 Multivariable equation error models 2.4
- 2.4 The multivariable identification problem 2.7
- 2.5 Questions 2.8

3. ARX identification

- 3.1 ARX models 3.1
- 3.2 ARX predictors 3.3
- 3.3 Least squares estimates of ARX models 3.3
 - 3.3.1 Algorithmic aspects 3.4
- 3.4 Identifiability and input selection 3.5
- 3.5 Bias and consistency of least squares estimates 3.6
- 3.6 Recursive least squares 3.8
- 3.7 Weighted least squares 3.11
- 3.8 Covariance of least squares estimates 3.12
- 3.9 Distribution of estimation errors 3.13
- 3.10 Statistical properties of residuals 3.13
- 3.11 Cramér–Rao lower bound 3.14
- 3.12 Efficiency of least squares estimates 3.14
- 3.13 Kalman filtering in recursive estimation 3.15
- 3.14 Order estimation and model validation 3.17
 - 3.14.1 PPCRE and singularity of the moments matrix 3.17
 - 3.14.2 FPE (Final Prediction Error) criterion 3.20
 - 3.14.3 AIC (Akaike Information Criterion) 3.20
 - 3.14.4 MDL (Minimum Description Length) criterion 3.20
 - 3.14.5 Whiteness test on residuals 3.21
 - 3.14.6 Test on the independence between residuals and previous inputs 3.21
 - 3.14.7 Cross validation by simulation 3.22
- 3.15 Example 3.1 3.22
 - 3.15.2 Parameter estimate 3.24
 - 3.15.3 Model validation 3.27
- 3.16 Example 3.2 3.28
 - 3.16.1 Determination of the model order 3.29
 - 3.16.2 Parameter estimate 3.31

- 3.16.3 On–line least squares identification 3.32
- 3.16.4 On–line identification by Kalman filtering 3.34
- 3.17 Identification of FIR models 3.36
- 3.18 Blind system identification 3.37
 - 3.18.1 Blind identification of two parallel FIR channels 3.37
 - 3.18.2 Input deconvolution 3.39
- 3.19 Example 3.3 3.40
- 3.20 Multivariable ARX models and predictors 3.42
- 3.21 Parametric identification of multivariable ARX models 3.45
- 3.22 Consistency of multivariable LS estimates 3.47
- 3.23 Structural identification of multivariable ARX models 3.49
- 3.24 Example 3.4 – Identification of a power plant 3.49
- 3.25 State space ARX models 3.56
 - 3.25.1 Multivariable ARX state space models 3.56
 - 3.25.2 Example 3.5 3.57
 - 3.25.3 MISO ARX state space models 3.58
- 3.26 Sensitivity analysis of identified models 3.59
 - 3.26.1 Example 3.6 3.59
- 3.27 Questions 3.61

4. AR identification

- 4.1 AR models 4.1
- 4.2 AR predictors 4.2
- 4.3 Parameter estimation 4.2
- 4.4 Estimation of increasing–order models 4.3
- 4.5 Yule–Walker equations 4.4
- 4.6 Levinson algorithm 4.6
- 4.7 Model order estimation 4.7
- 4.8 Example 4.1 4.7
 - 4.8.1 Determination of the model order 4.8
 - 4.8.2 Parameter estimate 4.8
 - 4.8.3 Model validation 4.11
- 4.9 Multivariable AR models and predictors 4.11
- 4.10 Parametric and structural identification of multivariable AR models 4.12
- 4.11 Yule–Walker equations for multivariable AR models 4.12
- 4.12 Questions 4.14

5. MA identification

- 5.1 MA models 5.1
- 5.2 Identification of MA models using auxiliary AR models 5.2
- 5.3 Example 5.1 5.3
- 5.4 Inverse Yule–Walker equations 5.5

- 5.5 Example 5.2 5.6
- 5.6 MA predictors 5.7
- 5.7 Example 5.3 5.7
- 5.8 Multivariable MA models 5.8
- 5.9 Questions 5.10

6. ARMAX identification

- 6.1 ARMAX models 6.1
- 6.2 ARMAX predictors 6.3
- 6.3 Instrumental variable methods 6.3
- 6.4 Estimation of ARMAX models 6.5
- 6.5 Example 6.1 6.5
- 6.6 Model order estimation 6.8
- 6.7 Asymptotic properties of IV estimates 6.9
- 6.8 Example 6.2 6.9
- 6.9 Extended IV methods 6.9
- 6.10 Recursive IV algorithms 6.11
- 6.11 Example 6.3 6.12
- 6.12 Maximum likelihood estimates 6.13
- 6.13 PEM estimation of ARMAX models 6.15
- 6.14 Example 6.4 6.17
- 6.15 Covariance and asymptotic properties of PEM estimates 6.19
- 6.16 Example 6.5 6.20
- 6.17 Multivariable ARMAX models 6.20
- 6.18 Example 6.6 6.22
- 6.19 Multivariable ARMAX predictors 6.23
- 6.20 Parametric identification of multivariable ARMAX models 6.24
- 6.21 PEM identification of multivariable ARMAX models 6.25
- 6.22 Example 6.7 6.29
- 6.23 Questions 6.32

7. ARMA identification

- 7.1 ARMA models 7.1
- 7.2 ARMA predictors 7.2
- 7.3 Estimation of ARMA models 7.2
- 7.4 Example 7.1 7.3
- 7.5 Optimal k-step-ahead ARMA predictor 7.7
- 7.6 Example 7.2 7.8
- 7.7 Questions 7.11

8. ARIMA(X) identification

- 8.1 ARIMA(X) models 8.1
- 8.2 Example 8.1 8.2
- 8.3 Questions 8.6

9. ARAR(X) identification

- 9.1 ARAR(X) models 9.1
- 9.2 Optimal ARARX predictors 9.2
- 9.3 Estimation of ARARX models 9.3
- 9.4 Model order estimation 9.4
- 9.5 PEM estimation of ARARX models 9.4
- 9.6 Example 9.1 9.5
- 9.7 ARAR models 9.8
- 9.8 Questions 9.9

10. ARARMA(X) identification

- 10.1 ARARMA(X) models 10.1
- 10.2 Optimal ARARMAX predictors 10.2
- 10.3 Estimation of ARARMAX models 10.3
- 10.4 PEM estimation of ARARMAX models 10.3
- 10.5 Questions 10.5

11. Identification bibliography

- 11.1 Identification literature 11.1
- 11.2 Bibliography 11.8

LA. Linear algebra

- LA.1 Equivalence and invariants LA.1
- LA.2 Properties of linear transformations LA.3
- LA.3 Eigenvalues and eigenvectors, S.V.D. LA.5
- LA.4 Norms of vectors and matrices LA.7
- LA.5 Properties of partitioned matrices LA.11
- LA.6 Matrix functions LA.12
- LA.7 Polynomial matrices LA.15

ST. System theory

- ST.1 Polynomial input–output models ST.1
- ST.2 Equivalence relations for MFD models ST.2
- ST.3 State space canonical forms ST.4
- ST.4 Links between state space and input–output models ST.8

- ST.5 Realization of MISO input–output sequences ST.13
- ST.6 Realization of MIMO input–output sequences ST.15

SP. Stochastic processes

- SP.1 Random variables SP.1
- SP.2 Stochastic processes SP.5
- SP.3 Convergence, consistency and hypothesis testing SP.6