
Contents

List of Abbreviations and Symbols	xviii
--	-------

List of Contributors	xxiii
-----------------------------------	-------

1 Direct Identification of Continuous-time Models from Sampled Data: Issues, Basic Solutions and Relevance

<i>Hugues Garnier, Liuping Wang and Peter C. Young</i>	1
1.1 Introduction	1
1.2 System Identification Problem and Procedure	2
1.3 Basic Discrete-time Model Identification.....	5
1.3.1 Difference Equation Models.....	5
1.3.2 The Traditional Least Squares Method	5
1.3.3 Example: First-order Difference Equation.....	6
1.3.4 Models for the Measurement Noise	7
1.4 Issues in Direct Continuous-time Model Identification	7
1.4.1 Differential Equation Models.....	7
1.4.2 Input–Output Time Derivatives	8
1.4.3 Models for the Measurement Noise	8
1.5 Basic Direct Continuous-time Model Identification	9
1.5.1 The Traditional State-variable Filter Method	9
1.5.2 Example: First-order Differential Equation	11
1.6 Motivations for Identifying Continuous-time Models Directly from Sampled Data	11
1.6.1 Physical Insight into the System Properties	12
1.6.2 Preservation of <i>a priori</i> Knowledge	12
1.6.3 Inherent Data Filtering	13
1.6.4 Non-uniformly Sampled Data	13
1.6.5 Transformation between CT and DT Models.....	13
1.6.6 Sensitivity Problems of DT Models at High Sampling Rates	14
1.6.7 Stiff Systems	14

1.7	Specialised Topics in System Identification	15
1.7.1	Identification of the Model Structure	15
1.7.2	Identification of Pure Time (Transportation) Delay	15
1.7.3	Identification of Continuous-time Noise Models	15
1.7.4	Identification of Multi-variable Systems	16
1.7.5	Identification in Closed Loop	16
1.7.6	Identification in the Frequency Domain	16
1.7.7	Software for Continuous-time Model Identification	16
1.8	Historical Review	16
1.9	Outline of the Book	20
1.10	Main References	25
	References	26

2 Estimation of Continuous-time Stochastic System Parameters

	<i>Erik K. Larsson, Magnus Mossberg, Torsten Söderström</i>	31
2.1	Background and Motivation	31
2.2	Modelling of Continuous-time Stochastic Systems	33
2.3	Sampling of Continuous-time Stochastic Models	34
2.3.1	Sampling of CARMA Systems	35
2.3.2	Sampling of Systems with Inputs	37
2.4	A General Approach to Estimation of Continuous-time Stochastic Models	38
2.4.1	Direct and Indirect Methods	40
2.5	Introductory Examples	42
2.6	Derivative Approximations for Direct Methods	46
2.6.1	Non-uniformly Sampled Data	52
2.7	The Cramér–Rao Bound	54
2.7.1	The Cramér–Rao Bound for Irregularly Sampled CARMA Models	55
2.8	Numerical Studies of Direct Methods	58
2.9	Conclusions	62
	References	63

3 Robust Identification of Continuous-time Systems from Sampled Data

	<i>Juan I. Yuz, Graham C. Goodwin</i>	67
3.1	Overview	68
3.2	Limited-bandwidth Estimation	69
3.2.1	Frequency-domain Maximum Likelihood	72
3.3	Robust Continuous-time Model Identification	75
3.3.1	Effect of Sampling Zeros in Deterministic Systems	75
3.3.2	Effect of Sampling Zeros in Stochastic Systems	79
3.3.3	Continuous-time Undermodelling	82
3.3.4	Restricted-bandwidth FDML Estimation	84

3.4	Conclusions	86
	References	87

4 Refined Instrumental Variable Identification of Continuous-time Hybrid Box–Jenkins Models

	<i>Peter C. Young, Hugues Garnier, Marion Gilson</i>	91
4.1	Introduction	91
4.2	Problem Formulation	93
4.3	Optimal RIVC Estimation: Theoretical Motivation	96
	4.3.1 The Hybrid Box–Jenkins Estimation Model	96
	4.3.2 RIVC Estimation	97
4.4	The RIVC and SRIVC Algorithms	100
	4.4.1 The RIVC Algorithm	100
	4.4.2 The SRIVC Algorithm	101
	4.4.3 Multiple-input Systems	103
	4.4.4 Non-uniformly Sampled Data	103
4.5	Theoretical Background and Statistical Properties of the RIVC Estimates	104
	4.5.1 Optimality of RIVC Estimation	104
	4.5.2 The Asymptotic Independence of the System and Noise Model Parameter Estimates	105
4.6	Model Order Identification	108
4.7	Simulation Examples	109
	4.7.1 The Rao–Garnier Test System	109
	4.7.2 Noise-free Case	110
	4.7.3 Noisy-output Case	112
4.8	Practical Examples	119
	4.8.1 Hadley Centre Global Circulation Model (GCM) Data ..	120
	4.8.2 A Multiple-input Winding Process	122
4.9	Conclusions	127
	References	129

5 Instrumental Variable Methods for Closed-loop Continuous-time Model Identification

	<i>Marion Gilson, Hugues Garnier, Peter C. Young, Paul Van den Hof</i> ...	133
5.1	Introduction	133
5.2	Problem Formulation	135
5.3	Basic Instrumental Variable Estimators	138
	5.3.1 Consistency Properties	138
	5.3.2 Accuracy Analysis	139
5.4	Extended Instrumental Variable Estimators	139
	5.4.1 Consistency Properties	140
	5.4.2 Accuracy Analysis	140
5.5	Optimal Instrumental Variable Estimators	140
	5.5.1 Main Results	140

5.5.2	Implementation Issues	141
5.5.3	Multi-step Approximate Implementations of the Optimal IV Estimate	144
5.5.4	Iterative Implementations of the Optimal IV Estimate ...	147
5.6	Summary	152
5.7	Numerical Examples	153
5.7.1	Example 1: White Noise	154
5.7.2	Example 2: Coloured Noise	155
5.8	Conclusions	159
	References	159

6 Model Order Identification for Continuous-time Models

	<i>Liuping Wang, Peter C. Young</i>	161
6.1	Introduction	161
6.2	Instrumental Variable Identification	162
6.3	Instrumental Variable Estimation using a Multiple-model Structure .	166
6.3.1	Augmented Data Regressor	166
6.3.2	Instrumental Variable Solution Using UDV Factorisation .	168
6.3.3	Computational Procedure	172
6.4	Model Structure Selection Using PRESS	174
6.5	Simulation Studies	179
6.6	Conclusions	185
	References	186

7 Estimation of the Parameters of Continuous-time Systems Using Data Compression

	<i>Liuping Wang, Peter J. Gawthrop</i>	189
7.1	Introduction	189
7.2	Data Compression Using Frequency-sampling Filters	189
7.2.1	FSF Model	190
7.2.2	FSF Model in Data Compression	192
7.2.3	Estimation Using FSF Structure	195
7.3	Data Compression with Constraints	197
7.3.1	Formulation of the Constraints	197
7.3.2	Solution of the Estimation Problem with Constraints ...	198
7.3.3	Monte Carlo Simulation Study	199
7.4	Physical-model-based Estimation	201
7.5	Example: Inverted Pendulum	203
7.5.1	FSF Estimation	205
7.5.2	PMB Estimation	207
7.6	Conclusions	210
	References	212

8 Frequency-domain Approach to Continuous-time System

Identification: Some Practical Aspects

<i>Rik Pintelon, Johan Schoukens, Yves Rolain</i>	215
8.1 Introduction	215
8.2 The Inter-sample Behaviour and the Measurement Setup	216
8.2.1 Plant Modelling	216
8.2.2 Noise Modelling	220
8.2.3 Summary	222
8.3 Parametric Models	223
8.3.1 Plant Models	223
8.3.2 Noise Models	225
8.3.3 Summary	226
8.4 The Stochastic Framework	227
8.4.1 Periodic Excitations	227
8.4.2 Arbitrary Excitations	228
8.5 Identification Methods	229
8.5.1 Asymptotic Properties of the Frequency-domain Gaussian Maximum Likelihood Estimators	231
8.5.2 Periodic Excitations	231
8.5.3 Arbitrary Excitations: Generalised Output Error	234
8.5.4 Arbitrary Excitations: Errors-in-variables	236
8.6 Real Measurement Examples	237
8.6.1 Operational Amplifier	237
8.6.2 Flight-flutter Analysis	240
8.7 Guidelines for Continuous-time Modelling	241
8.7.1 Prime Choice: Uniform Sampling, Band-limited Measurement Setup, Periodic Excitation	241
8.7.2 Second Choice: Uniform Sampling, Band-limited Measurement Setup, Arbitrary Excitation	242
8.7.3 Third Choice: Uniform Sampling, Zero-order-hold Measurement Setup	242
8.7.4 Last Resort: Non-uniform Sampling	243
8.7.5 To be Avoided	243
8.8 Conclusions	243
References	243

9 The CONTSID Toolbox: A Software Support for Data-based Continuous-time Modelling

<i>Hugues Garnier, Marion Gilson, Thierry Bastogne, Michel Mensler</i>	249
9.1 Introduction	249
9.2 General Procedure for Continuous-time Model Identification	250
9.3 Overview of the CONTSID Toolbox	250
9.3.1 Parametric Model Estimation	250
9.3.2 Model Order Selection and Validation	256
9.4 Software Description	260

9.4.1	Introductory Example to the Command Mode	261
9.4.2	The Graphical User Interface	267
9.5	Advantages and Relevance of the CONTSID Toolbox Methods ...	271
9.6	Successful Application Examples	275
9.6.1	Complex Flexible Robot Arm	275
9.6.2	Uptake Kinetics of a Photosensitising Agent into Cancer Cells.....	278
9.6.3	Multi-variable Winding Process	283
9.7	Conclusions.....	285
	References	287

10 Subspace-based Continuous-time Identification

<i>Rolf Johansson</i>	291
10.1 Introduction	291
10.2 Problem Formulation	292
10.2.1 Discrete-time Measurements	292
10.2.2 Continuous-time State-space Linear System	293
10.3 System Identification Algorithms	296
10.3.1 Theoretical Remarks on the Algorithms	299
10.3.2 Numerical Example	301
10.4 Statistical Model Validation	302
10.5 Discussion	306
10.6 Conclusions	308
References	309

11 Process Parameter and Delay Estimation from Non-uniformly Sampled Data

<i>Salim Ahmed, Biao Huang, Sirish L. Shah</i>	313
11.1 Introduction	313
11.2 Estimation of Parameters and Delay	315
11.2.1 Second-order Modelling	315
11.2.2 Higher-order Modelling	318
11.2.3 Treatment of Initial Conditions	320
11.2.4 Parameter Estimation	321
11.2.5 Non-minimum Phase Processes.....	323
11.2.6 Choice of $\hat{A}_0(s)$ and $\hat{\tau}_0$	324
11.3 Identification from Non-uniformly Sampled Data	324
11.3.1 The Iterative Prediction Algorithm	324
11.3.2 Input-only Modelling Using Basis-function Model	325
11.3.3 Choice of Basis-function Parameters	327
11.3.4 Criterion of Convergence	328
11.4 Simulation Results.....	328
11.4.1 Estimation from Uniformly Sampled Data	329
11.4.2 Estimation from Non-uniformly Sampled Data	330
11.5 Experimental Evaluation	331

11.5.1	Identification of a Dryer	331
11.5.2	Identification of a Mixing Process	332
11.6	Conclusions	333
	References	335

12 Iterative Methods for Identification of Multiple-input Continuous-time Systems with Unknown Time Delays

<i>Zi-Jiang Yang</i>	339
12.1 Introduction	339
12.2 Statement of the Problem	341
12.3 Approximate Discrete-time Model Estimation	342
12.4 SEPNLS Method	343
12.5 GSEPNLS Method	347
12.6 GSEPNIV Method	351
12.7 Numerical Results	355
12.7.1 GSEPNLS Method in the Case of Low Measurement Noise	357
12.7.2 GSEPNIV Method	358
12.8 Conclusions	360
References	361

13 Closed-loop Parametric Identification for Continuous-time Linear Systems via New Algebraic Techniques

<i>Michel Fliess, Hebertt Sira-Ramírez</i>	363
13.1 Introduction	363
13.2 A Module-theoretic Approach to Linear Systems: a Short Summary ..	364
13.2.1 Some Basic Facts about Modules over Principal Ideal Rings	364
13.2.2 Formal Laplace Transform	365
13.2.3 Basic System-theoretic Definitions	366
13.2.4 Transfer Matrices	367
13.3 Identifiability	368
13.3.1 Uncertain Parameters	368
13.3.2 The Algebraic Derivative and a New Module Structure ..	368
13.3.3 Linear Identifiability	368
13.3.4 An Elementary Example	369
13.4 Perturbations	370
13.4.1 Structured Perturbations	370
13.4.2 Unstructured Perturbations	370
13.4.3 Linear Identifier	371
13.4.4 Robustness	371
13.5 First Example: Dragging an Unknown Mass in Open Loop	371
13.5.1 Description and First Results	371
13.5.2 Denoising	374
13.5.3 A Comparison with an Adaptive-observer Approach	376
13.6 Second Example: A Perturbed First-order System	377

13.6.1	Presentation	377
13.6.2	A Certainty Equivalence Controller	378
13.6.3	Parameter Identification	378
13.6.4	Noise-free Simulation Results	380
13.6.5	Noisy Measurements and Plant Perturbations	381
13.6.6	Simulation Results with Noises	381
13.6.7	Comparison with Adaptive Control	381
13.6.8	Simulations for the Adaptive Scheme	383
13.7	Third Example: A Double-bridge Buck Converter	383
13.7.1	An Input–Output Model	384
13.7.2	Problem Formulation	385
13.7.3	A Certainty Equivalence Controller	385
13.7.4	Closed-loop Behaviour	385
13.7.5	Algebraic Determination of the Unknown Parameters ...	386
13.7.6	Simulation Results	387
13.8	Conclusion	388
	References	389

**14 Continuous-time Model Identification Using Spectrum
Analysis with Passivity-preserving Model Reduction**

	<i>Rolf Johansson</i>	393
14.1	Introduction	393
14.2	Preliminaries	394
14.2.1	Continuous-time Model Identification	394
14.2.2	Spectrum Analysis and Positivity	396
14.2.3	Spectral Factorisation and Positivity	399
14.2.4	Balanced Model Reduction	399
14.3	Problem Formulation	400
14.4	Main Results	401
14.5	Discussion	405
14.6	Conclusions	406
	References	406
	Index	409

Identification of Continuous-time Models from Sampled
Data

Garnier, H.; Wang, L. (Eds.)

2008, XXVI, 413 p., Hardcover

ISBN: 978-1-84800-160-2