

---

# CONTENTS

---

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Some Preliminary Concepts	1
1.2	Digital Control of Industrial Processes	4
1.3	Outline of the Book	5
<b>2</b>	<b>Linear Models of Dynamic Processes and Signals</b>	<b>8</b>
2.1	SISO Continuous-Time Models	8
2.2	SISO Discrete-Time Models	10
2.3	MIMO Models	14
2.4	Models of Signals	17
2.5	Linear Processes with Disturbances; Conclusion	20
<b>3</b>	<b>Identification Experiments and Data Pre-treatment</b>	<b>21</b>
3.1	Selection of Inputs/Outputs and Preliminary Experiments	22
3.2	Experiment for Model Estimation	26
3.3	Pre-treatment of Data	31
3.4	Conclusions	34
<b>4</b>	<b>Identification by the Least-Squares Method</b>	<b>37</b>
4.1	The Principle of Least-Squares	37
4.2	Estimating Models of Linear Processes	40
4.2.1	Finite Impulse Response (FIR) Models	40
4.2.2	Transfer Operator Models	42
4.2.3	Model Validation and Order Selection; A Simulation Approach	45
4.3	Two Industrial Case Studies	49
4.3.1	Identification and Control of a Single-Stand Rolling Mill	49

4.3.2	Identification and Control of a Glass Tube Process . . .	54
4.4	Properties of the Least-Squares Estimator . . . . .	58
4.5	Conclusions . . . . .	66
<b>5</b>	<b>Extensions of the Least-Squares Method . . . . .</b>	<b>68</b>
5.1	Modifying the Frequency Weighting by Prefiltering . . . . .	68
5.2	A Natural Choice of Criterion – Output Error Method . . . .	71
5.3	Using Correlation Techniques – Instrumental Variable (IV) Methods . . . . .	77
5.4	Obtaining White Residuals – Prediction Error Methods . . .	81
5.4.1	Generalized Least-Squares (GLS) Method . . . . .	82
5.4.2	General Properties of the Family of Prediction Error Methods . . . . .	87
5.5	Identifying the Glass Tube Process Using a Prediction Error Method . . . . .	93
5.6	Conclusions and Discussion . . . . .	94
<b>6</b>	<b>MIMO Process Identification: A Markov Parameter Approach . . .</b>	<b>97</b>
6.1	Rationale of the Method . . . . .	97
6.2	The Identification Procedure . . . . .	100
6.3	Identification of the Glass Tube Manufacturing Process . . .	104
6.4	Conclusions . . . . .	107
<b>7</b>	<b>Identification for Robust Control; SISO Case . . . . .</b>	<b>108</b>
7.1	Asymptotic Properties of Prediction Error Models . . . . .	109
7.2	The Identification Method . . . . .	114
7.2.1	The Procedure . . . . .	114
7.2.2	Model Order Selection . . . . .	119
7.2.3	Optimal Experiment Design for Simulation . . . . .	120
7.3	Recursive Estimation . . . . .	122
7.3.1	The Recursive LS Method . . . . .	123
7.3.2	A Recursive Output Error Method . . . . .	126
7.3.3	A Recursive Identifier for Robust Adaptive Control . . . .	127
7.4	A Simulation Study . . . . .	129
7.5	Conclusions . . . . .	135
<b>8</b>	<b>Identification for Robust Control; MIMO Case . . . . .</b>	<b>136</b>
8.1	The MIMO Version of the Asymptotic Theory . . . . .	136
8.2	The Identification Method . . . . .	139

8.2.1	The Procedure	139
8.2.2	Model Structure Selection	142
8.2.3	Input Design for Simulation	143
8.2.4	Determining a State Space Realization	143
8.3	Identification of Two Industrial Processes	146
8.3.1	Identification of the Glass Tube Process	146
8.3.2	Identification of a Four-Effect Evaporator	149
8.4	Closed Loop Identification of Coprime Factors	152
8.5	Conclusions	157
<b>9</b>	<b>Identification and Robust Control of the Glass Tube Process</b>	<b>159</b>
9.1	From Identification to Robust Control; Guidelines	159
9.2	Identification and Control of the Glass Tube Process; Control Results	164
9.3	Conclusions	166
<b>10</b>	<b>Identification for Fault Diagnosis; Estimation of Continuous-Time Models</b>	<b>167</b>
10.1	An Indirect Method of Continuous-Time Model Estimation	168
10.2	Enhancing a Parameters Subset by Input Design	171
10.3	A Simulation Study	172
10.4	Conclusions	175
	<b>Symbols and Abbreviations</b>	<b>176</b>
	<b>References</b>	<b>178</b>
	<b>Index</b>	<b>183</b>