

Contents

1	Introduction	1
1.1	Micro-/Nano-positioning Technique	1
1.2	Actuators and Sensors	2
1.3	Piezoelectric Nonlinearity	4
1.4	Feedforward Control Based on Hysteresis Models	5
1.4.1	Conventional Hysteresis Model	6
1.4.2	Intelligent Hysteresis Model	8
1.4.3	Feedforward Plus Feedback Control	8
1.5	Robust Feedback Control	9
1.5.1	Sliding-Mode Control	10
1.5.2	Model Predictive Control	11
1.5.3	Model-Reference Adaptive Control	12
1.5.4	Other Control Strategies	13
1.6	Position/Force Control in Micromanipulation	13
1.6.1	Hybrid Control	14
1.6.2	Impedance Control	14
1.6.3	Switching Control	15
1.7	Book Summary	16
	References	16

Part I Hysteresis-Model-Based Feedforward Control

2	Feedforward Control Based on Inverse Hysteresis Models	23
2.1	Introduction	23
2.2	System Description and Hysteresis Characterization	24
2.2.1	Experimental Setup	24
2.2.2	Hysteresis Characterization	25
2.3	Hysteresis Modeling	28
2.3.1	Hysteresis Modeling with the Bouc–Wen Model	28

2.3.2	Hysteresis Modeling with the MPI Model	29
2.3.3	Hysteresis Modeling with the LSSVM.	32
2.4	Experimental Studies.	36
2.4.1	Bouc–Wen Model Results	36
2.4.2	MPI Model Results	37
2.4.3	LSSVM Model Results	40
2.4.4	Model Capability Comparison	42
2.4.5	Generalization Study	44
2.5	Controller Design and Verification	47
2.5.1	Feedforward Controller Design	47
2.5.2	Feedforward Plus Feedback Controller Design	49
2.5.3	Controller Verification.	49
2.6	Chapter Summary	54
	References.	54
3	Feedforward Control Without Modeling Inverse Hysteresis	57
3.1	Introduction	57
3.2	Dynamics Modeling of Hysteretic System	58
3.2.1	Dynamics Modeling with Bouc–Wen Hysteresis.	58
3.2.2	Dynamics Modeling with Intelligent Hysteresis Model	59
3.3	Hysteresis Modeling Using LSSVM	60
3.3.1	Regression Model Establishment.	60
3.3.2	LSSVM Modeling	60
3.4	Experimental Studies on Hysteresis Identification	62
3.4.1	Experimental Setup	62
3.4.2	Dynamics Model Identification.	63
3.4.3	Bouc–Wen Model Results	64
3.4.4	LSSVM Model Results	67
3.5	Experimental Studies on Hysteresis Compensation	71
3.5.1	Feedforward Compensation	71
3.5.2	Feedforward Plus Feedback Control	73
3.6	Chapter Summary	74
	References.	75

Part II Hysteresis-Model-Free, State-Observer-Based Feedback Control

4	Model Predictive Discrete-Time Sliding-Mode Control	79
4.1	Introduction	79
4.2	Problem Formulation.	81
4.2.1	Dynamics Modeling of a Nanopositioning System	81

4.2.2	Sliding-Mode Controller Design	83
4.2.3	Control Gain Design	85
4.3	DTSMC Design	86
4.3.1	Controller Design and Analysis	86
4.3.2	Tracking Error Bound Analysis	88
4.4	MPDTSMC Design.	89
4.4.1	MPDTSMC Controller Design	89
4.4.2	Stability Analysis	91
4.4.3	State Observer Design	92
4.4.4	Tracking and Estimation Error Bound Analysis	93
4.5	Experimental Investigation	94
4.5.1	Experimental Setup	94
4.5.2	Hysteresis Characterization.	94
4.5.3	Plant Model Identification	95
4.5.4	Controller Parameter Design.	96
4.5.5	Simulation Studies	97
4.5.6	Experimental Testing Results	99
4.5.7	Discussion on System Performance	102
4.6	Chapter Summary	103
	References.	103
5	Model Predictive Output Integral Discrete-Time	
	Sliding-Mode Control	105
5.1	Introduction	105
5.2	Problem Formulation.	106
5.3	MPOIDSMC Design	107
5.3.1	OIDSMC Controller Design	107
5.3.2	MPOIDSMC Controller Design	109
5.4	Experimental Investigations	114
5.4.1	Experimental Setup	114
5.4.2	Plant Model Identification	115
5.4.3	Controller Parameter Design.	116
5.4.4	Experimental Studies.	118
5.4.5	Discussion on Controller Performance	121
5.5	Chapter Summary	122
	References.	122
Part III	Hysteresis-Model-Free, State-Observer-Free	
	Feedback Control	
6	Digital Sliding-Mode Control of Second-Order Systems	127
6.1	Introduction	127
6.2	Dynamics Model and Problem Formulation	128

6.3	DSMC Design	130
6.4	Experimental Studies.	133
6.4.1	Experimental Setup	133
6.4.2	Plant Model Identification	134
6.4.3	Experimental Results.	135
6.4.4	Discussion	145
6.5	Chapter Summary	145
	References.	146
7	Digital Sliding-Mode Control of High-Order Systems	147
7.1	Introduction	147
7.2	Problem Formulation.	148
7.2.1	System Modeling	148
7.2.2	Disturbance Estimation	150
7.3	IODSMC Design	151
7.3.1	Sliding Function Definition	151
7.3.2	Design of IODSMC	152
7.3.3	Robust IODSMC Design	154
7.4	Experimental Setup and Controller Setup	156
7.4.1	Experimental Setup	156
7.4.2	Plant Model Identification	157
7.4.3	Controller Parameter Design.	158
7.5	Experimental Results and Discussion.	159
7.5.1	Set-Point Positioning Results	159
7.5.2	Sinusoidal Positioning Results	159
7.5.3	Bandwidth Testing Results.	161
7.5.4	Robustness Testing Results	162
7.5.5	Further Discussion	164
7.6	Chapter Summary	164
	References.	165
8	Digital Sliding-Mode Prediction Control	167
8.1	Introduction	167
8.2	Problem Formulation.	168
8.2.1	System Modeling	168
8.2.2	Disturbance Estimation	169
8.3	DSMC Design	169
8.3.1	Sliding Function Definition	170
8.3.2	Design of DSMC	170
8.3.3	Error Bound Analysis	172
8.4	DSMPC Design	173
8.4.1	DSMPC Design	173
8.4.2	Stability Analysis	175
8.4.3	Error Bound Analysis	177

8.5	Experimental Studies and Discussion.	177
8.5.1	Experimental Setup.	177
8.5.2	Plant Model Identification	178
8.5.3	Controller Parameter Design.	179
8.5.4	Experimental Studies.	179
8.5.5	Further Discussion	183
8.6	Chapter Summary.	184
	References.	184
9	Model-Reference Adaptive Control with Perturbation	
	Estimation	187
9.1	Introduction	187
9.2	Dynamics Modeling and Perturbation Estimation	188
9.2.1	Dynamics Modeling	188
9.2.2	Perturbation Estimation	189
9.3	MRACPE Control Design	190
9.3.1	MRACPE Controller Design	190
9.3.2	Dead-Zone Modification of Adaptive Laws	193
9.3.3	Overview of Control Scheme	193
9.4	Experimental Setup and Controller Setup.	194
9.4.1	Experimental Setup.	194
9.4.2	Statics Testing and Dynamics Model Identification	196
9.4.3	Controller Setup	197
9.5	Experimental Results and Discussion.	198
9.5.1	Set-Point Positioning Testing	198
9.5.2	Sinusoidal Positioning Testing	200
9.5.3	Control Bandwidth Testing	200
9.5.4	Discussion	202
9.6	Chapter Summary.	204
	References.	205
Part IV	Applications to Micromanipulation	
10	Adaptive Impedance Control of Piezoelectric Microgripper.	209
10.1	Introduction	209
10.2	Problem Formulation.	211
10.2.1	Dynamics Modeling and Perturbation Estimation	212
10.2.2	Impedance Control Problem.	213
10.3	ADSMGIC Scheme Design	214
10.3.1	Sliding Function Definition	214
10.3.2	ADSMGIC Design	215
10.3.3	Stability Analysis	216
10.3.4	Evaluation of Steady-State Errors	218

10.4	Experimental Setup and Controller Setup	219
10.4.1	Experimental Setup	219
10.4.2	Force Observer Design	220
10.4.3	Controller Setup	222
10.5	Experimental Results and Discussion.	224
10.5.1	Interaction Control Results.	224
10.5.2	Discussion on Control Performance.	229
10.6	Chapter Summary	230
	References.	230
11	Position/Force Switching Control of a Miniature Gripper	233
11.1	Introduction	233
11.2	Experimental Setup and Calibration.	234
11.2.1	Working Principle of the Gripper	234
11.2.2	Experimental Setup	236
11.2.3	Calibration of Position and Force Sensors	237
11.2.4	Gripping Range Testing.	239
11.2.5	Frequency Response Testing	240
11.3	Position/Force Switching Control Scheme Design	241
11.3.1	Event-Based Switching Control Framework	241
11.3.2	Incremental DSMC Position Controller	242
11.3.3	Incremental PID Force Controller	245
11.3.4	Switching Criterion	245
11.4	Experimental Investigations and Discussion	246
11.4.1	Controller Setup	246
11.4.2	Position/Force Switching Control Results.	247
11.4.3	Further Discussion	249
11.5	Chapter Summary	252
	References.	252
	Index	255



<http://www.springer.com/978-3-319-21622-5>

Advanced Control of Piezoelectric
Micro-/Nano-Positioning Systems

Xu, Q.; Tan, K.K.

2016, XX, 257 p., Hardcover

ISBN: 978-3-319-21622-5