
Contents

Preface	xiii
SECTION I Preliminaries	
CHAPTER 1 ■ Introduction	3
1.1 BACKGROUNDS	3
1.2 TELEOPERATION SYSTEM CONTROL	4
1.3 TELEOPERATED CONTROL WITH INPUT SATURATION	8
1.4 MULTILATERAL TELE-COORDINATED CONTROL	9
1.5 HETEROGENEOUS TELEOPERATION CONTROL	11
1.6 HIGH-PERFORMANCE CONTROL OF TELEOPERATION SYSTEMS	13
BIBLIOGRAPHY	15
CHAPTER 2 ■ Preliminaries of teleoperation control	33
2.1 INTRODUCTION	33
2.2 ROBOT MODELS	33
2.2.1 Lagrange's equations	33
2.2.2 Robotic dynamics	37
2.2.3 Important property	39
2.2.4 Mathematical descriptions	41
2.3 SYSTEM WITH TIME DELAY	42
2.3.1 Modeling of time delay	42
2.3.2 Functional differential equation	43
2.3.3 Switched systems	44
2.3.4 Stability of time-delayed system	45
2.4 CONCLUSION	52
BIBLIOGRAPHY	52

SECTION II Single-Master Single-Slave Teleoperation**CHAPTER 3 ■ Adaptive control of bilateral teleoperation**

57

3.1	INTRODUCTION	57
3.2	PROBLEM FORMULATION	58
3.3	ADAPTIVE CONTROLLER DESIGN	59
3.4	STABILITY ANALYSIS	63
3.5	EXPANSION TO SINGLE-MASTER MULTI-SLAVE TELEOPERATION	67
3.6	SIMULATION STUDY	71
3.6.1	Stability verification	71
3.6.2	Contact stability verification	73
3.6.3	Comparison study	74
3.7	CONCLUSION	75
BIBLIOGRAPHY		75

CHAPTER 4 ■ Anti-saturation teleoperation control

79

4.1	INTRODUCTION	79
4.2	PROBLEM FORMULATION	80
4.3	ADAPTIVE CONTROLLER WITH INPUT CONSTRAINT	82
4.4	STABILITY ANALYSIS	85
4.5	EXPERIMENTAL VALIDATION	89
4.5.1	Stability verification	90
4.5.2	Comparison study	90
4.5.3	Some discussion	94
4.6	CONCLUSION	95
BIBLIOGRAPHY		96

SECTION III Multi-Master Multi-Slave Teleoperation**CHAPTER 5 ■ Adaptive tele-coordinated control of multiple mobile robots**

101

5.1	INTRODUCTION	101
5.2	PROBLEM FORMULATION	102
5.2.1	Dynamics of the master robots	103
5.2.2	Dynamics of the slave robots	104
5.2.3	Motion control objectives	107

5.3	MULTILATERAL COORDINATION CONTROLLER	108
5.4	STABILITY ANALYSIS	109
5.5	SIMULATION STUDY	113
5.6	CONCLUSION	118
	BIBLIOGRAPHY	119
CHAPTER	6 ■ Multilateral tele-coordinated control	121
<hr/>		
6.1	INTRODUCTION	121
6.2	PROBLEM FORMULATION	122
6.3	MULTILATERAL COORDINATED CONTROLLER	124
6.3.1	Neuroadaptive controller	127
6.3.2	Designs of filter subsystems	130
6.3.3	Complete closed-loop teleoperation system	131
6.4	STABILITY ANALYSIS	132
6.5	SIMULATION STUDY	138
6.5.1	Stability verification	139
6.5.2	Comparison studies	140
6.6	CONCLUSION	144
	BIBLIOGRAPHY	145
SECTION IV Heterogeneous Teleoperation		
CHAPTER	7 ■ Adaptive semi-autonomous control of heterogeneous teleoperation systems	149
<hr/>		
7.1	INTRODUCTION	149
7.2	PROBLEM FORMULATION	150
7.2.1	Robot dynamics	150
7.2.2	Input uncertainty	152
7.2.3	Control objectives	153
7.3	TASK SPACE TELEOPERATION	153
7.4	STABILITY ANALYSIS	156
7.5	SEMI-AUTONOMOUS CONTROL OF SLAVE ROBOT	161
7.6	SIMULATION	162
7.6.1	Stability verification with practical communication delay	163
7.6.2	Simulations with large artificial communication delays	167
7.6.3	Comparison with the existing work	169

7.6.4	Comparison on tracking response for different time delays	170
7.6.5	Discussions	171
7.7	CONCLUSION	175
	BIBLIOGRAPHY	176

SECTION V Finite-time Teleoperation

CHAPTER	8 ■ Adaptive finite-time teleoperation control	181
8.1	INTRODUCTION	181
8.2	PROBLEM FORMULATION	182
8.3	FINITE-TIME CONTROLLER	183
8.4	STABILITY ANALYSIS	185
8.5	SIMULATION	191
8.5.1	Stability verification	192
8.5.2	Comparison study	193
8.6	CONCLUSION	195
	BIBLIOGRAPHY	196

CHAPTER	9 ■ Finite-time adaptive anti-windup teleoperation control	199
9.1	INTRODUCTION	199
9.2	PROBLEM FORMULATION	200
9.3	ANTI-WINDUP FINITE-TIME CONTROLLER	203
9.4	STABILITY ANALYSIS	206
9.5	SIMULATION STUDY	212
9.5.1	Stability verification	214
9.5.2	Comparisons with the asymptotic control methods	217
9.5.3	Comparisons with the finite-time control methods	221
9.6	CONCLUSION	224
	BIBLIOGRAPHY	225

SECTION VI Prescribed-performance Teleoperation

CHAPTER	10 ■ Prescribed performance task-space teleoperation control	229
10.1	INTRODUCTION	229
10.2	PROBLEM FORMULATION	231

10.2.1	Dynamics of robots	231
10.2.2	Control objectives	232
10.3	ADAPTIVE CONTROLLER	233
10.3.1	PPC strategy	233
10.3.2	Design of the control torque	234
10.3.3	Complete closed-loop teleoperation system	238
10.4	STABILITY ANALYSIS	239
10.5	SIMULATION STUDY	245
10.5.1	Stability verification with artificial delays	247
10.5.2	Stability verification with practical delays	249
10.5.3	Comparisons on task performance	252
10.5.4	Comparison study with varying time delays	254
10.5.5	Discussions	256
10.6	CONCLUSION	256
BIBLIOGRAPHY		257
CHAPTER 11	■ Practical given performance control of robotic systems	261
11.1	INTRODUCTION	261
11.2	PROBLEM FORMULATION	266
11.2.1	Dynamics of the robotic vehicle	266
11.2.2	Switching-based PPLC strategy	267
11.3	ADAPTIVE CONTROLLER	269
11.4	STABILITY ANALYSIS	273
11.5	APPLICATION TO TELEOPERATION SYSTEM	282
11.6	SIMULATION STUDY	282
11.6.1	Stability verification	283
11.6.2	Function verification of PPLC	286
11.6.3	Comparison studies	288
11.6.4	Discussions	292
11.7	CONCLUSION	293
BIBLIOGRAPHY		294