

Contents

1	Introduction	1
	Yue Wang and Fumin Zhang	
1.1	Overview	1
1.2	Collaboration Between One Human–Robot Pair	4
1.3	Collaboration Between Human and Multiple Robots/Swarms	6
	References	8
2	Robust Shared-Control for Rear-Wheel Drive Cars	15
	Jingjing Jiang and Alessandro Astolfi	
2.1	Introduction	15
2.2	Problem Formulation, Definitions, and Assumptions	16
2.3	Design of the Shared-Control Law with Measurements of Absolute Positions	19
	2.3.1 Design of the Feedback Controller	19
	2.3.2 Shared-Control Algorithm	22
2.4	Disturbance Rejections	25
2.5	Design of the Shared Control Without Measurements of Absolute Positions	28
	2.5.1 Design of the Feedback Controller	29
	2.5.2 Shared-Control Algorithm	31
2.6	Case Studies	33
	2.6.1 Case I: Turning Without Absolute Positioning	33
	2.6.2 Case II: Driving on a Road with Parked Cars	36
	2.6.3 Case III: Emergency Breaking	36
2.7	Conclusions	38
	References	38

3	Baxter-On-Wheels (BOW): An Assistive Mobile Manipulator for Mobility Impaired Individuals	41
	Lu Lu and John T. Wen	
3.1	Introduction	41
3.2	System Description	44
3.2.1	Experimental Platform: BOW	44
3.2.2	System Kinematics	48
3.3	Control Algorithm	49
3.3.1	Baseline Shared-Control Algorithm	49
3.3.2	Free-Space Mode and Contact Mode	51
3.4	Application to the BOW	54
3.4.1	User Interface	54
3.4.2	Object Pick-Up and Placement Task	55
3.4.3	Board Cleaning Task	58
3.5	Conclusion	60
	References	61
4	Switchings Between Trajectory Tracking and Force Minimization in Human–Robot Collaboration	65
	Yanan Li, Keng Peng Tee and Shuzhi Sam Ge	
4.1	Introduction	65
4.2	Dynamic Models	67
4.2.1	Robot Model	68
4.2.2	Human Arm Model	68
4.2.3	Unified Model	70
4.2.4	Trajectory Tracking	71
4.3	Control Design	71
4.3.1	Control Objective	71
4.3.2	Selection of Cost Functions	72
4.3.3	Optimal Control	73
4.4	Simulations	75
4.4.1	Simulation Settings	75
4.4.2	Change of Weights	76
4.4.3	Adaptation of Desired Trajectory	78
4.5	Conclusions	79
	Appendix: Proof of Lemma 4.1	79
	References	80
5	Estimating Human Intention During a Human–Robot Cooperative Task Based on the Internal Force Model	83
	Ehsan Noohi and Miloš Žefran	
5.1	Introduction	83
5.2	Internal Force Model	86
5.2.1	Problem Formulation	86

5.2.2	Existing Models	87
5.2.3	Proposed Model	88
5.2.4	Discussion	91
5.3	Method	91
5.3.1	Apparatus	92
5.3.2	Procedure	92
5.4	Results	94
5.5	Validation of the Model.	97
5.6	Statistical Analysis of the Internal Force Features	99
5.6.1	Initial Grasp Force Magnitude	100
5.6.2	Final Grasp Force Magnitude	101
5.6.3	Internal Force Energy	101
5.6.4	Difference Between Initial and Final Grasp Forces	102
5.6.5	Internal Force Variation	102
5.6.6	Negotiation Force	103
5.6.7	Negotiation Force Versus Object Velocity	104
5.7	Proposed Cooperation Policy	105
5.8	Conclusion	107
	References	108
6	A Learning Algorithm to Select Consistent Reactions to Human Movements	111
	Carol Young and Fumin Zhang	
6.1	Introduction	111
6.2	Background	113
6.2.1	Expert-Based Learning	113
6.2.2	Binary Learning Algorithms	114
6.3	Analysis	115
6.3.1	Performance	116
6.3.2	Consistency	116
6.3.3	Adaptiveness	118
6.3.4	Tie Breaking	119
6.4	Expanded Dual Expert Algorithm	120
6.4.1	Performance Analysis	121
6.4.2	Consistency and Adaptiveness	122
6.5	Simulation	122
6.5.1	Dual Expert Algorithm	122
6.5.2	Expanded Dual Expert Algorithm	123
6.6	Experiment	125
6.6.1	Setup	126
6.6.2	Results	127
6.7	Conclusions	129
	References	129

7	Assistive Optimal Control-on-Request with Application in Standing Balance Therapy and Reinforcement	131
	Anastasia Mavrommati, Alex Ansari and Todd D. Murphey	
7.1	Introduction	131
7.2	Assistive Control Synthesis	133
7.2.1	Calculating a Schedule of Optimal Infinitesimal Actions	133
7.2.2	Computing the Control Duration	138
7.3	Human–Robot Interaction in Assisted Balance Therapy	139
7.3.1	Related Work: Assist-as-Needed Techniques	140
7.3.2	Interactive Simulation Study	141
7.4	Human–Robot Communication in Posture Reinforcement: A Short Study	145
7.5	Conclusion	148
	References	149
8	Intelligent Human–Robot Interaction Systems Using Reinforcement Learning and Neural Networks	153
	Hamidreza Modares, Isura Ranatunga, Bakur AlQaudi, Frank L. Lewis and Dan O. Popa	
8.1	Introduction	153
8.2	HRI Control: Motivation and Structure Overview of the Proposed Approach	155
8.3	Inner Robot-Specific Loop	156
8.4	Outer Task-Specific Loop Control	162
8.4.1	Task-Specific Outer Loop Control Method: An LQR Approach	162
8.4.2	Learning Optimal Parameters of the Prescribed Impedance Model Using Integral Reinforcement Learning	166
8.5	Simulation Results	167
8.6	Conclusion	174
	References	174
9	Regret-Based Allocation of Autonomy in Shared Visual Detection for Human–Robot Collaborative Assembly in Manufacturing	177
	S.M. Mizanoor Rahman, Zhanrui Liao, Longsheng Jiang and Yue Wang	
9.1	Introduction	177
9.2	The Hybrid Cell for Human–Robot Collaborative Assembly	179
9.3	Detection Problem Formulation with Focus on the Selected Assembly Task	182
9.3.1	Description of the Problem	182

9.3.2	Problem Formulation	185
9.4	Bayesian Sequential Decision-Making Algorithm for Allocation of Autonomy.	186
9.5	Inclusion of Regret in Bayesian Decision-Making Algorithm for Allocation of Autonomy	187
9.6	Illustration of the Decision-Making Approach	190
9.6.1	Illustration of the Optimal Bayesian Decision-Making Approach	190
9.6.2	Illustration of the Regret-Based Modified Decision-Making Approach	193
9.7	Implementation Scheme of the Regret-Based Bayesian Decision-Making Approach for the Assembly Task.	193
9.7.1	The Overall Scheme in a Flowchart	193
9.7.2	Measurement of Sensing Probability and Observation Cost	196
9.7.3	Measurement Method for Regret Intensity	197
9.8	Experimental Evaluation of the Regret-Based Bayesian Decision-Making Approach	199
9.8.1	Objective	199
9.8.2	Hypothesis	199
9.8.3	The Evaluation Criteria.	200
9.8.4	The Experiment Design	200
9.8.5	Subjects	200
9.8.6	The Experimental Procedures	201
9.9	Evaluation Results and Analyses	201
9.10	Conclusions and Future Innovations	203
	References	204
10	Considering Human Behavior Uncertainty and Disagreements in Human–Robot Cooperative Manipulation	207
	José Ramón Medina, Tamara Lorenz and Sandra Hirche	
10.1	Introduction	207
10.2	Human–Robot Cooperative Manipulation	209
10.2.1	Cooperative Manipulation.	209
10.2.2	Control Challenges in Physical Human–Robot Interaction.	212
10.2.3	Reactive Assistants	212
10.2.4	Proactive Assistants	213
10.3	Interaction Wrench Decomposition	215
10.3.1	Nonuniform Wrench Decomposition Matrices	216
10.3.2	Effective and Internal Wrenches	217
10.3.3	Load Share and Disagreement	221
10.4	Optimal Robot Assistance Considering Human Behavior Uncertainty and Disagreements.	221

10.4.1	Anticipatory Assistance Based on Learned Models	222
10.4.2	The Two-Dimensional Translational Case.	227
10.4.3	Experiments	229
10.5	Conclusions	235
	Appendix	235
	References	238
11	Designing the Robot Behavior for Safe Human–Robot Interactions	241
	Changliu Liu and Masayoshi Tomizuka	
11.1	Introduction	241
11.1.1	The Safety Issues and Existing Solutions	242
11.1.2	Safety Problems in HRI: Conflicts in Multiagent Systems	242
11.1.3	Safe Control and Exploration	243
11.2	Modeling the Human–Robot Interactions.	244
11.2.1	The Agent Model	244
11.2.2	The Closed-Loop System	245
11.2.3	Information Structure	246
11.3	The Safety-Oriented Behavior Design	247
11.3.1	The Safety Principle	247
11.3.2	The Safety Index	248
11.4	The Safe Set Algorithm (SSA).	250
11.4.1	The Control Algorithm	251
11.4.2	Online Learning and Prediction of Humans' Dynamics	252
11.4.3	Applications	253
11.5	The Safe Exploration Algorithm (SEA).	255
11.5.1	The Safe Set in the Belief Space	256
11.5.2	Learning in the Belief Space.	257
11.5.3	A Comparative Study Between SSA and SEA	260
11.6	Combining SSA and SEA in Time Varying MAS Topology	263
11.6.1	The Control Algorithm	264
11.6.2	The Learning Algorithm	265
11.6.3	Performance	265
11.7	Discussions	266
11.7.1	The Energy Based Methods	267
11.7.2	Limitations and Future Work	267
11.8	Conclusion.	268
	References	268

12	When Human Visual Performance Is Imperfect—How to Optimize the Collaboration Between One Human Operator and Multiple Field Robots	271
	Hong Cai and Yasamin Mostofi	
12.1	Introduction	271
12.2	Human and Robot Performance in Target Classification [4] . . .	273
12.3	Optimizing Human–Robot Collaboration for Target Classification	275
	12.3.1 Predetermined Site Allocation.	275
	12.3.2 Optimized Site Allocation.	280
12.4	Numerical Results	283
	12.4.1 Collaboration Between the Human Operator and One Robot [4]	284
	12.4.2 Predetermined Site Allocation.	286
	12.4.3 Optimized Site Allocation.	293
12.5	Conclusions	298
	References	298
13	Human-Collaborative Schemes in the Motion Control of Single and Multiple Mobile Robots	301
	Antonio Franchi	
13.1	Introduction	301
13.2	Modeling of the Robot and the Interactions.	302
	13.2.1 Mobile Robot	302
	13.2.2 Communication Infrastructure.	304
	13.2.3 Human–Robot Interface	304
13.3	A Taxonomy of Collaborative Human–Robot Control	306
	13.3.1 Physical Domain of the Robots	306
	13.3.2 Degree of Autonomy from the Human Operator.	307
	13.3.3 Force Interaction with the Operator	310
	13.3.4 Near-Operation Versus Teleoperation	312
	13.3.5 Physical Interaction with the Environment	313
	13.3.6 Use of Onboard Sensors Only	315
13.4	A Taxonomy of Collaborative Human–Multi-robot Control.	316
	13.4.1 Level of Centralization	316
	13.4.2 Master–Leader–Followers Schemes	317
	13.4.3 Formation-Orthogonal Control Schemes	318
	13.4.4 Group-Property Preservation Schemes	319
	13.4.5 Physical Interaction with Contact	320
13.5	Conclusions	321
	References	322

14	A Passivity-Based Approach to Human–Swarm Collaboration and Passivity Analysis of Human Operators	325
	T. Hatanaka, N. Chopra, J. Yamauchi and M. Fujita	
14.1	Introduction	325
14.2	Intended Scenario and Control Goals	328
14.3	Control Architecture and Passivity	331
14.4	Convergence Analysis	333
14.4.1	Synchronization in Position Control Mode	333
14.4.2	Synchronization in Velocity Control Mode	337
14.5	Passivity of the Human Operator Decision Process	340
14.5.1	Experimental Setup and Approach	341
14.5.2	Analysis on Human Passivity in Position Control Mode	344
14.5.3	Analysis on Human Passivity in Velocity Control Mode	347
14.5.4	Analysis on Individual Variability	349
14.6	Summary	353
	References	354
15	Human–Swarm Interactions via Coverage of Time-Varying Densities	357
	Yancy Diaz-Mercado, Sung G. Lee and Magnus Egerstedt	
15.1	Introduction	357
15.2	Human–Swarm Interactions via Coverage	359
15.2.1	The Coverage Problem	362
15.2.2	Centralized Coverage of Time-Varying Densities	365
15.2.3	Distributed Coverage of Time-Varying Densities	369
15.3	Designing Density Functions	374
15.3.1	Diffusion of Drawn Geometric Configurations	374
15.3.2	Control of Gaussian Functions	376
15.4	Robotic Experiments	377
15.5	Conclusions	380
	References	381
16	Co-design of Control and Scheduling for Human–Swarm Collaboration Systems Based on Mutual Trust	387
	Xiaotian Wang and Yue Wang	
16.1	Introduction	387
16.2	Swarm Setup	390
16.2.1	Dynamic Timing Model and Collaboration Delay	390
16.2.2	Cooperative Control for Swarm Agents	392
16.3	Collaboration Framework	398
16.3.1	Trust Model	398

16.3.2	Human Performance Model	399
16.3.3	Swarm Performance Model.	400
16.3.4	Human Attention Preference.	400
16.3.5	Fitness	402
16.4	Real-Time Scheduling	403
16.5	Simulation Results	404
16.5.1	Parameter Setup	404
16.5.2	Results and Discussions	406
16.6	Conclusions	410
	References	411
	Index	415

Trends in Control and Decision-Making for
Human-Robot Collaboration Systems

Wang, Y.; Zhang, F. (Eds.)

2017, XIX, 418 p. 173 illus., 121 illus. in color.,
Hardcover

ISBN: 978-3-319-40532-2