

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Passivity in Robot Control	1
1.2	What Is Networked Robotics?	2
1.3	Teleoperation	3
1.3.1	Literature Review of Bilateral Teleoperation	4
1.3.2	What Is in This Book?	7
1.4	Visual Feedback Control and Estimation	8
1.4.1	Literature Review of Visual Feedback Control	9
1.4.2	Literature Review of Visual Feedback Estimation	11
1.4.3	What Is in This Book?	13
1.5	Cooperative Control and Estimation	16
1.5.1	Why Multi-agent System?	17
1.5.2	General Description of Cooperative Control/Estimation	21
1.5.3	Group Goals	21
1.5.4	What Is in This Book?	24
1.6	Notations	27

## Part I Passivity-Based Teleoperation

<b>2</b>	<b>Foundation: Passivity, Stability and Passivity-Based Motion Control</b>	<b>31</b>
2.1	Passivity	31
2.1.1	Definition of Passivity	31
2.1.2	Passivity Preservation for Interconnections	37
2.2	Stability of Dynamical Systems and Passivity	39
2.2.1	$\mathcal{L}_2$ Stability	39
2.2.2	Lyapunov Stability	41
2.3	Passivity-Based Motion Control	45

<b>3</b>	<b>Scattering Variables-Based Control of Bilateral Teleoperators . . .</b>	<b>51</b>
3.1	Introduction . . . . .	51
3.2	The Scattering-Wave Variable-Based Bilateral Teleoperation Architecture . . . . .	51
3.2.1	Control Architecture . . . . .	52
3.2.2	Stability and Tracking Performance of Scattering Variables-Based Bilateral Teleoperators . . . . .	58
3.3	Improving Tracking Performance . . . . .	61
3.4	Experimental Verification. . . . .	66
3.5	Summary and Notes . . . . .	69
<b>4</b>	<b>Synchronization of Bilateral Teleoperators. . . . .</b>	<b>71</b>
4.1	Introduction . . . . .	71
4.2	Passivity and Output Synchronization of Interconnection of Passive Systems . . . . .	72
4.3	Application to Bilateral Teleoperation . . . . .	75
4.3.1	Master-Slave Velocity Synchronization . . . . .	76
4.3.2	Master-Slave State Synchronization. . . . .	78
4.4	Experiments . . . . .	81
4.5	Summary and Notes . . . . .	84

## **Part II Passivity-Based Visual Feedback Control and Estimation**

<b>5</b>	<b>Foundation: Rigid Motions and Image Formation . . . . .</b>	<b>87</b>
5.1	Rigid Body Motions . . . . .	87
5.2	Inherent Passivity in Rigid Body Motion . . . . .	92
5.3	Geometry of Image Formation . . . . .	97
5.3.1	Monocular Camera Model . . . . .	97
5.3.2	Panoramic Camera Model . . . . .	99
<b>6</b>	<b>Passivity-Based Visual Feedback Estimation. . . . .</b>	<b>101</b>
6.1	Introduction . . . . .	101
6.2	Visual Feedback Estimation . . . . .	102
6.2.1	Problem Formulation. . . . .	102
6.2.2	Passivity in Visual Feedback Estimation . . . . .	106
6.2.3	Visual Motion Observer and Stability Analysis. . . . .	110
6.3	Extension to a Panoramic Camera and Verification . . . . .	113
6.3.1	Construction of Estimation Error Vector . . . . .	113
6.3.2	Experimental Verification . . . . .	116
6.4	Visual Motion Observer with Object Motion Model . . . . .	117
6.4.1	Estimation Error System with Object Motion Model . . . . .	119

6.4.2	Visual Motion Observer with Object Motion Model . . . . .	124
6.4.3	Experimental Verification . . . . .	129
6.5	Summary . . . . .	138
<b>7</b>	<b>Passivity-Based Visual Feedback Control . . . . .</b>	<b>139</b>
7.1	Introduction . . . . .	139
7.2	Visual Feedback Control . . . . .	140
7.2.1	Estimation/Control Error System. . . . .	140
7.2.2	Passivity in Visual Feedback Control . . . . .	143
7.3	Dynamic Visual Feedback Control . . . . .	146
7.3.1	Visual Feedback Set-Point Control . . . . .	147
7.3.2	Visual Feedback Tracking Control . . . . .	150
7.3.3	Stability and Tracking Performance Analysis . . . . .	154
7.3.4	Experimental Verification . . . . .	158
7.4	Summary and Notes . . . . .	164

### Part III Passivity-Based Cooperative Control and Estimation

<b>8</b>	<b>Output Synchronization for Network of Passive Systems . . . . .</b>	<b>167</b>
8.1	Introduction . . . . .	167
8.2	Passivity-Based Output Synchronization for a Network of Passive Systems . . . . .	168
8.2.1	Network of Passive Systems. . . . .	168
8.2.2	Output Synchronization with Linear Coupling . . . . .	169
8.2.3	Output Synchronization with Nonlinear Coupling . . . . .	173
8.2.4	Examples and Verification . . . . .	174
8.3	Output Synchronization with Time Delay. . . . .	178
8.3.1	Delay Output Synchronization for a Network of Passive Systems . . . . .	179
8.3.2	Delay Output Synchronization for Systems Feedback Equivalent to Passive Systems . . . . .	180
8.4	Summary and Notes . . . . .	184
<b>9</b>	<b>Attitude Synchronization for Rigid Body Networks . . . . .</b>	<b>185</b>
9.1	Introduction . . . . .	185
9.2	Passivity-Based Attitude Synchronization. . . . .	186
9.2.1	Rigid Body Networks and Attitude Synchronization . . . . .	186
9.2.2	Passivity-Based Attitude Synchronization Law . . . . .	189
9.2.3	Verification . . . . .	191
9.3	Connectivity Analysis . . . . .	196
9.3.1	Algebraic Connectivity . . . . .	196

9.3.2	Brief Connectivity Loss . . . . .	199
9.3.3	Verification . . . . .	200
9.4	Summary and Notes . . . . .	202
<b>10</b>	<b>Pose Synchronization for Rigid Body Networks . . . . .</b>	<b>205</b>
10.1	Introduction . . . . .	205
10.2	Passivity-Based Pose Synchronization . . . . .	206
10.2.1	Passivity-Based Pose Synchronization . . . . .	206
10.2.2	Pose Synchronization with a Virtual Leader . . . . .	209
10.2.3	Pose Synchronization Under Not Strongly Connected Digraphs . . . . .	211
10.2.4	Verification . . . . .	216
10.3	Flocking Algorithm in Three Dimensions. . . . .	226
10.3.1	Alignment Rule . . . . .	228
10.3.2	Separation Rule . . . . .	229
10.3.3	Verification . . . . .	233
10.4	Summary and Notes . . . . .	235
<b>11</b>	<b>Cooperative Estimation for Visual Sensor Networks . . . . .</b>	<b>237</b>
11.1	Introduction . . . . .	237
11.2	Visual Sensor Networks and Average on $SE(3)$ . . . . .	239
11.3	Networked Visual Motion Observers . . . . .	244
11.4	Averaging Performance for Static Object . . . . .	246
11.4.1	Averaging Performance for Static Object . . . . .	247
11.4.2	Verification . . . . .	252
11.5	Averaging Performance for Moving Object . . . . .	255
11.5.1	Motion of Average . . . . .	255
11.5.2	Averaging Performance for Moving Objects . . . . .	259
11.5.3	Verification . . . . .	261
11.6	Summary and Notes . . . . .	269
	<b>Appendix A: Additional Results Related to Lyapunov Theory . . . . .</b>	<b>271</b>
	<b>Appendix B: Basis of Rigid Body Motion . . . . .</b>	<b>273</b>
	<b>Appendix C: Properties of Rotation Matrices . . . . .</b>	<b>287</b>
	<b>Appendix D: Basic Graph Theory . . . . .</b>	<b>291</b>
	<b>Appendix E: Proofs . . . . .</b>	<b>297</b>
	<b>References . . . . .</b>	<b>331</b>
	<b>Index . . . . .</b>	<b>347</b>

Passivity-Based Control and Estimation in Networked  
Robotics

Hatanaka, T.; Chopra, N.; Fujita, M.; Spong, M.W.

2015, X, 349 p. 251 illus., 192 illus. in color., Hardcover

ISBN: 978-3-319-15170-0