

Contents

1	Introduction	1
1.1	Rehabilitation Technologies	1
1.2	Role of Control Systems	3
1.3	Book Structure	4
	References	5
2	Modeling and Identification	7
2.1	Modeling of the Mechanically Supported Human Arm	7
2.1.1	Human Arm Dynamics	8
2.1.2	Muscle Selection and Modeling	8
2.1.3	Mechanical Support	9
2.1.4	Combined Dynamics	10
2.2	Model Identification	12
2.2.1	Muscle Axis Identification	12
2.2.2	Passive Parameter Identification	13
2.2.3	Muscle Identification	14
2.2.4	Multiplicative Muscle Function Identification	15
2.2.5	Case Study: Triceps and Anterior Deltoid with ArmeoSpring	16
2.3	Conclusions	19
	References	19
3	Feedback Control Design	21
3.1	General Feedback Control Framework	22
3.1.1	Stability of Unactuated Joints	23
3.2	Case Study: Input-Output Linearizing Controller	27
3.2.1	Optimal Tracking Controller	30
3.3	Robust Performance	31
3.4	Case Study: Proportional-Integral-Derivative Controller	40
3.5	Conclusions	41
	References	42

4	Iterative Learning Control Design	45
4.1	General ILC Framework	46
4.2	Case Study: ILC Applied to Input-Output Linearized System	53
4.2.1	Test Procedure	54
4.2.2	Experimental Results	55
4.3	Case Study: ILC Applied to Non-linearized System	56
4.3.1	Experimental Results	57
4.4	Robust Performance	59
4.5	Conclusions	72
	References	72
5	Clinical Application: Multiple Sclerosis	75
5.1	System Description and Set-Up	75
5.1.1	Outcome Measures	77
5.2	Results	78
5.2.1	Assisted Tracking Performance	78
5.2.2	Unassisted Tracking Performance	80
5.2.3	Clinical Outcome Measures	81
5.3	Discussion	81
5.4	Conclusions	83
	References	83
6	Constrained ILC for Human Motor Control	85
6.1	Extended Task Representation	85
6.2	Reduced Stimulation and Joint Subspaces	87
6.3	Extended ILC Framework	88
6.4	Robust Performance	95
6.5	Human Motor Control	98
6.5.1	Computational Models of Upper Limb Motion	98
6.5.2	Unimpaired Motion Data Collection	98
6.5.3	Data Analysis	100
6.6	Computational Model Development	101
6.7	Results	102
6.8	Conclusions	107
	References	108
7	Clinical Application: Goal-Orientated Stroke Rehabilitation	111
7.1	System Description and Set-Up	111
7.1.1	Outcome Measures	114
7.2	Results	115
7.2.1	Assisted Tracking Performance	115
7.2.2	Unassisted Tracking Performance	116
7.2.3	Clinical Outcome Measures	117
7.3	Discussion	118
7.4	Conclusions	118
	References	119

8	Electrode Array Control Design	121
8.1	Modeling of a Single Array	121
8.2	General Array Control Framework	122
8.3	Subspace Identification	126
8.3.1	Selection Using Experimental Data	126
8.3.2	Selection Using Structural Knowledge	130
8.3.3	General Stimulation Subspace Identification Procedure	132
8.4	Model Identification	134
8.5	Case Study: Functional Hand and Wrist Motion	135
8.5.1	Unrestricted Stimulation Space	136
8.5.2	Stimulation Subspace	139
8.6	Conclusions	140
	References	140
9	Clinical Application: Fully Functional Stroke Rehabilitation	141
9.1	General Integrated Control Framework	142
9.2	System Description and Set-Up	150
9.2.1	Task Design	151
9.2.2	System Software	151
9.2.3	Motion Tracking	153
9.2.4	Stimulation Hardware	154
9.2.5	Control Design	155
9.3	Results	156
9.3.1	Unimpaired Participants	157
9.3.2	Stroke Participants	159
9.4	Discussion	161
9.5	Conclusions	162
	References	162
10	Conclusions and Future Research Directions	163
10.1	Elimination of Identification and Manual Controller Tuning	164
10.2	Wearable ES Technology	172
10.3	Wider Application Domains and Greater Scope	174
	References	175

Control System Design for Electrical Stimulation in
Upper Limb Rehabilitation

Modelling, Identification and Robust Performance

Freeman, C.

2016, XIII, 176 p., Hardcover

ISBN: 978-3-319-25704-4