

# Contents

<b>1</b>	<b>Introduction to Systems . . . . .</b>	<b>1</b>
1.1	Introduction . . . . .	1
1.2	Some Special Types of Systems . . . . .	3
1.3	Mathematical Description and Analysis of Systems . . . . .	4
1.3.1	Input-Output Description of Systems in Time Domain . . . . .	4
1.3.2	Input-Output Description of Systems in Frequency Domain . . . . .	7
1.3.3	State Space Description of Systems . . . . .	8
1.4	Some Important System Properties . . . . .	14
1.5	Stability . . . . .	15
1.5.1	BIBO Stability . . . . .	15
1.5.2	Lyapunov Stability . . . . .	17
1.6	Exercises . . . . .	19
<b>2</b>	<b>Modeling and Identification . . . . .</b>	<b>23</b>
2.1	Introduction . . . . .	23
2.2	What Is a Model? . . . . .	24
2.3	Modeling Process . . . . .	31
2.3.1	Inverted Pendulum . . . . .	31
2.3.2	Stock Prices . . . . .	33
2.3.3	Lessons Learned . . . . .	36
2.4	Parameter Identification . . . . .	37
2.5	Model Validation . . . . .	38
2.6	Summary . . . . .	39
2.7	Exercises . . . . .	41
<b>3</b>	<b>The Human Operator . . . . .</b>	<b>45</b>
3.1	Introduction . . . . .	45
3.2	Types of Manual Control Systems . . . . .	51
3.3	Human Operator Models . . . . .	53
3.3.1	Second Order Linear Model . . . . .	53
3.3.2	Describing Function Model . . . . .	54

3.3.3 Optimal Control Model . . . . .	54
3.4 Exercises . . . . .	58
<b>4 Drug Administration and Dosage Optimization . . . . .</b>	<b>61</b>
4.1 Introduction . . . . .	61
4.2 Optimization of Drug Delivery Based on Pharmacokinetic Data . . . . .	64
4.2.1 Modeling Pharmacokinetic Relationships . . . . .	65
4.2.2 The Multiple Dosing Problem . . . . .	66
4.2.3 Linear Programming Solutions of the Multiple Dosing Problem . . . . .	68
4.2.4 Solution of the Multiple Dosing Problem with a Quadratic Objective Function . . . . .	83
4.2.5 Semi-analytical Solution of the Multiple Dosing Problem . . . . .	86
4.2.6 Optimization of Drug Administration By a Tauberian Approach . . . . .	88
4.2.7 Remarks on Pharmacokinetic Optimization . . . . .	92
4.3 Optimization of Drug Delivery Based on Pharmacodynamic Data . . . . .	95
4.4 Exercises . . . . .	97
<b>5 Parkinson's Disease . . . . .</b>	<b>99</b>
5.1 Introduction . . . . .	99
5.2 Etiology . . . . .	99
5.3 Pathophysiology . . . . .	101
5.4 Symptoms . . . . .	103
5.5 Treatment . . . . .	104
5.6 Measuring Parkinsonian Symptoms . . . . .	106
5.6.1 Measuring Tremor . . . . .	109
5.6.2 Measuring Bradykinesia . . . . .	112
5.6.3 Low-Tech Approach . . . . .	115
5.7 Dosage Optimization in Parkinson's Disease . . . . .	116
5.7.1 Parkinson Patients Are Poor Controllers . . . . .	117
5.7.2 Modeling the Effects of Levodopa on Parkinson Symptoms . . . . .	121
5.8 Optimal Control of Levodopa Therapy . . . . .	127
5.9 A Case Study . . . . .	130
5.10 Summary . . . . .	133
5.11 Exercises . . . . .	134
<b>6 Diabetes and Control of Blood Glucose . . . . .</b>	<b>137</b>
6.1 Introduction . . . . .	137
6.2 Measuring Blood Glucose Levels . . . . .	141
6.2.1 Invasive Techniques . . . . .	141
6.2.2 Minimally-Invasive Techniques . . . . .	142

6.2.3	Non-invasive Techniques . . . . .	145
6.2.4	Clarke's Error Grid Analysis . . . . .	146
6.3	Insulin Delivery . . . . .	148
6.4	Patient Dynamics . . . . .	149
6.4.1	Mathematical Models . . . . .	152
6.5	The Controller . . . . .	159
6.5.1	Rule Based Control . . . . .	159
6.5.2	Model Based Control Algorithms . . . . .	161
6.6	Commercial Insulin Pumps . . . . .	164
6.6.1	Accu-Chek® . . . . .	165
6.7	Exercises . . . . .	172
<b>7</b>	<b>Controlling Depth of Anaesthesia . . . . .</b>	<b>175</b>
7.1	Introduction . . . . .	175
7.2	Measuring Depth of Anaesthesia . . . . .	175
7.3	Anaesthetic Agents . . . . .	176
7.4	The Basic Control Loop . . . . .	177
7.5	Fuzzy Control of Anaesthesia . . . . .	178
7.6	Multivariable Control of Anaesthesia . . . . .	182
7.7	Implementation of the Multivariable Controller . . . . .	184
7.8	The Patient Model . . . . .	185
7.9	The Breathing System . . . . .	194
7.10	Surgical Stimulation . . . . .	204
7.11	Model Integration . . . . .	210
7.12	Controller Design and Implementation . . . . .	213
7.12.1	Observer Based State Feedback Controller with Reference Tracking . . . . .	213
7.12.2	Artifact Handling . . . . .	215
7.12.3	Implementation . . . . .	216
7.13	Exercises . . . . .	218
<b>Appendix A</b>	<b>Optimal Control . . . . .</b>	<b>219</b>
A.1	Introduction . . . . .	219
A.2	Calculus of Variations . . . . .	220
A.2.1	Subject Matter . . . . .	220
A.2.2	Fixed Endpoint Problem . . . . .	221
A.2.3	Variable Endpoint Problem . . . . .	222
A.2.4	Variation Problem with Constraints . . . . .	224
A.3	Optimal Dynamic Systems . . . . .	224
A.3.1	Fixed Endpoint Problem . . . . .	224
A.3.2	Variable Endpoint Problem . . . . .	227
A.3.3	Generalized Objective Function . . . . .	229
A.4	Pontryagin's Minimum Principle . . . . .	230
A.5	Hamilton-Jacobi Method . . . . .	233
A.6	Optimal Control of Linear Systems . . . . .	237

A.6.1 Riccati Equation .....	237
A.6.2 Optimal Control When Not All States Are Measurable .....	241
A.6.3 Dynamic Programming .....	243
<b>Appendix B Fuzzy Logic Control .....</b>	<b>247</b>
B.1 Fuzzy Logic Architecture .....	247
B.1.1 Membership Functions .....	248
B.1.2 Fuzzification .....	250
B.1.3 Fuzzy Rule Base .....	251
B.1.4 Inference Engine .....	251
B.1.5 Defuzzification .....	252
B.2 Fuzzy Logic Toolbox of MATLAB .....	253
B.3 Application: Fuzzy Control of a System .....	254
<b>References .....</b>	<b>259</b>