

Contents

Preface — V

1	Simulink and system simulation — 1
1.1	An introduction to system simulation techniques — 1
1.2	Mathematical modeling versus physical modeling — 2
1.3	Introduction to the development of simulation tools — 5
1.3.1	Analog and mixed computer simulation — 5
1.3.2	Simulation languages on digital computers — 6
1.3.3	Object-oriented simulation language — 8
1.3.4	The development of MATLAB and Simulink — 8
1.4	Main structure and comments of the book — 9
1.4.1	Main structure of the book — 9
1.4.2	Comments on the typesetting — 11
1.5	Exercises — 12
2	Commonly used blocks in Simulink — 13
2.1	Invoke the Simulink environment — 13
2.1.1	Invoke Simulink with interface — 14
2.1.2	Invoke Simulink with MATLAB commands — 16
2.1.3	Signals and ports — 18
2.2	Input and output groups — 18
2.2.1	Input signal group — 18
2.2.2	Signal builder interface — 23
2.2.3	Output sinks group — 24
2.2.4	Dashboard group — 26
2.3	System groups — 28
2.3.1	Linear continuous group — 29
2.3.2	Linear discrete group — 32
2.3.3	Discontinuities group — 33
2.4	Mathematical operations and manipulating groups — 35
2.4.1	Mathematical operations group — 35
2.4.2	User-defined functions group — 37
2.4.3	Lookup table group — 39
2.4.4	Logic and bit operations group — 39
2.5	Signal manipulation groups — 40
2.5.1	Signal routing group — 40
2.5.2	Signal attribute group — 42
2.5.3	Ports and subsystems group — 42
2.6	Simulink toolboxes and blocksets — 43
2.7	Exercises — 44

3	Block manipulation and menu systems — 47
3.1	Simple manipulation and decoration of blocks — 47
3.1.1	Shortcut menus — 47
3.1.2	Copying and moving blocks — 48
3.1.3	Font setting in blocks — 50
3.1.4	Linking blocks — 50
3.1.5	Rotating and flipping blocks — 51
3.1.6	Color and shading setting of blocks — 52
3.2	Modifying block parameters — 54
3.2.1	Commonly used controls in dialog boxes — 55
3.2.2	Filling information in dialog boxes — 57
3.3	Menu systems in earlier versions of Simulink — 59
3.3.1	File management menus — 59
3.3.2	Edit, view and display menus — 63
3.3.3	Model manipulation menus — 65
3.3.4	Setting menus for simulation parameters — 66
3.3.5	Analysis tool menus — 68
3.4	Toolbar and menu systems in new versions — 70
3.4.1	Simulation parameters and setting — 71
3.4.2	Model debugging — 72
3.4.3	Model creation and parameter setting — 74
3.4.4	Format setting — 75
3.4.5	Calling APPs — 75
3.5	Manipulation interface of model browser — 76
3.6	Exercises — 78
4	Modeling and simulation of ordinary differential equations — 79
4.1	Template design in Simulink — 79
4.1.1	General rules in ODE modeling — 80
4.1.2	Block diagram model of a simple ODE — 80
4.1.3	Template design for the new model — 82
4.1.4	Terminating conditions in simulation — 85
4.1.5	Zero-crossing detection — 86
4.2	Modeling of first-order explicit ODEs — 88
4.2.1	Defining and generating key signals — 89
4.2.2	Numerical solution validation and control parameter setting — 91
4.2.3	Vectorized modeling methods — 94
4.2.4	A general framework for first-order explicit ODEs — 95
4.2.5	Model framework for first-order time-varying explicit ODEs — 98
4.3	Modeling of high-order ODEs — 99
4.3.1	Defining key signals — 100
4.3.2	Modeling of high-order linear ODEs — 101

4.3.3	Transfer function model for constant linear ODEs —	105
4.3.4	Modeling of high-order nonlinear ODEs —	108
4.3.5	Modeling of implicit ODEs —	109
4.3.6	Modeling of discontinuous ODEs —	112
4.4	Modeling of high-order ODE sets —	114
4.4.1	Modeling methodologies of ODEs —	114
4.4.2	Solutions of ODEs —	116
4.4.3	Solutions of delay differential equations —	117
4.4.4	Neutral-type delay differential equations —	120
4.4.5	Switched ODEs —	121
4.4.6	ODEs with stochastic inputs —	123
4.5	Modeling and solving fractional-order ODEs —	126
4.5.1	An introduction to fractional calculus —	126
4.5.2	Approximating fractional-order operators —	127
4.5.3	Solving fractional-order ODEs —	130
4.6	Model of difference equations —	133
4.7	Exercises —	137
5	Simulink modeling of control systems —	145
5.1	Simulink modeling of linear continuous systems —	145
5.1.1	Transfer function models —	146
5.1.2	State space models —	147
5.1.3	Linear singular state space models —	148
5.1.4	Transfer functions with nonzero initial conditions —	151
5.1.5	Simulink modeling of transfer function matrices —	157
5.1.6	Simulink models with varying parameters —	160
5.2	Modeling and simulation of linear discrete systems —	160
5.2.1	Mathematical models of linear discrete systems —	161
5.2.2	Conversions between continuous and discrete models —	162
5.2.3	Simulink modeling of discrete systems —	163
5.2.4	Impact of simulation control parameters —	165
5.2.5	Impact of discrete parameter precisions —	166
5.3	Simulink modeling of nonlinear components —	167
5.3.1	Lookup table blocks —	168
5.3.2	Construction of single-valued nonlinearities —	169
5.3.3	Construction of double-valued nonlinearities —	170
5.3.4	Multidimensional lookup table blocks —	173
5.4	Automatic sorting of Simulink blocks —	175
5.5	Approximate analysis of nonlinear control systems —	178
5.5.1	Padé approximation of delay systems —	178
5.5.2	Linearization of Simulink models —	180
5.5.3	Algebraic loop phenomenon and elimination —	186
5.6	Exercises —	191

6	Subsystems and block masking — 197
6.1	Subsystem modeling — 197
6.1.1	Construction and extraction of subsystems — 198
6.1.2	Setting format in crossing lines — 200
6.1.3	Embedding Simulink models — 202
6.2	Complicated flow control subsystems — 204
6.2.1	Enabled and triggered subsystems — 204
6.2.2	Conditional subsystems — 207
6.2.3	Other flow control subsystems — 209
6.3	Block masking — 210
6.3.1	Icon design — 211
6.3.2	Design and decoration of other icon properties — 215
6.3.3	Parameter dialog box design — 215
6.3.4	Callback function for controls — 222
6.3.5	Initialization of mask blocks — 223
6.3.6	Document and help information — 224
6.3.7	Block masking examples — 225
6.3.8	Canceling mask status — 227
6.4	Drawing Simulink models with commands — 228
6.4.1	Create a blank Simulink model — 228
6.4.2	Copying blocks — 231
6.4.3	Linking blocks — 232
6.4.4	Filling block parameters — 234
6.4.5	Modeling examples — 236
6.4.6	Masking blocks with MATLAB commands — 239
6.5	Control simulation processes with MATLAB commands — 241
6.5.1	Invoke simulation process with MATLAB commands — 242
6.5.2	Setting control parameters — 243
6.5.3	Input and output data structures in Simulink models — 244
6.5.4	Parallel simulation — 247
6.6	Exercises — 249
7	Programming implementations of Simulink blocks — 251
7.1	M-function blocks and implementation — 251
7.1.1	Static nonlinearities — 252
7.1.2	Limitations in M-function blocks — 254
7.2	Programming of S-functions — 254
7.2.1	State space models — 255
7.2.2	Fundamental structures of S-functions — 255
7.2.3	Response functions in S-functions — 257
7.2.4	Execution mechanism of S-functions — 258
7.2.5	Writing S-functions with examples — 258

7.2.6	Masking S-function blocks —	267
7.2.7	Level-2 S-functions —	269
7.3	Programming S-functions with C —	271
7.3.1	C compiler setting —	272
7.3.2	Examples in S-functions —	272
7.4	Programming practice of S-functions – active disturbance rejection controllers —	274
7.4.1	Modeling of extended state observers —	275
7.4.2	Modeling of ADRC controllers —	276
7.4.3	Simulation of ADRC systems —	277
7.5	Exercises —	280
8	Promising combinations of Simulink and numerical optimization techniques —	283
8.1	Boundary value problems in ODEs —	284
8.1.1	Shooting algorithms in boundary value problems —	285
8.1.2	Converting shooting methods into optimization problems —	286
8.1.3	Examples of simple boundary value problems —	286
8.1.4	Fast restart mode of Simulink models —	290
8.1.5	Boundary value problems with parameters —	291
8.1.6	Solutions of multiple-point problems —	293
8.1.7	Boundary value problems of fractional-order ODEs —	295
8.1.8	Boundary value problems of delay differential equations —	296
8.1.9	Global optimum solutions —	298
8.2	APP interface design —	301
8.3	Design of optimum controllers —	307
8.3.1	Hidden problems in classical optimal control methods —	307
8.3.2	Performance indices and optimum design in servo control systems —	312
8.3.3	Optimal control design interface —	317
8.3.4	Other applications of OCD interface —	322
8.3.5	Open framework of the program —	323
8.3.6	PID-type controllers – the best second-order controller? —	323
8.4	OptimPID – optimal PID controller design APP —	326
8.4.1	Low-level simulation model of the control systems —	326
8.4.2	OptimPID APP examples —	327
8.4.3	Open frameworks and extensions —	331
8.5	Exercises —	331
9	Processing and simulation of multimedia information —	335
9.1	Input and output of audio information —	335
9.1.1	Introduction to Audio System Toolbox —	336

9.1.2	Input and output of audio information —	336
9.1.3	Data structure of audio signals —	341
9.1.4	Audio input and output with MATLAB commands —	341
9.2	Audio signals processing —	345
9.2.1	Audio signal filtering —	345
9.2.2	Dynamic range control —	347
9.2.3	Audio effect processing —	350
9.2.4	Detection of audio information —	351
9.3	Video information processing and Computer Vision Toolbox —	353
9.4	Input and output of images and videos —	355
9.4.1	Reading of images and videos —	355
9.4.2	Display and output of images and videos —	356
9.4.3	Video play with commands —	357
9.5	Simple transformation of images —	359
9.5.1	Color space representation of images —	359
9.5.2	Color space conversion —	360
9.5.3	Geometric transformation of images —	363
9.5.4	Gamma correction of images —	363
9.5.5	Frequency domain transform and filters —	365
9.6	Image Analysis and Enhancement —	366
9.6.1	Histogram equalization —	366
9.6.2	Edge detection —	370
9.6.3	Morphological processing —	372
9.6.4	Real-time video processing —	375
9.7	Exercises —	376
10	Modeling and simulation of engineering systems —	377
10.1	Introduction to physical modeling blockset Simscape —	377
10.1.1	Limitations in mathematical modeling methods —	378
10.1.2	Simscape introduction —	380
10.1.3	Foundation library in Simscape —	381
10.1.4	Conversions of two types of signals —	385
10.1.5	Creating simple Simscape models —	386
10.1.6	Modeling and simulation of complicated electric networks —	389
10.2	Introduction to electric system blockset —	391
10.2.1	Electrical sources —	392
10.2.2	Electrical sensors —	392
10.2.3	Electric and electronic elements —	393
10.2.4	Electromechanical blocks —	394
10.3	Modeling and simulation of electrical systems —	396
10.3.1	Simulation of electronic circuits —	396
10.3.2	Simulation of circuits with operational amplifiers —	398

10.3.3	Simulation examples in digital electronic circuits —	401
10.4	Modeling and simulation of mechanical systems —	406
10.4.1	Simulation of simple mechanical systems —	406
10.4.2	Introduction to Multibody blockset —	409
10.4.3	Modeling and simulation of four-bar mechanisms —	412
10.5	Exercises —	414
11	Simulation of nonengineering systems —	419
11.1	Modeling and simulation in pharmacokinetics —	419
11.1.1	Introduction to pharmacokinetics —	419
11.1.2	Compartment models in pharmacokinetics —	420
11.1.3	Wada models with transport delays —	423
11.1.4	Pharmacokinetics toolbox and Simulink models —	425
11.1.5	Mapleson models and code —	426
11.1.6	Pharmacodynamic modeling —	431
11.2	Finite state machine simulations with Stateflow —	432
11.2.1	Introduction of finite state machines —	432
11.2.2	Introduction to Stateflow —	433
11.2.3	Commonly used commands in Stateflow —	437
11.2.4	Stateflow modeling examples —	437
11.2.5	Draw control flow chart with Stateflow —	443
11.3	Simulation of discrete event systems with SimEvents —	444
11.3.1	Fundamental concepts in discrete event dynamical systems —	444
11.3.2	Introduction to SimEvents blockset —	445
11.3.3	Simulation demonstration of discrete event systems —	445
11.4	Exercises —	451
Bibliography —		453
MATLAB function index —		457
Index —		461