

# CONTENTS

## PART I: EMBEDDED SYSTEMS

1	Robots and Controllers	3
1.1	Mobile Robots	4
1.2	Embedded Controllers	7
1.3	Interfaces	10
1.4	Operating System	13
1.5	References	15
2	Central Processing Unit	17
2.1	Logic Gates	18
2.2	Function Units	23
2.3	Registers and Memory	28
2.4	Retro	30
2.5	Arithmetic Logic Unit	32
2.6	Control Unit	34
2.7	Central Processing Unit	35
2.8	References	47
3	Sensors	49
3.1	Sensor Categories	50
3.2	Binary Sensor	51
3.3	Analog versus Digital Sensors	51
3.4	Shaft Encoder	52
3.5	A/D Converter	54
3.6	Position Sensitive Device	55
3.7	Compass	57
3.8	Gyroscope, Accelerometer, Inclinometer	59
3.9	Digital Camera	62
3.10	References	70
4	Actuators	73
4.1	DC Motors	73
4.2	H-Bridge	76
4.3	Pulse Width Modulation	78
4.4	Stepper Motors	80
4.5	Servos	81
4.6	References	82

## Contents

5	Control	83
5.1	On-Off Control	83
5.2	PID Control	89
5.3	Velocity Control and Position Control	94
5.4	Multiple Motors – Driving Straight	96
5.5	V-Omega Interface	98
5.6	References	101
6	Multitasking	103
6.1	Cooperative Multitasking	103
6.2	Preemptive Multitasking	105
6.3	Synchronization	107
6.4	Scheduling	111
6.5	Interrupts and Timer-Activated Tasks	114
6.6	References	116
7	Wireless Communication	117
7.1	Communication Model	118
7.2	Messages	120
7.3	Fault-Tolerant Self-Configuration	121
7.4	User Interface and Remote Control	123
7.5	Sample Application Program	126
7.6	References	127

## PART II: MOBILE ROBOT DESIGN

8	Driving Robots	131
8.1	Single Wheel Drive	131
8.2	Differential Drive	132
8.3	Tracked Robots	136
8.4	Synchro-Drive	137
8.5	Ackermann Steering	139
8.6	Drive Kinematics	141
8.7	References	145
9	Omni-Directional Robots	147
9.1	Mecanum Wheels	147
9.2	Omni-Directional Drive	149
9.3	Kinematics	151
9.4	Omni-Directional Robot Design	152
9.5	Driving Program	154
9.6	References	155
10	Balancing Robots	157
10.1	Simulation	157
10.2	Inverted Pendulum Robot	158
10.3	Double Inverted Pendulum	162
10.4	References	163

## Contents

11	Walking Robots	165
11.1	Six-Legged Robot Design	165
11.2	Biped Robot Design	168
11.3	Sensors for Walking Robots	172
11.4	Static Balance	174
11.5	Dynamic Balance	175
11.6	References	182
12	Autonomous Planes	185
12.1	Application	185
12.2	Control System and Sensors	188
12.3	Flight Program	189
12.4	References	192
13	Autonomous Vessels and Underwater Vehicles	195
13.1	Application	195
13.2	Dynamic Model	197
13.3	AUV Design Mako	197
13.4	AUV Design USAL	201
13.5	References	204
14	Robot Manipulators	205
14.1	Homogeneous Coordinates	206
14.2	Kinematics	207
14.3	Simulation and Programming	212
14.4	References	213
15	Simulation Systems	215
15.1	Mobile Robot Simulation	215
15.2	EyeSim Simulation System	216
15.3	Multiple Robot Simulation	221
15.4	EyeSim Application	222
15.5	EyeSim Environment and Parameter Files	223
15.6	SubSim Simulation System	228
15.7	Actuator and Sensor Models	230
15.8	SubSim Application	232
15.9	SubSim Environment and Parameter Files	234
15.10	References	237

## PART III: MOBILE ROBOT APPLICATIONS

16	Localization and Navigation	241
16.1	Localization	241
16.2	Probabilistic Localization	245
16.3	Coordinate Systems	249
16.4	Environment Representation	251
16.5	Visibility Graph	253
16.6	Voronoi Diagram	255
16.7	Potential Field Method	258

## Contents

16.8	Wandering Standpoint Algorithm	259
16.9	Bug Algorithm Family	260
16.10	Dijkstra's Algorithm	263
16.11	A* Algorithm	267
16.12	References	268
17	Maze Exploration	271
17.1	Micro Mouse Contest	271
17.2	Maze Exploration Algorithms	273
17.3	Simulated versus Real Maze Program	281
17.4	References	282
18	Map Generation	283
18.1	Mapping Algorithm	283
18.2	Data Representation	285
18.3	Boundary-Following Algorithm	286
18.4	Algorithm Execution	287
18.5	Simulation Experiments	289
18.6	Robot Experiments	290
18.7	Results	293
18.8	References	294
19	Real-Time Image Processing	297
19.1	Camera Interface	297
19.2	Auto-Brightness	299
19.3	Edge Detection	300
19.4	Motion Detection	302
19.5	Color Space	303
19.6	Color Object Detection	305
19.7	Image Segmentation	310
19.8	Image Coordinates versus World Coordinates	312
19.9	References	314
20	Robot Soccer	317
20.1	RoboCup and FIRA Competitions	317
20.2	Team Structure	320
20.3	Mechanics and Actuators	321
20.4	Sensing	321
20.5	Image Processing	323
20.6	Trajectory Planning	325
20.7	References	330
21	Neural Networks	331
21.1	Neural Network Principles	331
21.2	Feed-Forward Networks	332
21.3	Backpropagation	337
21.4	Neural Network Examples	342
21.5	Neural Controller	343
21.6	References	344

## Contents

22	Genetic Algorithms	347
22.1	Genetic Algorithm Principles	348
22.2	Genetic Operators	350
22.3	Applications to Robot Control	352
22.4	Example Evolution	353
22.5	Implementation of Genetic Algorithms	357
22.6	Starman	361
22.7	References	363
23	Genetic Programming	365
23.1	Concepts and Applications	365
23.2	Lisp	367
23.3	Genetic Operators	371
23.4	Evolution	373
23.5	Tracking Problem	374
23.6	Evolution of Tracking Behavior	377
23.7	References	381
24	Behavior-Based Systems	383
24.1	Software Architecture	383
24.2	Behavior-Based Robotics	384
24.3	Behavior-Based Applications	387
24.4	Behavior Framework	388
24.5	Adaptive Controller	391
24.6	Tracking Problem	395
24.7	Neural Network Controller	396
24.8	Experiments	398
24.9	References	400
25	Evolution of Walking Gaits	403
25.1	Splines	403
25.2	Control Algorithm	404
25.3	Incorporating Feedback	406
25.4	Controller Evolution	407
25.5	Controller Assessment	409
25.6	Evolved Gaits	410
25.7	References	413
26	Automotive Systems	415
26.1	Autonomous Automobiles	415
26.2	Automobile Conversion for Autonomous Driving	418
26.3	Computer Vision for Driver-Assistance Systems	420
26.4	Image Processing Framework	421
26.5	Lane Detection	422
26.6	Vehicle Recognition and Tracking	429
26.7	Automatic Parking	433
26.8	References	436
27	Outlook	439

## Contents

### APPENDICES

A	Programming Tools	443
B	RoBIOS Operating System	453
C	Hardware Description Table	495
D	Hardware Specification	511
E	Laboratories	519
F	Solutions	529
	Index	533