

# 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

**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