
Contents

List of Figures	xiii
Preface	xix
Acknowledgements	xxv
Author	xxvii

SECTION I ROS Foundations

CHAPTER	1 ■ Introduction to ROS: ROS tools and nodes	5
1.1	SOME ROS CONCEPTS	5
1.2	WRITING ROS NODES	8
1.2.1	Creating ROS packages	9
1.2.2	Writing a minimal ROS publisher	11
1.2.3	Compiling ROS nodes	14
1.2.4	Running ROS nodes	15
1.2.5	Examining running minimal publisher node	16
1.2.6	Scheduling node timing	18
1.2.7	Writing a minimal ROS subscriber	20
1.2.8	Compiling and running minimal subscriber	22
1.2.9	Minimal subscriber and publisher node summary	23
1.3	MORE ROS TOOLS: CATKIN_SIMPLE, ROSLAUNCH, RQT_CONSOLE, AND ROSBAG	24
1.3.1	Simplifying CMakeLists.txt with catkin.simple	24
1.3.2	Automating starting multiple nodes	26
1.3.3	Viewing output in a ROS console	27
1.3.4	Recording and playing back data with rosbag	28
1.4	MINIMAL SIMULATOR AND CONTROLLER EXAMPLE	30
1.5	WRAP-UP	35
CHAPTER	2 ■ Messages, Classes and Servers	37
2.1	DEFINING CUSTOM MESSAGES	38

2.1.1	Defining a custom message	38
2.1.2	Defining a variable-length message	42
2.2	INTRODUCTION TO ROS SERVICES	47
2.2.1	Service messages	47
2.2.2	ROS service nodes	49
2.2.3	Manual interaction with ROS services	51
2.2.4	Example ROS service client	52
2.2.5	Running example service and client	53
2.3	USING C++ CLASSES IN ROS	54
2.4	CREATING LIBRARY MODULES IN ROS	60
2.5	INTRODUCTION TO ACTION SERVERS AND ACTION CLIENTS	64
2.5.1	Creating an action server package	65
2.5.2	Defining custom action-server messages	66
2.5.3	Designing an action client	72
2.5.4	Running the example code	75
2.6	INTRODUCTION TO PARAMETER SERVER	84
2.7	WRAP-UP	88

SECTION II Simulation and Visualization in ROS

CHAPTER	3 ■ Simulation in ROS	95
3.1	SIMPLE TWO-DIMENSIONAL ROBOT SIMULATOR	95
3.2	MODELING FOR DYNAMIC SIMULATION	103
3.3	UNIFIED ROBOT DESCRIPTION FORMAT	105
3.3.1	Kinematic model	105
3.3.2	Visual model	108
3.3.3	Dynamic model	109
3.3.4	Collision model	112
3.4	INTRODUCTION TO GAZEBO	114
3.5	MINIMAL JOINT CONTROLLER	122
3.6	USING GAZEBO PLUG-IN FOR JOINT SERVO CONTROL	127
3.7	BUILDING MOBILE-ROBOT MODEL	133
3.8	SIMULATING MOBILE-ROBOT MODEL	141
3.9	COMBINING ROBOT MODELS	145
3.10	WRAP-UP	148
CHAPTER	4 ■ Coordinate Transforms in ROS	153
4.1	INTRODUCTION TO COORDINATE TRANSFORMS IN ROS	153
4.2	TRANSFORM LISTENER	161
4.3	USING EIGEN LIBRARY	168

4.4	TRANSFORMING ROS DATATYPES	173
4.5	WRAP-UP	174
CHAPTER	5 ■ Sensing and Visualization in ROS	177
5.1	MARKERS AND INTERACTIVE MARKERS IN RVIZ	181
5.1.1	Markers in rviz	182
5.1.2	Triad display example	185
5.1.3	Interactive markers in rviz	191
5.2	DISPLAYING SENSOR VALUES IN RVIZ	199
5.2.1	Simulating and displaying LIDAR	199
5.2.2	Simulating and displaying color-camera data	205
5.2.3	Simulating and displaying depth-camera data	209
5.2.4	Selection of points in rviz	214
5.3	WRAP-UP	217
 SECTION III Perceptual Processing in ROS		
CHAPTER	6 ■ Using Cameras in ROS	223
6.1	PROJECTIVE TRANSFORMATION INTO CAMERA COORDINATES	223
6.2	INTRINSIC CAMERA CALIBRATION	225
6.3	INTRINSIC CALIBRATION OF STEREO CAMERAS	231
6.4	USING OPENCV WITH ROS	237
6.4.1	Example OpenCV: finding colored pixels	238
6.4.2	Example OpenCV: finding edges	243
6.5	WRAP-UP	245
CHAPTER	7 ■ Depth Imaging and Point Clouds	247
7.1	DEPTH FROM SCANNING LIDAR	247
7.2	DEPTH FROM STEREO CAMERAS	252
7.3	DEPTH CAMERAS	258
7.4	WRAP-UP	259
CHAPTER	8 ■ Point Cloud Processing	261
8.1	SIMPLE POINT-CLOUD DISPLAY NODE	261
8.2	LOADING AND DISPLAYING POINT-CLOUD IMAGES FROM DISK	266
8.3	SAVING PUBLISHED POINT-CLOUD IMAGES TO DISK	269
8.4	INTERPRETING POINT-CLOUD IMAGES WITH PCL METHODS	271
8.5	OBJECT FINDER	280
8.6	WRAP-UP	284

SECTION IV Mobile Robots in ROS

CHAPTER	9 ■ Mobile-Robot Motion Control	289
9.1	DESIRED STATE GENERATION	290
9.1.1	From paths to trajectories	290
9.1.2	A trajectory builder library	294
9.1.3	Open-loop control	299
9.1.4	Desired state publishing	300
9.2	ROBOT STATE ESTIMATION	308
9.2.1	Getting model state from Gazebo	308
9.2.2	Odometry	311
9.2.3	Combining odometry, GPS and inertial sensing	319
9.2.4	Combining odometry and LIDAR	325
9.3	DIFFERENTIAL-DRIVE STEERING ALGORITHMS	330
9.3.1	Robot motion model	331
9.3.2	Linear steering of a linear robot	332
9.3.3	Linear steering of a non-linear robot	332
9.3.4	Non-linear steering of a non-linear robot	333
9.3.5	Simulating non-linear steering algorithm	336
9.4	STEERING WITH RESPECT TO MAP COORDINATES	340
9.5	WRAP-UP	345
CHAPTER	10 ■ Mobile-Robot Navigation	347
10.1	MAP MAKING	347
10.2	PATH PLANNING	353
10.3	EXAMPLE MOVE-BASE CLIENT	358
10.4	MODIFYING NAVIGATION STACK	360
10.5	WRAP-UP	364

SECTION V Robot Arms in ROS

CHAPTER	11 ■ Low-Level Control	371
11.1	A ONE-DOF PRISMATIC-JOINT ROBOT MODEL	371
11.2	EXAMPLE POSITION CONTROLLER	372
11.3	EXAMPLE VELOCITY CONTROLLER	375
11.4	EXAMPLE FORCE CONTROLLER	377
11.5	TRAJECTORY MESSAGES FOR ROBOT ARMS	381
11.6	TRAJECTORY INTERPOLATION ACTION SERVER FOR A SEVEN-DOF ARM	386
11.7	WRAP-UP	386

CHAPTER 12 ■ Robot Arm Kinematics	389
12.1 FORWARD KINEMATICS	390
12.2 INVERSE KINEMATICS	394
12.3 WRAP-UP	399
CHAPTER 13 ■ Arm Motion Planning	401
13.1 CARTESIAN MOTION PLANNING	402
13.2 DYNAMIC PROGRAMMING FOR JOINT-SPACE PLANNING	403
13.3 CARTESIAN-MOTION ACTION SERVERS	408
13.4 WRAP-UP	412
CHAPTER 14 ■ Arm Control with Baxter Simulator	413
14.1 RUNNING BAXTER SIMULATOR	413
14.2 BAXTER JOINTS AND TOPICS	415
14.3 BAXTER'S GRIPPERS	418
14.4 HEAD PAN CONTROL	421
14.5 COMMANDING BAXTER JOINTS	422
14.6 USING ROS JOINT TRAJECTORY CONTROLLER	425
14.7 JOINT-SPACE RECORD AND PLAYBACK NODES	426
14.8 BAXTER KINEMATICS	432
14.9 BAXTER CARTESIAN MOVES	434
14.10 WRAP-UP	438
CHAPTER 15 ■ An Object-Grabber Package	441
15.1 OBJECT-GRABBER CODE ORGANIZATION	441
15.2 OBJECT MANIPULATION QUERY SERVICE	443
15.3 GENERIC GRIPPER SERVICES	447
15.4 OBJECT-GRABBER ACTION SERVER	449
15.5 EXAMPLE OBJECT-GRABBER ACTION CLIENT	452
15.6 WRAP-UP	464

SECTION VI System Integration and Higher Level Control

CHAPTER 16 ■ Perception-Based Manipulation	469
16.1 EXTRINSIC CAMERA CALIBRATION	469
16.2 INTEGRATED PERCEPTION AND MANIPULATION	472
16.3 WRAP-UP	480
CHAPTER 17 ■ Mobile Manipulation	481
17.1 MOBILE MANIPULATOR MODEL	481

17.2	MOBILE MANIPULATION	482
17.3	WRAP-UP	486
CHAPTER 18	■ Conclusion	487
	Bibliography	491
	Index	495