



# The Duckiebook

..



The last version of this book and other documents are available at the URL

<http://book.duckietown.org/>

[Google search the documentation](#) (with some delay, for Google to index the pages)

# TABLE OF CONTENTS



<b>Part 1 - The Duckietown project .....</b>	<b>13</b>
<b>Chapter 1 - What is Duckietown?.....</b>	<b>14</b>
Section 1.1 - Goals and objectives.....	14
Section 1.2 - Learn about the Duckietown educational experience.....	14
Section 1.3 - Learn about the platform.....	14
<b>Chapter 2 - Duckietown history and future.....</b>	<b>16</b>
Section 2.1 - The beginnings of Duckietown .....	16
Section 2.2 - University-level classes in 2016.....	17
Section 2.3 - University-level classes in 2017.....	17
Section 2.4 - Chile.....	18
Section 2.5 - Duckietown High School.....	18
<b>Chapter 3 - Duckietown classes .....</b>	<b>19</b>
Section 3.1 - 2016.....	19
Section 3.2 - 2017.....	20
<b>Chapter 4 - First steps .....</b>	<b>22</b>
Section 4.1 - How to get started .....	22
Section 4.2 - Duckietown for instructors .....	22
Section 4.3 - Duckietown for self-guided learners .....	22
Section 4.4 - Introduction for companies .....	22
Section 4.5 - How to keep in touch .....	22
Section 4.6 - How to contribute .....	22
Section 4.7 - Frequently Asked Questions .....	22
<b>Part 2 - Duckumentation documentation .....</b>	<b>24</b>
<b>Chapter 5 - Accounts .....</b>	<b>25</b>
Section 5.1 - Complete list of accounts.....	25
Section 5.2 - For other contributors.....	25
<b>Chapter 6 - Contributing to the documentation .....</b>	<b>26</b>
Section 6.1 - Where the documentation is .....	26
Section 6.2 - Editing links.....	26
Section 6.3 - Comments .....	26
Section 6.4 - Installing the documentation system .....	26
Section 6.5 - Compiling the documentation .....	28
Section 6.6 - Troubleshooting compilation .....	28
Section 6.7 - The workflow to edit documentation .....	29
Section 6.8 - *Deploying the documentation .....	29
Section 6.9 - *Compiling the PDF version .....	29
<b>Chapter 7 - Features of the documentation writing system .....</b>	<b>32</b>
Section 7.1 - Markdown .....	32
Section 7.2 - Embedded LaTeX .....	32
Section 7.3 - LaTeX equations .....	33
Section 7.4 - LaTeX symbols.....	34
Section 7.5 - Variables in command lines and command output .....	34
Section 7.6 - Character escapes .....	35
Section 7.7 - Keyboard keys.....	35
Section 7.8 - Figures .....	35
Section 7.9 - Subfigures.....	36
Section 7.10 - Shortcut for tables .....	37
Section 7.11 - Linking to documentation .....	38
Section 7.12 - Embedding videos .....	39
Section 7.13 - Bibliography .....	40
Section 7.14 - move-here tag .....	40
Section 7.15 - Comments .....	41

Section 7.16 - Special paragraphs tags.....	41
Section 7.17 - Div environments .....	44
Section 7.18 - Referring to Github files .....	45
<b>Chapter 8 - Documentation style guide .....</b>	<b>46</b>
Section 8.1 - General guidelines for technical writing.....	46
Section 8.2 - Style guide for the Duckietown documentation.....	46
Section 8.3 - Writing command lines .....	46
Section 8.4 - Frequently misspelled words .....	47
Section 8.5 - Other conventions.....	47
Section 8.6 - Troubleshooting sections.....	47
<b>Chapter 9 - Knowledge graph .....</b>	<b>49</b>
Section 9.1 - Formalization.....	49
Section 9.2 - Atoms properties .....	50
Section 9.3 - Markdown format for text-like atoms .....	50
Section 9.4 - How to describe the semantic graphs of atoms .....	51
Section 9.5 - How to describe modules .....	51
<b>Chapter 10 - Translations .....</b>	<b>53</b>
Section 10.1 - File organization.....	53
Section 10.2 - Guidelines for English writers .....	53
Section 10.3 - File format.....	53
<b>Part 3 - Operation manual - Duckiebot.....</b>	<b>55</b>
<b>Chapter 11 - Duckiebot configurations .....</b>	<b>56</b>
Section 11.1 - Configuration list .....	56
Section 11.2 - Configuration functionality.....	56
<b>Chapter 12 - Acquiring the parts for the Duckiebot C0.....</b>	<b>58</b>
Section 12.1 - Bill of materials.....	58
Section 12.2 - Chassis .....	59
Section 12.3 - Raspberry Pi 3 - Model B .....	59
Section 12.4 - Camera .....	61
Section 12.5 - DC Stepper Motor HAT .....	62
Section 12.6 - Battery .....	63
Section 12.7 - Standoffs, Nuts and Screws .....	63
Section 12.8 - Zip Tie.....	64
Section 12.9 - Configuration C0-w.....	64
Section 12.10 - Configuration C0-j.....	65
Section 12.11 - Configuration C0-d.....	65
<b>Chapter 13 - Soldering boards for C0 .....</b>	<b>66</b>
<b>Chapter 14 - Preparing the power cable for C0 .....</b>	<b>67</b>
Section 14.1 - Step 1: Find a cable.....	67
Section 14.2 - Step 2: Cut the cable.....	68
Section 14.3 - Step 3: Strip the cable .....	68
Section 14.4 - Step 3: Strip the wires.....	69
Section 14.5 - Step 4: Find the power wires .....	70
Section 14.6 - Step 5: Test correct operation .....	70
<b>Chapter 15 - Assembling the Duckiebot C0.....</b>	<b>72</b>
<b>Chapter 16 - Reproducing the image.....</b>	<b>73</b>
Section 16.1 - Download and uncompress the Ubuntu Mate image.....	73
Section 16.2 - Burn the image to an SD card .....	73
Section 16.3 - Raspberry Pi Config .....	74
Section 16.4 - Install packages .....	74
Section 16.5 - Install Edimax driver .....	75
Section 16.6 - Install ROS .....	76
Section 16.7 - Wireless configuration (old version) .....	76
Section 16.8 - Wireless configuration .....	77
Section 16.9 - SSH server config .....	79
Section 16.10 - Create swap Space .....	79
Section 16.11 - Passwordless sudo .....	80
Section 16.12 - Clean up .....	80
Section 16.13 - Ubuntu user configuration.....	81

Section 16.14 - Check that all required packages were installed.....	82
Section 16.15 - Creating the image .....	82
Section 16.16 - Some additions since last image to add in the next image .....	83
<b>Chapter 17 - Installing Ubuntu on laptops .....</b>	<b>84</b>
Section 17.1 - Install Ubuntu .....	84
Section 17.2 - Install useful software .....	84
Section 17.3 - Install ROS .....	85
Section 17.4 - Other suggested software.....	85
Section 17.5 - Installation of the duckuments system .....	85
Section 17.6 - Passwordless sudo .....	85
Section 17.7 - SSH and Git setup.....	85
<b>Chapter 18 - Duckiebot Initialization .....</b>	<b>87</b>
Section 18.1 - Acquire and burn the image.....	87
Section 18.2 - Turn on the Duckiebot.....	87
Section 18.3 - Connect the Duckiebot to a network.....	88
Section 18.4 - Ping the Duckiebot.....	88
Section 18.5 - SSH to the Duckiebot .....	88
Section 18.6 - (For D17-C1) Configure the robot-generated network .....	89
Section 18.7 - Setting up wireless network configuration .....	89
Section 18.8 - Update the system .....	90
Section 18.9 - Give a name to the Duckiebot .....	90
Section 18.10 - Change the hostname .....	90
Section 18.11 - Expand your filesystem.....	91
Section 18.12 - Create your user .....	92
Section 18.13 - Other customizations.....	94
Section 18.14 - Hardware check: camera .....	94
<b>Chapter 19 - Software setup and RC remote control .....</b>	<b>95</b>
Section 19.1 - Clone the Duckietown repository.....	95
Section 19.2 - Set up ROS environment on the Duckiebot.....	95
Section 19.3 - Add your vehicle to the scuderia file .....	96
Section 19.4 - Test that the joystick is detected .....	96
Section 19.5 - Run the joystick demo .....	96
Section 19.6 - The proper shutdown procedure for the Raspberry Pi .....	97
<b>Chapter 20 - Reading from the camera .....</b>	<b>99</b>
Section 20.1 - Check the camera hardware .....	99
Section 20.2 - Create two windows.....	99
Section 20.3 - First window: launch the camera nodes .....	99
Section 20.4 - Second window: view published topics.....	100
<b>Chapter 21 - RC control launched remotely .....</b>	<b>102</b>
Section 21.1 - Two ways to launch a program .....	102
Section 21.2 - Download and setup Software repository on the laptop .....	102
Section 21.3 - Edit the machines files on your laptop .....	102
Section 21.4 - Start the demo .....	102
Section 21.5 - Watch the program output using rqt_console.....	103
Section 21.6 - Troubleshooting.....	103
<b>Chapter 22 - RC+camera remotely .....</b>	<b>105</b>
Section 22.1 - Assumptions .....	105
Section 22.2 - Terminal setup .....	105
Section 22.3 - First window: launch the joystick demo .....	105
Section 22.4 - Second window: launch the camera nodes.....	106
Section 22.5 - Third window: view data flow .....	106
Section 22.6 - Fourth window: visualize the image using rviz .....	106
Section 22.7 - Proper shutdown procedure .....	107
<b>Chapter 23 - Interlude: Ergonomics .....</b>	<b>108</b>
Section 23.1 - set_ros_master.sh .....	108
Section 23.2 - SSH aliases .....	108
<b>Chapter 24 - Wheel calibration .....</b>	<b>110</b>
<b>Chapter 25 - Camera calibration .....</b>	<b>111</b>
<b>Chapter 26 - Taking a log .....</b>	<b>112</b>

<b>Part 4 - Operation manual - Duckietowns .....</b>	<b>113</b>
<b>Chapter 27 - Duckietown parts.....</b>	<b>114</b>
Section 27.1 - Bill of materials.....	114
Section 27.2 - Duckies.....	114
Section 27.3 - Floor Mats .....	115
Section 27.4 - Duck Tape .....	115
Section 27.5 - Traffic Signs.....	116
<b>Chapter 28 - Traffic lights Parts .....</b>	<b>117</b>
Section 28.1 - Bill of materials.....	117
Section 28.2 - Raspberry Pi .....	117
<b>Chapter 29 - Duckietown Assembly.....</b>	<b>118</b>
<b>Chapter 30 - Traffic lights Assembly .....</b>	<b>119</b>
<b>Chapter 31 - The Duckietown specification .....</b>	<b>120</b>
Section 31.1 - Topology .....	120
Section 31.2 - Signs placement.....	120
<b>Part 5 - Operation manual - Duckiebot with LEDs.....</b>	<b>121</b>
<b>Chapter 32 - Acquiring the parts for the Duckiebot C1.....</b>	<b>122</b>
Section 32.1 - Bill of materials.....	122
Section 32.2 - LEDs .....	123
Section 32.3 - Bumpers .....	124
Section 32.4 - Headers, resistors and jumper .....	125
<b>Chapter 33 - Soldering boards for C1 .....</b>	<b>126</b>
<b>Chapter 34 - Assembling the Duckiebot C1.....</b>	<b>127</b>
<b>Chapter 35 - C1 (LEDs) setup .....</b>	<b>128</b>
<b>Part 6 - Theory chapters.....</b>	<b>129</b>
<b>Chapter 36 - Chapter template.....</b>	<b>130</b>
Section 36.1 - Example Title: PID control .....	130
Section 36.2 - Problem Definition.....	130
Section 36.3 - Introduced Notions .....	131
Section 36.4 - Examples .....	132
Section 36.5 - Pointers to Exercises.....	132
Section 36.6 - Conclusions.....	133
Section 36.7 - Next Steps.....	133
Section 36.8 - References .....	133
<b>Chapter 37 - Symbols and conventions .....</b>	<b>134</b>
Section 37.1 - Conventions .....	134
Section 37.2 - Table of symbols .....	134
<b>Chapter 38 - Linear algebra.....</b>	<b>135</b>
Section 38.1 - Problem Definition.....	135
Section 38.2 - Vectors .....	136
Section 38.3 - Matrices .....	137
Section 38.4 - Matrix as representation of linear (vector) spaces .....	138
Section 38.5 - Examples .....	138
Section 38.6 - Pointers to Exercises.....	138
Section 38.7 - Conclusions.....	138
Section 38.8 - Next Steps.....	139
<b>Chapter 39 - Probability basics.....</b>	<b>140</b>
<b>Chapter 40 - Dynamics .....</b>	<b>141</b>
<b>Chapter 41 - Coordinate systems .....</b>	<b>142</b>
<b>Chapter 42 - Reference frames .....</b>	<b>143</b>
<b>Chapter 43 - Transformations .....</b>	<b>144</b>
<b>Chapter 44 - Autonomy overview .....</b>	<b>145</b>
Section 44.1 - Perception, planning, control.....	145
<b>Chapter 45 - Autonomy architectures .....</b>	<b>146</b>
Section 45.1 - Contracts .....	146
<b>Chapter 46 - Representations .....</b>	<b>147</b>
Section 46.1 - Preliminaries.....	147

## TABLE OF CONTENTS

Section 46.2 - Robot Representations .....	148
Section 46.3 - Environment Representations .....	148
Chapter 47 - Software architectures and middlewares.....	149
Chapter 48 - Modern signal processing.....	150
Chapter 49 - Basic Kinematics .....	151
Chapter 50 - Basic Dynamics .....	152
Chapter 51 - Odometry Calibration.....	153
Chapter 52 - Computer vision basics.....	154
Chapter 53 - Illumination invariance.....	155
Chapter 54 - Line Detection .....	156
Chapter 55 - Feature extraction .....	157
Chapter 56 - Place recognition.....	158
Chapter 57 - Filtering 1.....	159
Chapter 58 - Filtering 2.....	160
Chapter 59 - Mission planning.....	161
Chapter 60 - Planning in discrete domains .....	162
Chapter 61 - Motion planning.....	163
Chapter 62 - RRT.....	164
Chapter 63 - Feedback control .....	165
Chapter 64 - PID Control.....	166
Chapter 65 - MPC Control.....	167
Chapter 66 - Object detection.....	168
Chapter 67 - Object classification .....	169
Chapter 68 - Object tracking .....	170
Chapter 69 - Reacting to obstacles.....	171
Chapter 70 - Semantic segmentation .....	172
Chapter 71 - Text recognition.....	173
Chapter 72 - SLAM - Problem formulation .....	174
Chapter 73 - SLAM - Broad categories .....	175
Chapter 74 - VINS .....	176
Chapter 75 - Advanced place recognition.....	177
Chapter 76 - Fleet level planning (placeholder).....	178
Chapter 77 - Fleet level planning (placeholder).....	179
Chapter 78 - Bibliography.....	180
 Part 7 - Exercises .....	181
Chapter 79 - ROS Exercises .....	182
Section 79.1 - Parameters.....	182
Section 79.2 - Running from a log .....	182
Section 79.3 - Unit tests .....	182
Section 79.4 - Analytics.....	182
Section 79.5 - Visualization .....	182
Chapter 80 - Line detection .....	183
Chapter 81 - Data processing .....	184
Chapter 82 - Git and conventions .....	185
 Part 8 - Software reference .....	186
Chapter 83 - Ubuntu packaging with APT .....	187
Section 83.1 - apt install .....	187
Section 83.2 - apt update .....	187
Section 83.3 - apt-key .....	187
Section 83.4 - apt-mark .....	187
Section 83.5 - add-apt-repository .....	187
Section 83.6 - wajig .....	187
Section 83.7 - dpigs .....	187
Chapter 84 - GNU/Linux general notions .....	188
Section 84.1 - Background reading .....	188
Chapter 85 - Every day Linux.....	189
Section 85.1 - cd .....	189

Section 85.2 - sudo .....	189
Section 85.3 - ls .....	189
Section 85.4 - cp .....	189
Section 85.5 - mkdir .....	189
Section 85.6 - touch .....	189
Section 85.7 - reboot .....	189
Section 85.8 - shutdown .....	189
Section 85.9 - rm .....	189
<b>Chapter 86 - Users .....</b>	190
Section 86.1 - passwd .....	190
<b>Chapter 87 - UNIX tools .....</b>	191
Section 87.1 - cat .....	191
Section 87.2 - tee .....	191
Section 87.3 - truncate .....	191
<b>Chapter 88 - Linux disks and files .....</b>	192
Section 88.1 - fdisk .....	192
Section 88.2 - mount .....	192
Section 88.3 - umount .....	192
Section 88.4 - losetup .....	192
Section 88.5 - gparted .....	192
Section 88.6 - dd .....	192
Section 88.7 - sync .....	192
Section 88.8 - df .....	192
<b>Chapter 89 - Other administration commands .....</b>	193
Section 89.1 - visudo .....	193
Section 89.2 - update-alternatives .....	193
Section 89.3 - udevadm .....	193
Section 89.4 - systemctl .....	193
<b>Chapter 90 - Make .....</b>	194
Section 90.1 - make .....	194
<b>Chapter 91 - Python-related tools .....</b>	195
Section 91.1 - virtualenv .....	195
Section 91.2 - pip .....	195
<b>Chapter 92 - Raspberry-PI commands .....</b>	196
Section 92.1 - raspi-config .....	196
Section 92.2 - vcgencmd .....	196
Section 92.3 - raspistill .....	196
Section 92.4 - jstest .....	196
Section 92.5 - swapon .....	196
Section 92.6 - mkswap .....	196
<b>Chapter 93 - Users and permissions .....</b>	197
Section 93.1 - chmod .....	197
Section 93.2 - groups .....	197
Section 93.3 - adduser .....	197
Section 93.4 - useradd .....	197
<b>Chapter 94 - Downloading .....</b>	198
Section 94.1 - curl .....	198
Section 94.2 - wget .....	198
Section 94.3 - sha256sum .....	198
Section 94.4 - xz .....	198
<b>Chapter 95 - Shells and environments .....</b>	199
Section 95.1 - source .....	199
Section 95.2 - which .....	199
Section 95.3 - export .....	199
<b>Chapter 96 - Other misc commands .....</b>	200
Section 96.1 - pgrep .....	200
Section 96.2 - npm .....	200
Section 96.3 - nodejs .....	200
Section 96.4 - ntpdate .....	200
Section 96.5 - chsh .....	200

Section 96.6 - echo .....	200
Section 96.7 - sh .....	200
Section 96.8 - fc-cache.....	200
<b>Chapter 97 - Linux resources usage.....</b>	201
Section 97.1 - Measuring CPU usage using htop .....	201
Section 97.2 - Measuring I/O usage using iotop.....	201
Section 97.3 - How fast is the SD card? .....	201
<b>Chapter 98 - SD Cards tools .....</b>	202
Section 98.1 - Testing SD Card and disk speed.....	202
Section 98.2 - How to burn an image to an SD card .....	202
Section 98.3 - How to shrink an image .....	203
<b>Chapter 99 - Networking tools.....</b>	206
Section 99.1 - hostname.....	206
Section 99.2 - Visualizing information about the network .....	206
<b>Chapter 100 - Accessing computers using SSH.....</b>	207
Section 100.1 - Background reading .....	207
Section 100.2 - Installation of SSH.....	207
Section 100.3 - Local configuration .....	207
Section 100.4 - How to login with SSH and a password .....	207
Section 100.5 - Creating an SSH keypair.....	208
Section 100.6 - How to login without a password .....	210
Section 100.7 - Fixing SSH Permissions .....	211
Section 100.8 - ssh-keygen .....	211
<b>Chapter 101 - Wireless networking in Linux.....</b>	212
Section 101.1 - iwconfig .....	212
Section 101.2 - iwlist .....	212
<b>Chapter 102 - Moving files between computers.....</b>	214
Section 102.1 - SCP .....	214
Section 102.2 - RSync .....	214
<b>Chapter 103 - VIM.....</b>	215
Section 103.1 - External documentation .....	215
Section 103.2 - Installation .....	215
Section 103.3 - vi .....	215
Section 103.4 - Suggested configuration .....	215
Section 103.5 - Visual mode .....	215
Section 103.6 - Indenting using VIM .....	215
<b>Chapter 104 - Atom .....</b>	217
<b>Chapter 105 - Eclipse .....</b>	218
Section 105.1 - Installing LiClipse .....	218
<b>Chapter 106 - Byobu.....</b>	219
Section 106.1 - Advantages of using Byobu .....	219
Section 106.2 - Installation .....	219
Section 106.3 - Documentation .....	219
Section 106.4 - Quick command reference .....	219
Section 106.5 - Commands on OS X.....	220
<b>Chapter 107 - Source code control with Git.....</b>	221
Section 107.1 - Background reading .....	221
Section 107.2 - Installation .....	221
Section 107.3 - Setting up global configurations for Git .....	221
Section 107.4 - Git tips .....	221
Section 107.5 - Git troubleshooting .....	222
Section 107.6 - git .....	222
<b>Chapter 108 - Git LFS .....</b>	223
Section 108.1 - Generic installation instructions .....	223
Section 108.2 - Ubuntu 16 installation (laptop) .....	223
Section 108.3 - Ubuntu 16 Mate installation (Raspberry Pi 3).....	223
<b>Chapter 109 - Setup Github access .....</b>	224
Section 109.1 - Create a Github account .....	224
Section 109.2 - Become a member of the Duckietown organization .....	224
Section 109.3 - Add a public key to Github.....	224

<b>Chapter 110 - ROS installation and reference .....</b>	226
Section 110.1 - Install ROS .....	226
Section 110.2 - rqt_console .....	226
Section 110.3 - roslaunch.....	227
Section 110.4 - rviz.....	227
Section 110.5 - rostopic.....	227
Section 110.6 - catkin_make .....	227
Section 110.7 - rosrun .....	227
Section 110.8 - rostest .....	227
Section 110.9 - rospack .....	227
Section 110.10 - rosparam.....	227
Section 110.11 - rosdep .....	228
Section 110.12 - roswtf .....	228
Section 110.13 - rosbag .....	228
Section 110.14 - roscore .....	228
Section 110.15 - Troubleshooting ROS .....	228
Section 110.16 - Other materials about ROS.....	228
<b>Part 9 - Software development guide.....</b>	229
<b>Chapter 111 - Python .....</b>	230
Section 111.1 - Background reading .....	230
Section 111.2 - Python virtual environments .....	230
Section 111.3 - Useful libraries.....	230
Section 111.4 - Context managers.....	230
<b>Chapter 112 - Duckietown code conventions .....</b>	231
Section 112.1 - Python .....	231
Section 112.2 - Logging .....	232
Section 112.3 - Exceptions .....	232
Section 112.4 - Scripts .....	232
<b>Chapter 113 - Configuration .....</b>	233
Section 113.1 - Environment variables .....	233
Section 113.2 - The scuderia file .....	233
Section 113.3 - The machines file .....	234
Section 113.4 - People database .....	234
Section 113.5 - Modes of operation .....	234
<b>Chapter 114 - Node configuration mechanisms .....</b>	235
<b>Chapter 115 - Minimal ROS node - pkg_name .....</b>	236
Section 115.1 - The files in the package .....	236
Section 115.2 - Writing a node: talker.py .....	237
Section 115.3 - The Talker class .....	239
Section 115.4 - Launch File .....	240
Section 115.5 - Testing the node .....	241
Section 115.6 - Documentation .....	243
Section 115.7 - Guidelines .....	243
<b>Chapter 116 - ROS package verification .....</b>	244
Section 116.1 - Naming .....	244
Section 116.2 - package.xml .....	244
Section 116.3 - Messages .....	244
Section 116.4 - Readme file .....	244
Section 116.5 - Launch files .....	244
Section 116.6 - Test files .....	244
<b>Chapter 117 - Creating unit tests with ROS .....</b>	245
<b>Part 10 - Duckietown system.....</b>	246
<b>Chapter 118 - Teleoperation .....</b>	247
Section 118.1 - Implementation .....	247
Section 118.2 - Camera .....	247
Section 118.3 - Actuators .....	247
Section 118.4 - IMU .....	247

Chapter 119 - Parallel autonomy .....	248
Chapter 120 - Lane control.....	249
Section 120.1 - Implementation .....	249
Chapter 121 - Indefinite navigation.....	250
Section 121.1 - Implementation .....	250
Chapter 122 - Planning .....	251
Section 122.1 - Implementation .....	251
Chapter 123 - Coordination.....	252
Section 123.1 - Implementation .....	252
Chapter 124 - Duckietown ROS Guidelines .....	253
Section 124.1 - Node and Topics .....	253
Section 124.2 - Parameters.....	253
Section 124.3 - Launch file .....	253
 Part 11 - Fall 2017 .....	255
Chapter 125 - General remarks.....	256
Section 125.1 - The rules of Duckietown .....	256
Section 125.2 - Synchronization between classes.....	256
Section 125.3 - Accounts for students .....	256
Section 125.4 - Accounts for all instructors and TAs .....	257
Chapter 126 - Additional information for ETH Zürich students.....	258
Chapter 127 - Additional information for UdeM students.....	259
Chapter 128 - Additional information for TTIC students .....	260
Chapter 129 - Additional information for NCTU students .....	261
Chapter 130 - Milestone: ROS node working .....	262
Chapter 131 - Homework: Take and process a log .....	263
Chapter 132 - Milestone: Calibrated robot.....	264
Chapter 133 - Homework: Camera geometry.....	265
Chapter 134 - Milestone: Illumination invariance .....	266
Chapter 135 - Homework: Place recognition .....	267
Chapter 136 - Milestone: Lane following.....	268
Chapter 137 - Homework: localization .....	269
Chapter 138 - Milestone: Navigation.....	270
Chapter 139 - Homework: group forming .....	271
Chapter 140 - Milestone: Ducks in a row.....	272
Chapter 141 - Homework: Comparison of PID .....	273
Chapter 142 - Homework: RRT .....	274
Chapter 143 - Caffe tutorial.....	275
Chapter 144 - Milestone: Object Detection.....	276
Chapter 145 - Homework: Object Detection .....	277
Chapter 146 - Milestone: Semantic perception .....	278
Chapter 147 - Homework: Semantic perception .....	279
Chapter 148 - Milestone: Reacting to obstacles.....	280
Chapter 149 - Homework: Reacting to obstacles .....	281
Chapter 150 - Milestone: SLAM demo .....	282
Chapter 151 - Homework: SLAM .....	283
Chapter 152 - Milestone: fleet demo .....	284
Chapter 153 - Homework: fleet.....	285
Chapter 154 - Project proposals .....	286
Chapter 155 - Template of a project.....	287
Section 155.1 - Checklist for students .....	287
Section 155.2 - Checklist for TAs .....	287
 Part 12 - Packages - Infrastructure.....	288
Chapter 156 - Package duckietown .....	289
Chapter 157 - Package duckietown_msgs .....	290
Chapter 158 - Package easy_node .....	291
Section 158.1 - Transition plan .....	291
Section 158.2 - YAML file format.....	291

Section 158.3 - Automatic docs generation.....	293
<b>Chapter 159 - Duckietown ROS Guideline.....</b>	<b>294</b>
Section 159.1 - Node and Topics .....	294
Section 159.2 - Parameters.....	294
Section 159.3 - Launch file .....	294
<b>Chapter 160 - Package what_the_duck .....</b>	<b>296</b>
Section 160.1 - What the duck .....	296
Section 160.2 - Adding more tests to what-the-duck .....	296
Section 160.3 - Tests already added .....	296
Section 160.4 - List of tests to add .....	297
<b>Part 13 - Packages - Lane control.....</b>	<b>299</b>
<b>Chapter 161 - Package adafruit_drivers .....</b>	<b>300</b>
<b>Chapter 162 - Package anti_instagram.....</b>	<b>301</b>
Section 162.1 - Unit tests integrated with rostest .....	301
Section 162.2 - Unit tests needed external files .....	301
Section 162.3 - Node anti_instagram_node .....	301
<b>Chapter 163 - Package car_supervisor .....</b>	<b>303</b>
<b>Chapter 164 - Package dagu_car.....</b>	<b>304</b>
<b>Chapter 165 - Package ground_projection.....</b>	<b>305</b>
<b>Chapter 166 - Package joy_mapper .....</b>	<b>306</b>
Section 166.1 - Testing .....	306
Section 166.2 - Dependencies.....	306
Section 166.3 - Node: joy_mapper.py .....	306
<b>Chapter 167 - Package lane_control .....</b>	<b>308</b>
Section 167.1 - lane_controller_node.....	308
<b>Chapter 168 - Package lane_filter .....</b>	<b>309</b>
Section 168.1 - lane_filter_node.....	309
<b>Chapter 169 - Package line_detector2 .....</b>	<b>312</b>
Section 169.1 - Testing the line detector using visual inspection .....	312
Section 169.2 - Quantitative tests.....	314
Section 169.3 - line_detector_node2 .....	314
<b>Chapter 170 - Package line_detector .....</b>	<b>316</b>
<b>Chapter 171 - Package pi_camera .....</b>	<b>317</b>
<b>Part 14 - Packages - Indefinite navigation.....</b>	<b>318</b>
<b>Chapter 172 - Package apriltags_ros .....</b>	<b>319</b>
<b>Chapter 173 - Package fsm .....</b>	<b>320</b>
<b>Chapter 174 - Package indefinite_navigation .....</b>	<b>321</b>
<b>Chapter 175 - Package intersection_control .....</b>	<b>322</b>
<b>Chapter 176 - Package navigation .....</b>	<b>323</b>
<b>Chapter 177 - Package stop_line_filter .....</b>	<b>324</b>
<b>Part 15 - Packages - Localization and planning .....</b>	<b>325</b>
<b>Chapter 178 - Package duckietown_description .....</b>	<b>326</b>
<b>Chapter 179 - Package localization .....</b>	<b>327</b>
<b>Part 16 - Packages - Coordination.....</b>	<b>328</b>
<b>Chapter 180 - Package led_detection .....</b>	<b>329</b>
Section 180.1 - LED detector .....	329
Section 180.2 - Unit tests .....	329
<b>Chapter 181 - Package led_emitter .....</b>	<b>331</b>
<b>Chapter 182 - Package led_interpreter .....</b>	<b>332</b>
<b>Chapter 183 - Package led_joy_mapper .....</b>	<b>333</b>
<b>Chapter 184 - Package rgb_led .....</b>	<b>334</b>
Section 184.1 - Demos.....	334
<b>Chapter 185 - Package traffic_light .....</b>	<b>335</b>

Part 17 - Packages - Additional functionality .....	336
Part 18 - Packages - Templates .....	337
Chapter 186 - Package <code>pkg_name</code> .....	338
Section 186.1 - Status .....	338
Chapter 187 - Package <code>rostest_example</code> .....	339
Part 19 - Packages - Convenience .....	340
Chapter 188 - Package <code>duckietown_demos</code> .....	341
Chapter 189 - Package <code>duckietown_unit_test</code> .....	342
Part 20 - Packages - To sort.....	343
Chapter 190 - Package <code>adafruit_imu</code> .....	344
Section 190.1 - Testing .....	344
Section 190.2 - Dependencies.....	344
Section 190.3 - Node <code>adafruit_imu</code> .....	344
Chapter 191 - Package <code>duckie_rr_bridge</code> .....	345
Chapter 192 - Package <code>duckiebot_visualizer</code> .....	346
Chapter 193 - Package <code>duckietown_logs</code> .....	347
Chapter 194 - Package <code>bag_stamper</code> .....	348
Chapter 195 - Package <code>kinematics</code> .....	349
Chapter 196 - Package <code>visual_odometry</code> .....	350
Chapter 197 - Package <code>mdoap</code> .....	351
Chapter 198 - Package <code>parallel_autonomy</code> .....	352
Chapter 199 - Package <code>scene_segmentation</code> .....	353
Chapter 200 - Package <code>veh_coordinator</code> .....	354
Chapter 201 - Package <code>vehicle_detection</code> .....	355
Chapter 202 - Package <code>visual_odometry_line</code> .....	356
Part 21 - Packages - Failed projects.....	357
Chapter 203 - Package <code>mouse_encoder</code> .....	358
Section 203.1 - Publish Topic .....	358
Section 203.2 - Parameters.....	358
Section 203.3 - Getting access to <code>/dev/input/mice</code> .....	358
Chapter 204 - Package <code>simcity</code> - Map Editor Version 0.1 .....	359
Section 204.1 - How to run the map editor .....	359
Section 204.2 - How to edit the map.....	359
Section 204.3 - What am I looking at, anyway?.....	359
Section 204.4 - What else is there to do? .....	359
Chapter 205 - Package <code>slam</code> .....	360
Chapter 206 - Package <code>street_name_detector</code> .....	361

PART 1

# The Duckietown project

..

# CHAPTER 1

## What is Duckietown?

### 1.1. Goals and objectives

Duckietown is a robotics educations and outreach effort.

The most tangible goal of the project is to provide a low-cost educational platform for learning autonomy, consisting of the Duckiebots, an autonomous robot, and the Duckietowns, the infrastructure in which the Duckiebots navigate.

However, we focus on the *learning experience* as a whole, by providing a set of modules teaching plans and other guides, as well as a curated role-play experience.

We have two targets:

1. For **instructors**, we want to create a “class-in-a-box” that allows to offer a modern and engaging learning experience. Currently, this is feasible at the advanced undergraduate and graduate level, though in the future we would like to present the platform as multi-grade experiences.
2. For **self-guided learners**, we want to create a “self-learning experience”, that allows to go from zero knowledge of robotics to graduate-level understanding.

In addition, the Duckietown platform has been used as a research platform.

### 1.2. Learn about the Duckietown educational experience

This video is a Duckumentary about the first version of the class, during Spring 2016. The Duckumentary was shot by Chris Welch.

TODO: Add Duckumentary

Figure 1. The Duckumentary

See also this documentary by Red Hat:



Figure 2. The road to autonomy

If you'd like to know more about the educational experience, [1] present a more formal description of the course design for Duckietown: learning objectives, teaching methods, etc.

### 1.3. Learn about the platform

The best way to get a sense of how the platform looks is to watch these videos. They

show off the capabilities of the platform.

If you would like to know more, the paper [2] describes the Duckiebot and its software.  
(With 29 authors, we made the record for a robotics conference!)

**TODO:** add the video here that we showed at ICRA.

Can you do it by night?



Figure 3. Cool Duckietown by night

## CHAPTER 2

# Duckietown history and future

### 2.1. The beginnings of Duckietown

The original Duckietown class was at MIT in 2016.



Figure 4. Part of the first MIT class, during the final demo.



Figure 5. The need for autonomy



Figure 6. Advertisement



Figure 7. The elves of Duckietown

## 2.2. University-level classes in 2016

Later that year, the Duckietown platform was also used in these classes:

- [National Chiao Tung University 2016](#), Taiwan - Prof. Nick Wang;
- [Tsinghua University](#), People's Republic of China - Prof. (Samuel) Qing-Shan Jia's *Computer Networks with Applications* course;
- [Rensselaer Polytechnic Institute 2016](#) - Prof. John Wen;



Figure 8. Duckietown at NCTU in 2016

## 2.3. University-level classes in 2017

In 2017, these four courses will be taught together, with the students interacting among institutions:

- [ETH Zürich 2017](#) - Prof. Emilio Frazzoli, Dr. Andrea Censi;
- [University of Montreal, 2017](#) - Prof. Liam Paull;
- [TTI/Chicago 2017](#) - Prof. Matthew Walter;
- National Chiao Tung University, Taiwan - Prof. Nick Wang's course;

Furthermore, the Duckietown platform is used also in the following universities:

- Rensselaer Polytechnic Institute (Jeff Trinkle)
- National Chiao Tung University, Taiwan - Prof. Yon-Ping Chen's *Dynamic system simulation and implementation*.
- Chosun University, Korea - Prof. Woosuk Sung's course;

- Petra Christian University, Indonesia - Prof. Resmana Lim's *Mobile Robot Design Course*
- National Tainan Normal University, Taiwan - Prof. Jen-Jee Chen's *Vehicle to Everything* (V2X) Course;
- Yuan Zhu University, Taiwan - Prof. Kan-Lin Hsiung's Control course;

## 2.4. Chile

TODO: to write



## 2.5. Duckietown High School

TODO: to write



## CHAPTER 3

# Duckietown classes



Duckietown is an international effort. Many educational institutions have adopted the platform and used to teach robotics and related subjects. If you have used Duckietown in any of your course and cannot find a mention to it here, contact us.

**TODO:** add contact email

Here, we provide a chronologically ordered compendium of the Duckietown related learning experiences worldwide.

### 3.1. 2016



Duckietown was created in 2016.

#### 1) Massachusetts Institute of Technology

---



Location: United States of America, Cambridge, Massachusetts

Course title: 2.166 Vehicle Autonomy

Instructors: *plenty*

Educational Level: Graduate

Time period:

Link:

Highlights: Role-playing experience (Duckietown Engineering Co.), public demo

Summary:

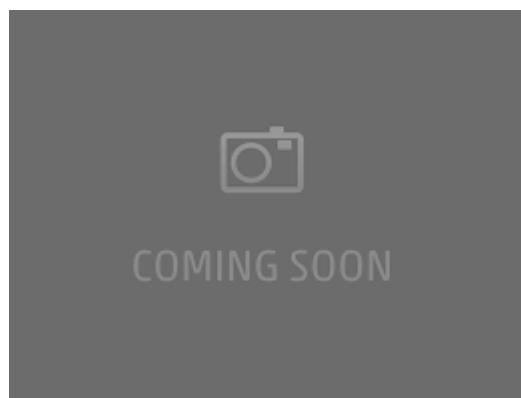


Figure 9. Duckietown at MIT in 2016

#### 2) National Chiao Tung University

---



Location:

Course title:

Instructors: Prof. Nick Wang

Educational Level:

Time period:

Link:

Summary:

Highlights:

### 3) Tsinghua University

---

Location:

Course title:

Instructors:

Educational Level:

Time period:

Link:

Summary:

Highlights:

### 4) Rensselaer Polytechnic Institute

---

Location:

Course title:

Instructors:

Educational Level:

Time period:

Link:

Summary:

Highlights:

## 3.2. 2017

### 1) ETH Zürich

---

Assigned to: Censi/Tani

### 2) Université de Montréal

---

Location: Montreal

Course title: IFT 6080 Sujets en exploitation des ordinateurs

Instructors: Liam Paull

Educational Level: Graduate

Time period: Sept. - Dec. 2017

Link: [Official Course Website](#)

Summary: 12 students admitted spanning across Université de Montréal, École Polytechnic, McGill University and Concordia University

**Highlights:**

3) Toyota Technological Institute at Chicago / University of Chicago

---

Assigned to: Matt Walter

## CHAPTER 4

# First steps

### 4.1. How to get started

If you are an instructor, please jump to [Section 4.2](#).

If you are a self-guided learner, please jump to [Section 4.3](#).

If you are a company, and interested in working with Duckietown, please jump to [Section 4.4](#).

### 4.2. Duckietown for instructors

TODO: to write

### 4.3. Duckietown for self-guided learners

TODO: to write

### 4.4. Introduction for companies

TODO: to write

### 4.5. How to keep in touch

TODO: add link to Facebook

TODO: add link to Mailing list

TODO: add link to Slack?

### 4.6. How to contribute

TODO: If you want to contribute to the software...

TODO: If you want to contribute to the hardware...

TODO: If you want to contribute to the documentation...

TODO: If you want to contribute to the dissemination...

### 4.7. Frequently Asked Questions

---

## 1) General questions

*Q: What is Duckietown?*

Duckietown is a low-cost educational and research platform.

*Q: Is Duckietown free to use?*

Yes. All materials are released according to an open source license.

*Q: Is everything ready?*

Not quite! Please [sign up to our mailing list](#) to get notified when things are a bit more ready.

*Q: How can I start?*

See the section [First Steps](#).

*Q: How can I help?*

If you would like to help actively, please email [duckietown@mit.edu](mailto:duckietown@mit.edu).

---

## 2) FAQ by students / independent learners

*Q: I want to build my own Duckiebot. How do I get started?*

TODO: to write

---

## 3) FAQ by instructors

*Q: How large a class can it be? I teach large classes.*

TODO: to write

*Q: What is the budget for the robot?*

TODO: to write

*Q: I want to teach a Duckietown class. How do I get started?*

Please get in touch with us at [duckietown@mit.edu](mailto:duckietown@mit.edu). We will be happy to get you started and sign you up to the Duckietown instructors mailing list.

*Q: Why the duckies?*

Compared to other educational robotics projects, the presence of the duckies is what makes this project stand out. Why the duckies?

We want to present robotics in an accessible and friendly way.

TODO: copy usual discussion from somewhere else.

TODO: add picture of kids with Duckiebots.

PART 2

## Duckumentation documentation



## CHAPTER 5

# Accounts

### 5.1. Complete list of accounts

Currently, Duckietown has the following accounts:

- Github: for source code, and issue tracking;
- Slack: a forum for wide communication;
- Twist: to be used for instructors coordination;
- Google Drive: to be used for instructors coordination, maintaining TODOs, etc;
- Dropbox Folders (part of Andrea's personal accounts): to be abandoned;
- Vimeo, for storing the videos;
- The `duckietown-teaching` mailing list, for low-rate communication with instructors;
- We also have a list of addresses, of people signed up on the website, that we didn't use yet;
- The Facebook page.

### 5.2. For other contributors

If you are an international contributor:

- Sign up on Slack, to keep up with the project.
- (optional) Get Github permissions if you do frequent updates to the repositories.

## CHAPTER 6

# Contributing to the documentation

### 6.1. Where the documentation is

All the documentation is in the repository `duckietown/duckuments`.

The documentation is written as a series of small files in Markdown format.

It is then processed by a series of scripts to create this output:

- [a publication-quality PDF](#);
- [an online HTML version, split in multiple pages and with comments boxes](#).

### 6.2. Editing links

The simplest way to contribute to the documentation is to click any of the “” icons next to the headers.

They link to the “edit” page in Github. There, one can make and commit the edits in only a few seconds.

### 6.3. Comments

In the multiple-page version, each page also includes a comment box powered by a service called Disqus. This provides a way for people to write comments with a very low barrier. (We would periodically remove the comments.)

### 6.4. Installing the documentation system

In the following, we are going to assume that the documentation system is installed in `~/duckuments`. However, it can be installed anywhere.

We are also going to assume that you have setup a Github account with working public keys.

We are also going to assume that you have installed the `duckietown/software` in `~/duckietown`.

#### 1) Dependencies (Ubuntu 16.04)

---

On Ubuntu 16.04, these are the dependencies to install:

```
$ sudo apt install libxml2-dev libxslt1-dev
$ sudo apt install libffi6 libffi-dev
$ sudo apt install python-dev python-numpy python-matplotlib
$ sudo apt install virtualenv
$ sudo apt install bibtex2html pdftk
```

#### 2) Download the duckuments repo

---

Download the `duckietown/duckuments` repository in that directory:

```
$ git clone git@github.com:duckietown/duckuments ~/duckuments
```

### 3) Setup the virtual environment

---

Next, we will create a virtual environment using inside the `~/duckuments` directory. Change into that directory:

```
$ cd ~/duckuments
```

Create the virtual environment using `virtualenv`:

```
$ virtualenv --system-site-packages deploy
```

Other distributions: In other distributions you might need to use `venv` instead of `virtualenv`.

Activate the virtual environment:

```
$ source ~/duckuments/deploy/bin/activate
```

### 4) Setup the `mcdp` external repository

---

Make sure you are in the directory:

```
$ cd ~/duckuments
```

Clone the `mcdp` external repository, with the branch `duckuments`.

```
$ git clone -b duckuments git@github.com:AndreaCensi/mcdp
```

Install it and its dependencies:

```
$ cd ~/duckuments/mcdp  
$ python setup.py develop
```

**Note:** If you get a permission error here, it means you have not properly activated the virtual environment.

Other distributions: If you are not on Ubuntu 16, depending on your system, you might need to install these other dependencies:

```
$ pip install numpy matplotlib
```

You also should run:

```
$ pip install -U SystemCmd==2.0.0
```



## 6.5. Compiling the documentation

### Check before you continue

Make sure you have deployed and activated the virtual environment. You can check this by checking which `python` is active:

```
$ which python  
/home/user/duckuments/deploy/bin/python
```

Then:

```
$ cd ~/duckuments  
$ make duckuments-dist
```

This creates the directory `duckuments-dist`, which contains another checked out copy of the repository, but with the branch `gh-pages`, which is the branch that is published by Github using the “Github Pages” mechanism.

### Check before you continue

At this point, please make sure that you have these two `.git` folders:

```
~/duckuments/.git  
~/duckuments/duckuments-dist/.git
```

To compile the docs, run `make clean compile`:

```
$ make clean compile
```

To see the result, open the file

```
./duckuments-dist/master/duckiebook/index.html
```

### 1) Incremental compilation



If you want to do incremental compilation, you can omit the `clean` and just use:

```
$ make compile
```

This will be faster. However, sometimes it might get confused. At that point, do `make clean`.



## 6.6. Troubleshooting compilation



| **Symptom:** “Invalid XML”

**Resolution:** “Markdown” doesn’t mean that you can put anything in a file. Except for the code blocks, it must be valid XML. For example, if you use “`>`” and “`<`” without quoting, it will likely cause a compile error.

**Symptom:** “Tabs are evil”

**Resolution:** Do not use tab characters. The error message in this case is quite helpful in telling you exactly where the tabs are.

**Symptom:** The error message contains `ValueError: Suspicious math fragment 'KEYMATHS000END-KEY'`

**Resolution:** You probably have forgotten to indent a command line by at least 4 spaces. The dollar in the command line is now being confused for a math formula.

## 6.7. The workflow to edit documentation.

This is the workflow:

1. Edit the Markdown in the `master` branch of the `duckuments` repository.
2. Run `make compile` to make sure it compiles.
3. Commit the Markdown and push on the `master` branch.

Done. A bot will redo the compilation and push the changes in the `gh-pages` branch.

Step 2 is there so you know that the bot will not encounter errors.

## 6.8. \*Deploying the documentation

**Note:** This part is now done by a bot, so you don’t need to do it manually.

To deploy the documentation, jump into the `DUCKUMENTS/duckuments-dist` directory.

Run the command `git branch`. If the output does not say that you are on the branch `gh-pages`, then one of the steps before was done incorrectly.

```
$ cd $DUCKUMENTS/duckuments-dist
$ git branch
...
* gh-pages
...
```

Now, after triple checking that you are in the `gh-pages` branch, you can use `git status` to see the files that were added or modified, and simply use `git add`, `git commit` and `git push` to push the files to Github.

## 6.9. \*Compiling the PDF version

**Note:** The dependencies below are harder to install. If you don’t manage to do it, then you only lose the ability to compile the PDF. You can do `make compile` to compile the HTML version, but you cannot do `make compile-pdf`.

### 1) Installing node.js

Ensure the latest version (`>6`) of `node.js` is installed.

Run:

```
$ nodejs --version  
6.xx
```

If the version is 4 or less, remove `nodejs`:

```
$ sudo apt remove nodejs
```

Install `nodejs` using [the instructions at this page](#).

Next, install the necessary Javascript libraries using `npm`:

```
$ cd $DUCKUMENTS  
$ npm install MathJax-node jsdom@9.3 less
```

## 2) Troubleshooting nodejs installation problems

The only pain point in the installation procedure has been the installation of `nodejs` packages using `npm`. For some reason, they cannot be installed globally (`npm install -g`).

Do not use `sudo` for installation. It will cause problems.

If you use `sudo`, you probably have to delete a bunch of directories, such as: `~/duckuments/node_modules`, `~/.npm`, and `~/.node_modules`, if they exist.

## 3) Installing Prince

Install PrinceXML from [this page](#).

## 4) Installing fonts

Copy the `~/duckuments/fonts` directory in `~/.fonts`:

```
$ mkdir -p ~/.fonts    # create if not exists  
$ cp -R ~/duckuments/fonts ~/.fonts
```

and then rebuild the font cache using:

```
$ fc-cache -fv
```

## 5) Compiling the PDF

To compile the PDF, use:

```
$ make compile-pdf
```

This creates the file:

```
./duckuments-dist/master/duckiebook.pdf
```



## CHAPTER 7

# Features of the documentation writing system



The Duckiebook is written in a Markdown dialect. A subset of LaTeX is supported. There are also some additional features that make it possible to create publication-worthy materials.

## 7.1. Markdown



The Duckiebook is written in a Markdown dialect.

→ [A tutorial on Markdown.](#)

## 7.2. Embedded LaTeX



You can use ***LaTeX*** math, environment, and references. For example, take a look at

$$x^2 = \int_0^t f(\tau) d\tau$$

or refer to [Proposition 1](#).

**Proposition 1.** (Proposition example) This is an example proposition:  $2x = x + x$ .

The above was written as in [Listing 1](#).

You can use `$\LaTeX$` math, environment, and references.

For example, take a look at

```
\[
x^2 = \int_0^t f(\tau) \text{d}\tau
]
```

or refer to `[](#prop:example)`.

```
\begin{proposition}[Proposition example]\label{prop:example}
```

This is an example proposition:  $2x = x + x$ .

```
\end{proposition}
```

Listing 1. Use of LaTeX code.

For the LaTeX environments to work properly you *must* add a `\label` declaration inside. Moreover, the label must have a prefix that is adequate to the environment. For example, for a proposition, you must insert `\label{def:name}` inside.

The following table shows the list of the LaTeX environments supported and the label prefix that they need.

TABLE 1. LATEX ENVIRONMENTS AND LABEL PREFIXES

definition	def: <code>name</code>
proposition	prop: <code>name</code>
remark	rem: <code>name</code>
problem	prob: <code>name</code>
theorem	thm: <code>name</code>
lemma	lem: <code>name</code>

Examples of all environments follow.

### example

```
<div id='def:lorem' class="definition latex_env" markdown="1">Lorem</div>
```

### Definition 1. Lorem

```
<div id='prop:lorem' class="proposition latex_env" markdown="1">Lorem</div>
```

### Proposition 2. Lorem

```
<div id='rem:lorem' class="remark latex_env" markdown="1">Lorem</div>
```

### Remark 1. Lorem

```
<div id='prob:lorem' class="problem latex_env" markdown="1">Lorem</div>
```

### Problem 1. Lorem

```
<div id='exa:lorem' class="example latex_env" markdown="1">Lorem</div>
```

### Example 1. Lorem

```
<div id='thm:lorem' class="theorem latex_env" markdown="1">Lorem</div>
```

### Theorem 1. Lorem

```
<div id='lem:lorem' class="lemma latex_env" markdown="1">Lorem</div>
```

### Lemma 1. Lorem

I can also refer to all of them:

```
[](#def:lorem),
[](#prop:lorem),
[](#rem:lorem),
[](#prob:lorem),
[](#exa:lorem),
[](#thm:lorem),
[](#lem:lorem).
```

I can also refer to all of them: [Definition 1](#), [Proposition 2](#), [Remark 1](#), [Problem 1](#), [Example 1](#), [Theorem 1](#), [Lemma 1](#).

## 7.3. LaTeX equations



We can refer to equations, such as (1):

$$2a = a + a \quad (1)$$

This uses `align` and contains (2) and (3).

$$\begin{aligned} a &= b \\ &= c \end{aligned} \quad (2) \quad (3)$$

We can refer to equations, such as `\eqref{eq:one}`:

```
\begin{equation}
  2a = a + a \quad \label{eq:one}
\end{equation}
```

This uses `align` and contains `\eqref{eq:two}` and `\eqref{eq:three}`.

```
\begin{aligned}
  a &\triangleq b \quad \label{eq:two} \\
  &\triangleq c \quad \label{eq:three}
\end{aligned}
```

Note that referring to the equations is done using the syntax `\eqref{eq:name}`, rather than `[](#eq:name)`.

**TODO:** other LaTeX features supported

## 7.4. LaTeX symbols

The LaTeX symbols definitions are in a file called [docs/symbols.tex](#).

Put all definitions there; if they are centralized it is easier to check that they are coherent.

## 7.5. Variables in command lines and command output

Use the syntax “`![name]`” for describing the variables in the code.

*example* For example, to obtain:

```
$ ssh robot name.local
```

Use the following:

For example, to obtain:

```
$ ssh ![robot name].local
```

Make sure to quote (with 4 spaces) all command lines. Otherwise, the dollar symbol confuses the LaTeX interpreter.

## 7.6. Character escapes

Use the string “`&#36;`” to write the dollar symbol “\$”, otherwise it gets confused with LaTeX math materials. Also notice that you should probably use “USD” to refer to U.S. dollars.

Other symbols to escape are shown in [Table 2](#).

TABLE 2. SYMBOLS TO ESCAPE

- |                            |               |
|----------------------------|---------------|
| use <code>&amp;#36;</code> | instead of \$ |
| use <code>&amp;#96;</code> | instead of `  |
| use <code>&amp;lt;</code>  | instead of <  |
| use <code>&amp;gt;</code>  | instead of >  |

## 7.7. Keyboard keys

Use the `kbd` element for keystrokes.

*example*

For example, to obtain:

Press `a` then `Ctrl-C`.

use the following:

```
Press <kbd>a</kbd> then <kbd>Ctrl</kbd>-<kbd>C</kbd>.
```

## 7.8. Figures

For any element, adding an attribute called `figure-id` with value `fig:figure ID` or `tab:table ID` will create a figure that wraps the element.

For example:

```
<div figure-id="fig:figure ID">  
    figure content  
</div>
```

It will create HMTL of the form:

```
<div id='fig:code-wrap' class='generated-figure-wrap'>
  <figure id='fig:figure ID' class='generated-figure'>
    <div>
      figure content
    </div>
  </figure>
</div>
```

To add a caption, add an attribute `figure-caption`:

```
<div figure-id='fig:figure ID' figure-caption='This is my caption'>
  figure content
</div>
```

Alternatively, you can put anywhere an element `figcaption` with ID `fig:figure ID:caption`:

```
<element figure-id="fig:figure ID">
  figure content
</element>

<figcaption id='fig:figure ID:caption'>
  This the caption figure.
</figcaption>
```

To refer to the figure, use an empty link:

```
Please see [](#fig:figure ID).
```

The code will put a reference to “Figure XX”.

## 7.9. Subfigures

You can also create subfigures, using the following syntax.

```
<div figure-id="fig:big">
  <figcaption>Caption of big figure</figcaption>

  <div figure-id="subfig:first">
    <figcaption>Caption 1</figcaption>
    <p>Content of first subfig</p>
  </div>

  <div figure-id="subfig:second">
    <figcaption>Caption 2</figcaption>
    <p>Content of second subfig</p>
  </div>
</div>
```

Content of first subfig

(a) Caption 1

Content of second subfig

(b) Caption 2

Figure 10. Caption of big figure

## 7.10. Shortcut for tables

The shortcuts `col2`, `col3`, `col4`, `col5` are expanded in tables with 2, 3, 4 or 5 columns.

The following code:

```
<col2 figure-id="tab:mytable" figure-caption="My table">
  <span>A</span>
  <span>B</span>
  <span>C</span>
  <span>D</span>
</col2>
```

gives the following result:

TABLE 3. MY TABLE

A	B
C	D

### 1) `labels-row1` and `labels-row1`

---

Use the classes `labels-row1` and `labels-row1` to make pretty tables like the following.

`labels-row1`: the first row is the headers.

`labels-col1`: the first column is the headers.

TABLE 4. USING CLASS="LABELS-COL1"

header A	B	C	1
header D	E	F	2
header G	H	I	3

TABLE 5. USING CLASS="LABELS-ROW1"

header A	header B	header C
D	E	F
G	H	I
1	2	3

## 7.11. Linking to documentation

### 1) Establishing names of headers

You give IDs to headers using the format:

```
### header title {#topic ID}
```

For example, for this subsection, we have used:

```
### Establishing names of headers {#establishing}
```

With this, we have given this header the ID “establishing”.

### 2) Linking from the documentation to the documentation

You can use the syntax:

```
[](#topic ID)
```

to refer to the header.

You can also use some slightly more complex syntax that also allows to link to only the name, only the number or both ([Table 6](#)).

**TABLE 6. SYNTAX FOR REFERRING TO SECTIONS.**

See `[](#establishing)`.

See [Subsection 7.11.1](#)

See `<a class="only_name" href="#establishing"></a>`.

See [Establishing names of headers](#).

See `<a class="only_number" href="#establishing"></a>`.

See [7.11.1](#).

See `<a class="number_name" href="#establishing"></a>`.

See [Subsection 7.11.1 - Establishing names of headers](#).

### 3) Linking to the documentation from outside the documentation

You are encouraged to put links to the documentation from the code or scripts.

To do so, use links of the form:

`http://purl.org/dth/topic ID`

Here “`dth`” stands for “Duckietown Help”. This link will get redirected to the corresponding document on the website.

For example, you might have a script whose output is:

```
$ rosrun mypackage myscript
Error. I cannot find the scuderia file.
See: http://purl.org/dth/scuderia
```

When the user clicks on the link, they will be redirected to [Section 113.2](#).

## 7.12. Embedding videos

It is possible to embed Vimeo videos in the documentation.

**Note:** Do not upload the videos to your personal Vimeo account; they must all be posted to the Duckietown Engineering account.

This is the syntax:

```
<dvtvideo src="vimeo:vimeo ID"/>
```

*example*

For example, this code:

```
<div figure-id="fig:example-embed">
    <figcaption>Cool Duckietown by night</figcaption>
    <dtvideo src="vimeo:152825632"/>
</div>
```

produces this result:



Figure 11. Cool Duckietown by night

Depending on the output media, the result will change:

- On the online book, the result is that a player is embedded.
- On the e-book version, the result is that a thumbnail is produced, with a link to the video;
- On the dead-tree version, a thumbnail is produced with a QR code linking to the video (TODO).

## 7.13. Bibliography



You need to have installed `bibtex2html`.

The system supports Bibtex files.

Place `*.bib` files anywhere in the directory.

Then you can refer to them using the syntax:

```
[](#bib:bibtex_ID)
```

For example:

```
Please see [](#bib:siciliano07handbook).
```

Will result in:

Please see [\[3\]](#).

## 7.14. move-here tag



If a file contains the tag `move-here`, the fragment pointed by the `src` attribute is moved at

the place of the tag.

This is used for autogenerated documentation.

Syntax:

```
# Node `node`  
  
<move-here src="#package-node-autogenerated">
```

## 7.15. Comments

You can insert comments using the HTML syntax for comments: any text between “`<!--`” and “`-->`” is ignored.

```
# My section  
  
<!-- this text is ignored --&gt;<br/>  
Let's start by...
```

## 7.16. Special paragraphs tags

The system supports parsing of some special paragraphs.

Note that some of these might be redundant.

For now, documenting what is implemented.

### 1) Todos, task markers

---

TODO: todo

**TODO: todo**

TOWRITE: towrite

**To write: towrite**

Task: task

**Task: task**

Assigned: assigned

**Assigned to: assigned**

## 2) Notes and remarks



Remark: remark

| **Remark:** remark

Note: note

| **Note:** note

Symptom: symptom

| **Symptom:** symptom

Warning: warning

| **Warning:** warning

## 3) Troubleshooting



Symptom: symptom

| **Symptom:** symptom

Resolution: resolution

Resolution: resolution

## 4) Guidelines



Bad: bad

\* bad

Better: better

✓ better

## 5) Questions and answers



Q: question

*Q: question*

A: answer

**Answer:** answer

6) Authors, maintainers, point of contact

---

Maintainer: maintainer

**Maintainer:** maintainer

Author: author

**Author:** author

Point of contact: point of contact

**Point of contact:** point of contact

Slack channel: slack channel

**Slack channel:** slack channel

7) References

---

See: see

→ see

Reference: reference

→ reference

Requires: requires

|| **Requires:** requires

Recommended: recommended

| Recommended: recommended

See also: see also

\* *see also*

## 7.17. Div environments

For these, note the rules:

- You must include `markdown="1"`.
- There must be an empty line after the first `div` and before the closing `/div`.

### 1) Example usage

```
<div class='example-usage' markdown='1'>  
  
This is how you can use `rosbag`:  
  
    $ rosbag play log.bag  
  
</div>
```

*example*

This is how you can use `rosbag`:

`$ rosbag play log.bag`

### 2) Check

```
<div class='check' markdown='1'>  
  
Check that you didn't forget anything.  
  
</div>
```

**Check before you continue**

Check that you didn't forget anything.

### 3) Requirements

```
<div class='requirements' markdown='1'>  
  
List of requirements at the beginning of setup chapter.  
  
</div>
```

List of requirements at the beginning of setup chapter.

## 7.18. Referring to Github files

You can refer to files in the repository by using:

```
See [this file](github:org=org,repo=repo,path=path,branch=branch).
```

The available keys are:

- org (required): organization name (e.g. duckietown);
- repo (required): repository name (e.g. Software);
- path (required): the filename. Can be just the file name or also include directories;
- branch (optional) the repository branch; defaults to master;
- from\_text (optional);
- from\_line (optional);
- to\_text (optional);
- to\_line (optional).

For example, you can [refer to this exact line](#) by using:

```
See [this  
file](github:org=duckietown,repo=duckuments,path=65_docs_features.md,from_text=For%20example)
```

You can also [refer to a range](#).

You can copy the contents of a file by using the tag `display-file`:

```
<display-file src="github:path=65_docs_features.md"/>
```

```
[line]: github:org=duckietown,path=65_docs_features.md,repo=duckuments,from_text=For%20example
```

```
See [this  
file](github:org=duckietown,repo=duckuments,path=65_docs_features.md,from_text=For%20example)
```

```
[interval]:
```

```
github:org=duckietown,path=65_docs_features.md,repo=duckuments,from_text=exact%20line,to_text=display-file
```

Listing 2. [65\\_docs\\_features.md](#)

## CHAPTER 8

# Documentation style guide

This chapter describes the conventions for writing the technical documentation.

### 8.1. General guidelines for technical writing

The following holds for all technical writing.

- The documentation is written in correct English.
- Do not say “should” when you mean “must”. “Must” and “should” have precise meanings and they are not interchangeable. These meanings are explained [in this document](#).
- “Please” is unnecessary in technical documentation.
  - ✗ “Please remove the SD card.”
  - ✓ “Remove the SD card”.
- Do not use colloquialisms or abbreviations.
  - ✗ “The pwd is `ubuntu`.”
  - ✓ “The password is `ubuntu`.”
  - ✗ “To create a ROS pkg...”
  - ✓ “To create a ROS package...”
- Python is capitalized when used as a name.
  - ✗ “If you are using python...”
  - ✓ “If you are using Python...”
- Do not use emojis.
- Do not use ALL CAPS.
- Make infrequent use of **bold statements**.
- Do not use exclamation points.

### 8.2. Style guide for the Duckietown documentation

- It's ok to use “it's” instead of “it is”, “can't” instead of “cannot”, etc.
- All the filenames and commands must be enclosed in code blocks using Markdown backticks.
- `Ctrl-C`, ssh etc. are not verbs.
  - ✗ “`Ctrl-C` from the command line”.
  - ✓ “Use `Ctrl-C` from the command line”.
- Subtle humor and puns about duckies are encouraged.

### 8.3. Writing command lines

Use either “`laptop`” or “`duckiebot`” (not capitalized, as a hostname) as the prefix for the command line.

For example, for a command that is supposed to run on the laptop, use:

```
laptop $ cd ~/duckietown
```

It will become:

 `$ cd ~/duckietown`

For a command that must run on the Duckiebot, use:

```
duckiebot $ cd ~/duckietown
```

It will become:

 `$ cd ~/duckietown`

If the command is supposed to be run on both, omit the hostname:

```
$ cd ~/duckietown
```

## 8.4. Frequently misspelled words

- “Duckiebot” is always capitalized.
- Use “Raspberry Pi”, not “PI”, “raspi”, etc.
- These are other words frequently misspelled: 5 GHz WiFi

## 8.5. Other conventions

When the user must edit a file, just say: “edit `/this/file`”.

Writing down the command line for editing, like the following:

```
$ vi /this/file
```

is too much detail.

(If people need to be told how to edit a file, Duckietown is too advanced for them.)

## 8.6. Troubleshooting sections

Write the documentation as if every step succeeds.

Then, at the end, make a “Troubleshooting” section.

Organize the troubleshooting section as a list of symptom/resolution.

The following is an example of a troubleshooting section.

## 1) Troubleshooting

---

| **Symptom:** This strange thing happens.

Resolution: Maybe the camera is not inserted correctly. Remove and reconnect.

| **Symptom:** This other strange thing happens.

Resolution: Maybe the plumbus is not working correctly. Try reformatting the plumbus.

# CHAPTER 9

## Knowledge graph

**Note:** This chapter describes something that is not implemented yet.

### 9.1. Formalization

#### 1) Atoms

**Definition 2. (Atom)** An *atom* is a concrete resource (text, video) that is the smallest unit that is individually addressable. It is indivisible.

Each atom as a type, as follows:

```
text
  text/theory
  text/setup
  text/demo
  text/exercise
  text/reference
  text/instructor-guide
  text/quiz

video
  video/lecture
  video/instructable
  video/screencast
  video/demo
```

#### 2) Semantic graph of atoms

Atoms form a directed graph, called “semantic graph”.

Each node is an atom.

The graph has four different types of edges:

- “Requires” edges describe a strong dependency: “You need to have done this. Otherwise it will not work.”
- “Recommended” edges describe a weaker dependency; it is not strictly necessary to have done that other thing, but it will significantly improve the result of this.
- “Reference” edges describe background information. “If you don’t know / don’t remember, you might want to see this”
- “See also” edges describe interesting materials for the interested reader. Completely optional; it will not impact the result of the current procedure.

#### 3) Modules

A “module” is an abstraction from the point of view of the teacher.

**Definition 3. (Module)** A *module* is a directed graph, where the nodes are either atoms or other modules, and the edges can be of the four types described in [Subsection 9.1.2](#).

Because modules can contain other modules, they allow to describe hierarchical contents. For example, a class module is a module that contains other modules; a “degree” is a module that contains “class” modules, etc.

Modules can overlap. For example, a “Basic Object Detection” and an “Advanced Object Detection” module might have a few atoms in common.

## 9.2. Atoms properties



Each atom has the following properties:

- An ID (alphanumeric + - and ‘\_’). The ID is used for cross-referencing. It is the same in all languages.
- A type, as above.

There might be different versions of each atom. This is used primarily for dealing with translations of texts, different representations of the same image, Powerpoint vs Keynote, etc.

A version is a tuple of attributes.

The attributes are:

- Language: A [language code](#), such as en-US (default), zh-CN, etc.
- Mime type: a MIME type.

Each atom version has:

- A status value: one of draft, beta, ready, to-update ([Table 7](#)).
- A human-readable title.
- A human-readable summary (1 short paragraph).

TABLE 7. STATUS CODES

	We just started working on it, and it is not ready for public consumption.
draft	
beta	Early reviewers should look at it now.
ready	The document is ready for everybody.
to-up-	A new pass is needed on this document, because it is not up to date any-
date	more.

## 9.3. Markdown format for text-like atoms



For the text-like resources, they are described in Markdown files.

The name of the file does not matter.

All files are encoded in UTF-8.

Each file starts with a H1 header. The contents is the title.

The header has the following attributes:

1. The ID. ({#ID})
2. The language is given by an attribute lang ({lang=en-US}).
3. The type is given by an attribute type ({type=demo}).
4. The status is given by an attribute status ({status=draft}).

Here is an example of a header with all the attributes:

```
# Odometry calibration {#odometry-calibration lang=en-US type='text/theory' status=ready}
```

This first paragraph will be used as the "summary" for this text.

Listing 3. `calibration.en.md`

And this is how the Italian translation would look like:

```
# Calibrazione dell'odometria {#odometry-calibration lang=it type='text/theory' status=draft}
```

Questo paragrafo sarà usato come un sommario del testo.

Listing 4. `calibration.it.md`

## 9.4. How to describe the semantic graphs of atoms



In the text, you describe the semantic graph using tags and IDs.

In Markdown, you can give IDs to sections using the syntax:

```
# Setup step 1 {#setup-step1}
```

This is the first setup step.

Then, when you write the second step, you can add a semantic edge using the following.

```
# Setup step 2 {#setup-step2}
```

This is the second setup step.

Requires: You have completed the first step in [](#setup-step1).

The following table describes the syntax for the different types of semantic links:

TABLE 8. SEMANTIC LINKS

Requires	Requires: You need to have done [](#setup-step).
Recommended	Recommended: It is better if you have setup Wifi as in [](#setup-wifi).
Reference	Reference: For more information about <code>rostopic</code> , see [](#rostopic).
See also	See also: If you are interested in feature detection, you might want to learn about [SIFT](#SIFT).

## 9.5. How to describe modules



**TODO:** Define a micro-format for this.

# CHAPTER 10

## Translations

**Note:** This part is not implemented yet.

### 10.1. File organization

Translations are organized file-by-file.

For every file `name.md`, name the translated file `name.language code.md`, where the language code is one of the standard codes, and put it in the same directory.

For example, these could be a set of files, including a Chinese (simplified), Italian, and Spanish translation:

```
representations.md  
representations.zh-CN.md  
representations.it.md  
representations.es.md
```

The reason is that in this way you can check automatically from Git whether `representations.zh-CN.md` is up to date or `representations.md` has been modified since.

### 10.2. Guidelines for English writers

Here are some considerations for the writers of the original version, to make the translators' job easier.

It is better to keep files smallish so that (1) the translation tasks can feel approachable by translators; (2) it is easier for the system to reason about the files.

Name all the headers with short, easy identifiers, and never change them.

### 10.3. File format

All files are assumed to be encoded in UTF-8.

The header IDs should not be translated and should remain exactly the same. This will allow keeping track of the different translations.

For example, if this is the original version:

```
# Robot uprising {#robot-uprising}  
  
Hopefully it will never happen.
```

Then the translated version should be:

```
# La rivolta dei robot {#robot-uprising}
```

Speriamo che non succeda.

PART 3

## Operation manual - Duckiebot



## CHAPTER 11

# Duckiebot configurations

Here we define the different Duckiebot hardware configurations, and describe their functionalities. This is a good starting point if you are wondering what parts you should purchase to get started. Once you have decided which configuration best suits your needs, you can proceed to purchasing the components for a [C0+wd](#) or [C1](#) Duckiebot.

### 11.1. Configuration list

- Configuration `C0`: Only camera and motors.
- Configuration `C0+w`: `C0`, plus an additional wireless adapter.
- Configuration `C0+j`: `C0`, plus an additional wireless joypad for remote control.
- Configuration `C0+d`: `C0`, plus an additional USB drive.
- Configuration `C1`: `C0+w+jd`, plus LEDs and bumpers.

### 11.2. Configuration functionality

#### 1) `C0`

This is the minimal configuration for a Duckiebot. It will be able to navigate a Duckietown, but not communicate with other Duckiebots. It is the configuration of choice for tight budgets or when operation of a single Duckiebot is more of interest than fleet behaviours.

**TODO:** Insert pic of assembled Duckiebot in `C0` configuration.

#### 2) `C0+w`

In this configuration, the minimal `C0` version is augmented with a 5 GHz wireless adapter, which drastically improves connectivity. This feature is particularly useful in connection saturated environments, e.g., classrooms.

**TODO:** Insert pic of assembled Duckiebot in `C0+w` configuration.

#### 3) `C0+j`

In this configuration, the minimal `C0` version is augmented with a 2.4 GHz wireless joypad, used for manual remote control of the Duckiebot. It is particularly useful for getting the Duckiebot out of tight spots or letting younger ones have a drive.

**TODO:** Insert pic of assembled Duckiebot in `C0+j` configuration.

#### 4) `C0+d`

In this configuration, the minimal `C0` version is augmented with a USB flash hard drive. This drive is convenient for storing videos (logs) as it provides both extra capacity and faster data transfer rates than the microSD card in the Raspberry Pi. Moreover, it is easy

to unplug it from the Duckiebot at the end of teh day and bring it over to a computer for downloading and analyzing stored data.

**TODO:** Insert pic of assembled Duckiebot in `c0+d` configuration.

#### 5) C0+wjd

The upgrades of the minimal `c0` version are not mutually exclusive. We will refer to `C0+wjd` when any or all of the add-ons to the minimal version are considered.

**TODO:** Insert pic of assembled Duckiebot in `c0+wjd` configuration.

#### 6) C1

This is the ultimate Duckiebot configuration and it includes the necessary hardware for controlling and placing 5 RGB LEDs on the Duckiebot. It is the necessary configuration to enable communication between Duckiebots, hence fleet behaviours (e.g., negotiating crossing an intersection).

**TODO:** Insert pic of assembled Duckiebot in `c1` configuration.

## CHAPTER 12

# Acquiring the parts for the Duckiebot C0



The trip begins with acquiring the parts. Here, we provide a link to all bits and pieces that are needed to build a Duckiebot, along with their price tag. If you are wondering what is the difference between different Duckiebot configurations, read [this](#).

In general, keep in mind that:

- The links might expire, or the prices might vary.
- Shipping times and fees vary, and are not included in the prices shown below.
- Substitutions are OK for the mechanical components, and not OK for all the electronics, unless you are OK in writing some software.
- Buying the parts for more than one Duckiebot makes each one cheaper than buying only one.

| Requires: Cost: USD 159 + Shipping Fees (minimal configuration C0)

| Requires: Time: 15 days (average shipping for cheapest choice of components)

Results: A kit of parts ready to be assembled in a C0 or C0+wjd configuration.

Next Steps:

- After receiving these components, you are ready to do some [soldering](#) before [assembling](#) your C0 or C0+wjd Duckiebot.

TODO: Add a different “Tools” section in the table (e.g., solderer), or add in the resources beginning snippet; Differentiate pricing for bulk vs detail purchase (?)

### 12.1. Bill of materials



TABLE 9. BILL OF MATERIALS

<u>Chassis</u>	USD 20
<u>Camera with 160-FOV Fisheye Lens</u>	USD 22
<u>Camera Mount</u>	USD 8.50
<u>300mm Camera Cable</u>	USD 2
<u>Raspberry Pi 3 - Model B</u>	USD 35
<u>Heat Sinks</u>	USD 5
<u>Power supply for Raspberry Pi</u>	USD 7.50
<u>16 GB Class 10 MicroSD Card</u>	USD 10
<u>Mirco SD card reader</u>	USD 6
<u>Stepper Motor HAT</u>	USD 22.50
<u>Stacking Header</u>	USD 2.50/piece
<u>Battery</u>	USD 20
<u>16 Nylon Standoffs (M2.5 12mm F 6mm M</u>	USD 0.05/piece
<u>4 Nylon Hex Nuts (M2.5)</u>	USD 0.02/piece
<u>4 Nylon Screws (M2.5x10)</u>	USD 0.05/piece
<u>2 Zip Ties (300x5mm)</u>	USD 9
<u>Wireless Adapter (5 GHz) (Cθ+w)</u>	USD 20
<u>Joypad (Cθ+j)</u>	USD 10.50
<u>Tiny 32GB USB Flash Drive (Cθ+d)</u>	USD 12.50
Total for Cθ configuration	USD 159
Total for Cθ+w configuration	USD 179
Total for Cθ+j configuration	USD 169.50
Total for Cθ+d configuration	USD 171.50
Total for Cθ+wd configuration	USD 212

## 12.2. Chassis

We selected the Magician Chassis as the basic chassis for the robot ([Figure 12](#)).

We chose it because it has a double-decker configuration, and so we can put the battery in the lower part.

The chassis pack includes the motors and wheels as well as the structural part.



Figure 12. The Magician Chassis

## 12.3. Raspberry Pi 3 - Model B

The Raspberry Pi is the central computer of the Duckiebot. Duckiebots use Model B ([Figure 13](#)) (A1.2GHz 64-bit quad-core ARMv8 CPU, 1GB RAM), a small but powerful computer.



Figure 13. The Raspberry Pi 3 Model B

The price for this in the US is about USD 35.

### 1) Power Supply

---

We want a hard-wired power source (5VDC, 2.4A, Micro USB) to supply the Raspberry Pi ([Figure 14](#)).



Figure 14. The Power Supply

The price for this in the US is about USD 5-10.

### 2) Heat Sinks

---

The Raspberry Pi will heat up significantly during use. It is warmly recommended to add heat sinks, as in [Figure 15](#). Since we will be stacking HATs on top of the Raspberry Pi with 15 mm standoffs, the maximum height of the heat sinks should be well below 15 mm. The chip dimensions are 15x15mm and 10x10mm.



Figure 15. The Heat Sinks

### 3) Class 10 MicroSD Card

---

The MicroSD card ([Figure 16](#)) is the hard disk of the Raspberry Pi. 16 Gigabytes of capacity are sufficient for the system image.



Figure 16. The MicroSD card

#### 4) Mirco SD card reader

A microSD card reader ([Figure 17](#)) is useful to copy the system image to a Duckiebot from a computer to the Raspberry Pi microSD card, when the computer does not have a native SD card slot.



Figure 17. The Mirco SD card reader

### 12.4. Camera

The Camera is the main sensor of the Duckiebot. All versions equip a 5 Mega Pixels 1080p camera with wide field of view (160°) fisheye lens ([Figure 18](#)).



Figure 18. The Camera with Fisheye Lens

#### 1) Camera Mount

The camera mount ([Figure 19](#)) serves to keep the camera looking forward at the right angle to the road (looking slightly down). The front cover is not essential.

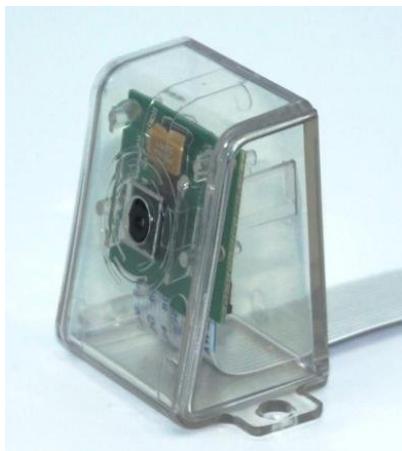


Figure 19. The Camera Mount

## 2) 300mm Camera Cable

A longer (300 mm) camera cable [Figure 20](#) make assembling the Duckiebot easier, allowing for more freedom in the relative positioning of camera and computational stack.

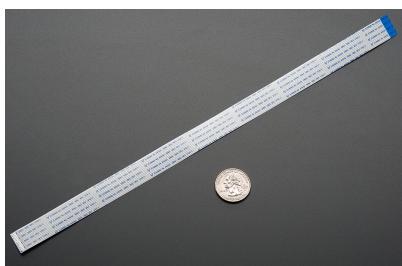


Figure 20. A 300 mm camera cable for the Raspberry Pi

## 12.5. DC Stepper Motor HAT

We use the DC Stepper motor HAT ([Figure 27](#)) to control the DC motors that drive the wheels. This item will require [soldering](#) to be functional.

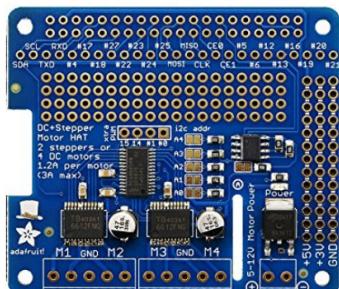


Figure 21. The Stepper Motor HAT

### 1) Stacking Headers

We use a long 20x2 stacking header ([Figure 22](#)) to connect the Raspberry Pi with the DC Stepper Motor HAT. This item will require [soldering](#) to be functional.

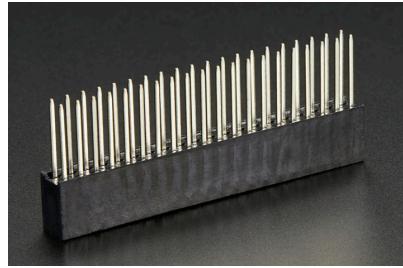


Figure 22. The Stacking Headers

### 12.6. Battery

The battery ([Figure 23](#)) provides power to the Duckiebot.

We choose this battery because it has a good combination of size (to fit in the lower deck of the Magician Chassis), high output amperage (2.4A and 2.1A at 5V DC) over two USB outputs, a good capacity (10400 mAh) at an affordable price.



Figure 23. The Battery

### 12.7. Standoffs, Nuts and Screws

We use non electrically conductive standoffs (M2.5 12mm F 6mm M), nuts (M2.5), and screws (M2.5x10mm) to hold the Raspberry Pi to the chassis and the HATs stacked on top of the Raspberry Pi.

The Duckiebot requires 8 standoffs, 4 nuts and 4 screws.

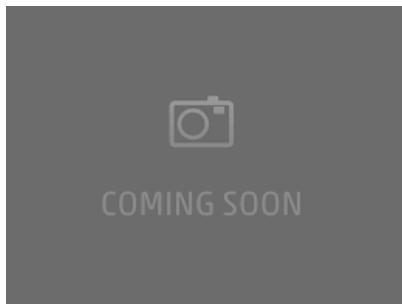


Figure 24. Standoffs, Nuts and Screws

## 12.8. Zip Tie

Two 300x5mm zip ties are needed to keep the battery at the lower deck from moving around.



Figure 25. The zip ties

## 12.9. Configuration C0-w

### 1) Wireless Adapter (5 GHz)

The Edimax AC1200 EW-7822ULC 5 GHz wireless adapter ([Figure 26](#)) boosts the connectivity of the Duckiebot, especially useful in busy Duckietowns (e.g., classroom).



Figure 26. The Edimax AC1200 EW-7822ULC wifi adapter

## 12.10. Configuration C0-j

### 1) Joypad

The joypad is used to manually remote control the Duckiebot. Any 2.4 GHz wireless controller (with a *tiny* USB dongle) will do.

The model linked in the table ([Figure 27](#)) does not include batteries.

| **Requires:** 2 AA 1.5V batteries.



Figure 27. A Wireless Joypad

**TODO:** Add figure with 2 AA batteries

## 12.11. Configuration C0-d

### 1) Tiny 32GB USB Flash Drive

In configuration C0+d, the Duckiebot is equipped with a “external” hard drive ([Figure 28](#)). This add-on is very convenient to store logs during experiments and later port them to a workstation for analysis. It provides storage capacity and faster data transfer than the MicroSD card.



Figure 28. The Tiny 32GB USB Flash Drive

## CHAPTER 13

# Soldering boards for C0



Assigned to: Shiyeng

Resources necessary:

Requires: Duckiebot ~~C0+wjd~~ parts. The acquisition process is explained in [Chapter 12](#). The configurations are described in [Chapter 11](#).

Requires: Time: ??? minutes

Results:

- ...

TODO: finish above

# CHAPTER 14

## Preparing the power cable for C0



In configuration C0 we will need a cable to power the DC motor HAT from the battery. The keen observer might have noticed that such a cable was not included in the [C0 Duckiebot parts](#) chapter. Here, we create this cable by splitting open any USB-A cable, identifying and stripping the power wires, and using them to power the DC motor HAT. If you are unsure about the definitions of the different Duckiebot configurations, read [Chapter 11](#).

It is important to note that these instructions are relevant only for assembling a C0+wd configuration Duckiebot. If you intend to build a C1 configuration Duckiebot, you can skip these instructions.

Resources necessary:

- | **Requires:** One male USB-A to anything cable.
- | **Requires:** A pair of scissors.
- | **Requires:** A multimeter (only if you are not purchasing the [suggested components](#))
- | **Requires:** Time: 5 minutes

Results: One male USB-A to wires power cable

### 14.1. Step 1: Find a cable



To begin with, find a male USB-A to anything cable.

If you have purchased the suggested components listed in [Chapter 12](#), you can use the longer USB cable contained inside the battery package ([Figure 29](#)), which will be used as an example in these instructions.



Figure 29. The two USB cables in the suggested battery pack.

Put the shorter cable back in the box, and open the longer cable ([Figure 30](#))



Figure 30. Take the longer cable, and put the shorter on back in the box.

#### 14.2. Step 2: Cut the cable



##### Check before you continue

Make sure the USB cable is *unplugged* from any power source before proceeding.

Take the scissors and cut it ([Figure 31](#)) at the desired length from the USB-A port.

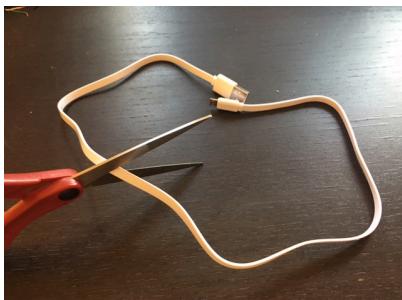


Figure 31. Cut the USB cable using the scissors.

The cut will look like in [Figure 32](#).



Figure 32. A cut USB cable.

#### 14.3. Step 3: Strip the cable



Paying attention not to get hurt, strip the external white plastic. A way to do so without damaging the wires is shown in [Figure 33](#).



Figure 33. Stripping the external layer of the USB cable.

After removing the external plastic, you will see four wires: black, green, white and red ([Figure 34](#)).

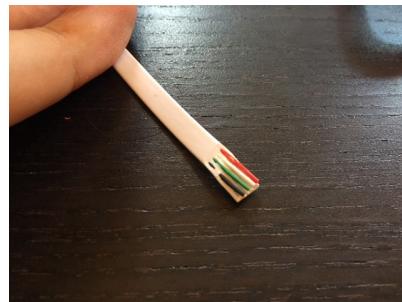


Figure 34. Under the hood of a USB-A cable.

Once the bottom part of the external cable is removed, you will have isolated the four wires ([Figure 35](#)).

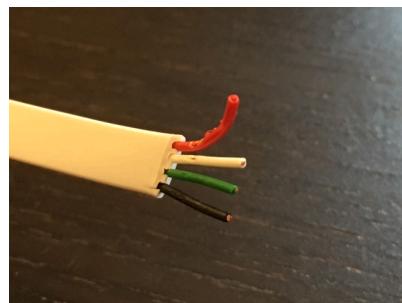


Figure 35. The four wires inside a USB-A cable.

#### 14.4. Step 3: Strip the wires

##### Check before you continue

Make sure the USB cable is *unplugged* from any power source before proceeding.

Once you have isolated the wires, strip them, and use the scissors to cut off the data wires (green and white, central positions) ([Figure 36](#)).



Figure 36. Strip the power wires and cut the data wires.

If you are not using the suggested cable, or want to verify which are the data and power wires, continue reading.

#### 14.5. Step 4: Find the power wires

If you are using the USB-A cable from the suggested battery pack, black and red are the power wires and green and white are instead for data.

If you are using a different USB cable, or are curious to verify that black and red actually are the power cables, take a multimeter and continue reading.

Plug the USB port inside a power source, e.g., the Duckiebot's battery. You can use some scotch tape to keep the cable from moving while probing the different pairs of wires with a multimeter. The voltage across the pair of power cables will be roughly twice the voltage between a power and data cable. The pair of data cables will have no voltage differential across them. If you are using the suggested Duckiebot battery as power source, you will measure around 5V across the power cables ([Figure 37](#)).

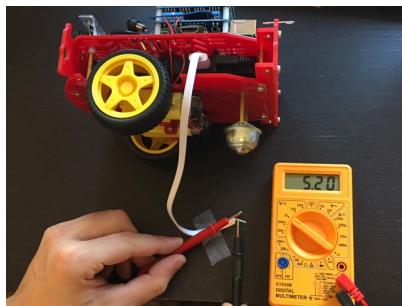


Figure 37. Finding which two wires are for power.

#### 14.6. Step 5: Test correct operation

You are now ready to secure the power wires to the DC motor HAT power pins. To do so though, you need to have soldered the boards first. If you have not done so yet, read [Chapter 13](#).

If you have soldered the boards already, you may test correct functionality of the newly crafted cable. Connect the battery with the DC motor HAT by making sure you plug the black wire in the pin labeled with a minus: - and the red wire to the plus: + ([Figure 38](#)).

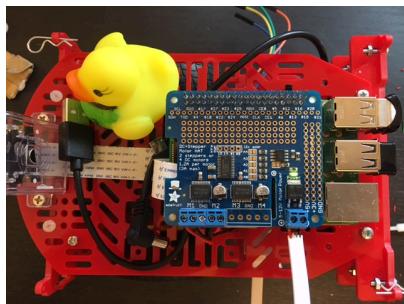


Figure 38. Connnect the power wires to the DC motor HAT

If the green LED turns on, the DC motor HAT is receving power.

## CHAPTER 15

# Assembling the Duckiebot C0

•

Assigned to: Shiyiing

Requires: Duckiebot `C0+wjd` parts. The acquisition process is explained in [Chapter 12](#).

Requires: Having soldered the `C0+wjd` parts. The soldering process is explained in [Chapter 13](#).

Requires: Having prepared the power cable. The power cable preparation is explained in [Chapter 14](#).

Requires: Time: about ??? minutes.

**TODO:** estimate time.

Results: An assembled Duckiebot in configuration `C0+wjd`.

Shiyiing: here will be the instruction about assembling the Duckiebot.

# CHAPTER 16

## Reproducing the image

Assigned to: Andrea

These are the instructions to reproduce the Ubuntu image that we use.

Please note that the image is already available, so you don't need to do this manually. However, this documentation might be useful if you would like to port the software to a different distribution.

Resources necessaries:

- ─ **Requires:** Internet connection to download the packages.
- ─ **Requires:** A PC running any Linux with an SD card reader.
- ─ **Requires:** Time: about 20 minutes.

Results:

- A baseline Ubuntu Mate 16.04.2 image with updated software.

### 16.1. Download and uncompress the Ubuntu Mate image

Download the image from the page

<https://ubuntu-mate.org/download/>

The file we are looking for is:

```
filename: ubuntu-mate-16.04.2-desktop-armhf-raspberry-pi.img.xz
size: 1.2 GB
SHA256: dc3afcad68a5de3ba683dc30d2093a3b5b3cd6b2c16c0b5de8d50fede78f75c2
```

After download, run the command `sha256sum` to make sure you have the right version:



```
$ sha256sum ubuntu-mate-16.04.2-desktop-armhf-raspberry-pi.img.xz
dc3afcad68a5de3ba683dc30d2093a3b5b3cd6b2c16c0b5de8d50fede78f75c2
```

If the string does not correspond exactly, your download was corrupted. Delete the file and try again.

Then decompress using the command `xz`:



```
$ xz -d ubuntu-mate-16.04.2-desktop-armhf-raspberry-pi.img.xz
```

### 16.2. Burn the image to an SD card

Next, burn the image on to the SD card.

- This procedure is explained in [Section 98.2](#).

### 1) Verify that the SD card was created correctly

Remove the SD card and plug it in again in the laptop.

Ubuntu will mount two partitions, by the name of `PI_ROOT` and `PI_BOOT`.

### 2) Installation

Boot the disk in the Raspberry Pi.

Choose the following options:

```
language: English  
username: ubuntu  
password: ubuntu  
hostname: duckiebot
```

Choose the option to log in automatically.

Reboot.

### 3) Update installed software

The WiFi was connected to airport network `duckietown` with password `quackquack`.

Afterwards I upgraded all the software preinstalled with these commands:



```
$ sudo apt update  
$ sudo apt dist-upgrade
```

Expect `dist-upgrade` to take quite a long time (up to 2 hours).

## 16.3. Raspberry Pi Config

The Raspberry Pi is not accessible by SSH by default.

Run `raspi-config`:



```
$ sudo raspi-config
```

choose “3. Interfacing Options”, and enable SSH,

We need to enable the camera and the I2C bus.

choose “3. Interfacing Options”, and enable camera, and I2C.

Also disable the graphical boot

## 16.4. Install packages

Install these packages.

Etkeeper:



```
$ sudo apt install etckeeper
```

Editors / shells:



```
$ sudo apt install -y vim emacs byobu zsh
```

Git:



```
$ sudo apt install -y git git-extras
```

Other:



```
$ sudo apt install htop atop nethogs iftop  
$ sudo apt install aptitude apt-file
```

Development:



```
$ sudo apt install -y build-essential libblas-dev liblapack-dev libatlas-base-dev gfortran  
libyaml-cpp-dev
```

Python:



```
$ sudo apt install -y python-dev ipython python-sklearn python-smbus  
$ sudo apt install -y python-termcolor  
$ sudo pip install scipy --upgrade
```

I2C:



```
$ sudo apt install -y i2c-tools
```

## 16.5. Install Edimax driver



First, mark the kernel packages as not upgradeable:

```
$ sudo apt-mark hold raspberrypi-kernel raspberrypi-kernel-headers  
raspberrypi-kernel set on hold.  
raspberrypi-kernel-headers set on hold
```

Then, download and install the Edimax driver from [this repository](#).

```
$ git clone git@github.com:duckietown/rtl8822bu.git  
$ cd rtl8822bu  
$ make  
$ sudo make install
```

## 16.6. Install ROS

Install ROS.

- The procedure is given in [Section 110.1](#).

## 16.7. Wireless configuration (old version)

This is the old version.

There are two files that are important to edit.

The file `/etc/network/interfaces` should look like this:

```
# interfaces(5) file used by ifup(8) and ifdown(8)  
# Include files from /etc/network/interfaces.d:  
#source-directory /etc/network/interfaces.d  
  
auto wlan0  
  
# The loopback network interface  
auto lo  
iface lo inet loopback  
  
# Wireless network interface  
allow-hotplug wlan0  
iface wlan0 inet dhcp  
wpa-conf /etc/wpa_supplicant/wpa_supplicant.conf  
iface default inet dhcp
```

The file `/etc/wpa_supplicant/wpa_supplicant.conf` should look like this:

```
ctrl_interface=DIR=/var/run/wpa_supplicant GROUP=netdev
update_config=1

network={
ssid="duckietown"
psk="quackquack"
proto=RSN
key_mgmt=WPA-PSK
pairwise=CCMP
auth_alg=OPEN
}
network={
    key_mgmt=NONE
}
```

## 16.8. Wireless configuration

The files that describe the network configuration are in the directory

```
/etc/NetworkManager/system-connections/
```

This is the contents of the connection file `duckietown`, which describes how to connect to the `duckietown` wireless network:

```
[connection]
id=duckietown
uuid=e9cef1bd-f6fb-4c5b-93cf-cca837ec35f2
type=wifi
permissions=
secondaries=
timestamp=1502254646

[wifi]
mac-address-blacklist=
mac-address-randomization=0
mode=infrastructure
ssid=duckietown

[wifi-security]
group=
key-mgmt=wpa-psk
pairwise=
proto=
psk=quackquack

[ipv4]
dns-search=
method=auto

[ipv6]
addr-gen-mode=stable-privacy
dns-search=
ip6-privacy=0
method=auto
```

This is the file

```
/etc/NetworkManager/system-connections/create-5ghz-network
```

Contents:

```
[connection]
id=create-5ghz-network
uid=7331d1e7-2cdf-4047-b426-c170ecc16f51
type=wifi
# Put the Edimax interface name here:
interface-name=wlx74da38c9caa0 - to change
permissions=
secondaries=
timestamp=1502023843

[wifi]
band=a
# Put the Edimax MAC address here
mac-address=74:DA:38:C9:CA:A0 - to change
mac-address-blacklist=
mac-address-randomization=@
mode=ap
seen-bssids=
ssid=duckiebot-not-configured

[ipv4]
dns-search=
method=shared

[ipv6]
addr-gen-mode=stable-privacy
dns-search=
ip6-privacy=@
method=ignore
```

Note that there is an interface name and MAC address that need to be changed on each PI.

## 16.9. SSH server config

This enables the SSH server:

```
$ sudo systemctl enable ssh
```

## 16.10. Create swap Space

Do the following:

Create an empty file using the `dd` (device-to-device copy) command:



```
$ sudo dd if=/dev/zero of=/swap0 bs=1M count=512
```

This is for a 512 MB swap space.

Format the file for use as swap:

 \$ sudo mkswap /swap0

Add the swap file to the system configuration:

 \$ sudo vi /etc/fstab

Add this line to the bottom:

/swap0 swap swap

Activate the swap space:

 \$ sudo swapon -a

## 16.11. Passwordless sudo

First, make `vi` the default editor, using

\$ sudo update-alternatives --config editor

and then choose `vim.basic`.

Then run:

\$ sudo visudo

And then change this line:

%sudo ALL=(ALL:ALL) ALL

into this line:

%sudo ALL=(ALL:ALL) NOPASSWD:ALL

## 16.12. Clean up

You can use the command `dpkg` to find out which packages take lots of space.

\$ sudo apt install wajig debian-goodies

Either:

```
$ wajig large  
$ dpigs -H -n 20
```

Stuff to remove:

```
$ sudo apt remove thunderbird  
$ sudo apt remove libreoffice-*  
$ sudo apt remove openjdk-8-jre-headless  
$ sudo apt remove fonts-noto-cjk  
$ sudo apt remove brasero
```

At the end, remove extra dependencies:

```
$ sudo apt autoremove
```

And remove the `apt` cache using:

```
$ sudo apt clean
```

The total size should be around 6.6GB.

### 16.13. Ubuntu user configuration

#### 1) Groups

You should make the `ubuntu` user belong to the `i2c` and `input` groups:



```
$ sudo adduser ubuntu i2c  
$ sudo adduser ubuntu input
```

: forgot to add to aug20 image:



```
$ sudo adduser ubuntu video
```

You may need to do the following (but might be done already through `raspi-config`):



```
$ sudo udevadm trigger
```

#### 2) Basic SSH config

Do the basic SSH config.

→ The procedure is documented in [Section 100.3](#).

**Note:** this is not in the aug10 image.

### 3) Passwordless SSH config

Add `.authorized_keys` so that we can all do passwordless SSH.

The key is at the URL

[https://www.dropbox.com/s/pxyou3qy1p8m4d0/duckietown\\_key1.pub?dl=1](https://www.dropbox.com/s/pxyou3qy1p8m4d0/duckietown_key1.pub?dl=1)

Download to `.ssh/authorized_keys`:

 \$ curl -o .ssh/authorized\_keys URL above

### 4) Shell prompt

Add the following lines to `~ubuntu/.bashrc`:

```
echo ""
echo "Welcome to a duckiebot!"
echo ""
echo "Reminders:"
echo ""
echo "1) Do not use the user 'ubuntu' for development – create your own user."
echo "2) Change the name of the robot from 'duckiebot' to something else."
echo ""

export EDITOR=vim
```

## 16.14. Check that all required packages were installed

At this point, before you copy/distribute the image, create a user, install the software, and make sure that `what-the-duck` does not complain about any missing package.

(Ignore `what-the-duck`'s errors about things that are not set up yet, like users.)

## 16.15. Creating the image

You may now want to create an image that you can share with your friends. They will think you are cool because they won't have to duplicate all of the work that you just did. Luckily this is easy. Just power down the duckiebot with:

 \$ sudo shutdown -h now

and put the SD card back in your laptop.

- The procedure of how to burn an image is explained in [Section 98.2](#); except you will invert the `if` and `of` destinations.

You may want to subsequently shrink the image, for example if your friends have smaller SD cards than you.

- The procedure of how to shrink an image is explained in [Section 98.3](#).

## 16.16. Some additions since last image to add in the next image



Note here the additions since the last image was created.

Create a file

```
/etc/duckietown-image.yaml
```

Containing these lines

```
base: Ubuntu 16.04.2
date: DATE
comments: |
    any comments you have
```

So that we know which image is currently in used.

Install `ntpdate`:

```
$ sudo apt install ntpdate
```

**Note:** We should install Git LFS on the Raspberry Pi, but so far AC did not have any luck. See [Section 108.1](#).

## CHAPTER 17

# Installing Ubuntu on laptops



Assigned to: Andrea

Before you prepare the Duckiebot, you need to have a laptop with Ubuntu installed.

Requires: A laptop with free disk space.

Requires: Internet connection to download the Ubuntu image.

Requires: About ??? minutes.

Results: A laptop ready to be used for Duckietown.

### 17.1. Install Ubuntu



Install Ubuntu 16.04.2.

→ For instructions, see for example [this online tutorial](#).

**On the choice of username:** During the installation, create a user for yourself with a username different from `ubuntu`, which is the default. Otherwise, you may get confused later.

### 17.2. Install useful software



Use `etckeeper` to keep track of the configuration in `/etc`:

 \$ sudo apt install etckeeper

Install `ssh` to login remotely and the server:

 \$ sudo apt install ssh

Use `byobu`:

 \$ sudo apt install byobu

Use `vim`:

 \$ sudo apt install vim

Use `htop` to monitor CPU usage:

 \$ sudo apt install htop

Additional utilities for `git`:

 `$ sudo apt install git git-extras`

Other utilities:

 `$ sudo apt install avahi-utils ecryptfs-utils`

### 17.3. Install ROS

Install ROS on your laptop.

- The procedure is given in [Section 110.1](#).

### 17.4. Other suggested software

#### 1) Redshift

This is Flux for Linux. It is an accessibility/lab safety issue: bright screens damage eyes and perturb sleep [\[4\]](#).

Install redshift and run it.

 `$ sudo apt install redshift-gtk`

Set to “autostart” from the icon.

### 17.5. Installation of the duckuments system

Optional but very encouraged: install the duckuments system. This will allow you to have a local copy of the documentation and easily submit questions and changes.

- The procedure is documented in [Section 6.4](#).

### 17.6. Passwordless sudo

Set up passwordless `sudo`.

- This procedure is described in [Section 16.11](#).

### 17.7. SSH and Git setup

#### 1) Basic SSH config

Do the basic SSH config.

- The procedure is documented in [Section 100.3](#).

## 2) Create key pair for `username`

---

Next, create a private/public key pair for the user; call it `username@robot name`.

- The procedure is documented in [Section 100.5](#).

## 3) Add `username`'s public key to Github

---

Add the public key to your Github account.

- The procedure is documented in [Section 109.3](#).

If the step is done correctly, this command should succeed:



```
$ ssh -T git@github.com
```

## 4) Local Git setup

---

Set up Git locally.

- The procedure is described in [Section 107.3](#).

# CHAPTER 18

## Duckiebot Initialization

Assigned to: Andrea

Requires: An SD card of dimensions at least ??? GB.

Requires: A computer with an internet connection, an SD card reader, and 35 GB of free space.

Requires: An assembled Duckiebot in configuration D17-C0. This is the result of [Chapter 15](#).

Results: A Duckiebot that is ready to use.

What does it mean “ready to use”?

### 18.1. Acquire and burn the image

On the laptop, download the compressed image at this URL:

<https://www.dropbox.com/s/1p4am7erdd9e53r/duckiebot-RPI3-AC-aug10.img.xz?dl=1>

The size is 2.5 GB.

You can use:

```
$ curl -o duckiebot-RPI3-AC-aug10.img.xz URL above
```

Uncompress the file:

```
$ xz -d -k duckiebot-RPI3-AC-aug10.img.xz
```

This will create a file of 32 GB in size.

To make sure that the image is downloaded correctly, compute its hash using the program sha256sum:

```
$ sha256sum duckiebot-RPI3-AC-aug10.img
2ea79b0fc63533610f63c89977417fc5e8fde70611e8afa5cbf2d3a166d57e8cf duckiebot-ac-aug10.img
```

Compare the hash that you obtain with the hash above. If they are different, there was some problem in downloading the image.

Next, burn the image on disk.

→ The procedure of how to burn an image is explained in [Section 98.2](#).

### 18.2. Turn on the Duckiebot

Put the SD Card in the Duckiebot.

Turn on the Duckiebot by connecting the power cable to the battery.

**TODO:** Add figure

### 18.3. Connect the Duckiebot to a network

You can login to the Duckiebot in two ways:

1. Through an Ethernet cable.
2. Through a duckietown WiFi network.

In the worst case, you can use an HDMI monitor and a USB keyboard.

#### 1) Option 1: Ethernet cable

Connect the Duckiebot and your laptop to the same network switch.

Allow 30 s - 1 minute for the DHCP to work.

#### 2) Option 2: Duckietown network

The Duckiebot connects automatically to a 2.4 GHz network called “`duckietown`” and password “`quackquack`”.

Connect your laptop to the same wireless network.

### 18.4. Ping the Duckiebot

To test that the Duckiebot is connected, try to ping it.

The hostname of a freshly-installed duckiebot is `duckiebot-not-configured`:

 \$ ping `duckiebot-not-configured.local`

You should see output similar to the following:

```
PING duckiebot-not-configured.local (X.X.X.X): 56 data bytes  
64 bytes from X.X.X.X: icmp_seq=0 ttl=64 time=2.164 ms  
64 bytes from X.X.X.X: icmp_seq=1 ttl=64 time=2.303 ms  
...
```

### 18.5. SSH to the Duckiebot

Next, try to log in using SSH, with account `ubuntu`:

 \$ ssh `ubuntu@duckiebot-not-configured.local`

The password is `ubuntu`.

By default, the robot boots into Byobu.

Please see [Chapter 106](#) for an introduction to Byobu.

Not sure it's a good idea to boot into Byobu.

## 18.6. (For D17-C1) Configure the robot-generated network

D17-0+w The Duckiebot in configuration D17-C0+w can create a WiFi network.  
It is a 5 GHz network; this means that you need to have a 5 GHz WiFi adapter in your laptop.

First, make sure that the Edimax is correctly installed. Using `iwconfig`, you should see four interfaces:



```
$ iwconfig  
wlan0 unassociated Nickname:"rt18822bu"  
...  
lo      no wireless extensions.  
  
enx027eb1f81a4  no wireless extensions.  
  
wlan1    IEEE 802.11bgn  ESSID:"duckietown"  
...  
...
```

Make note of the name `wlxAABBCCDDEEFFGG`.

Look up the MAC address using the command:



```
$ ifconfig wlan0  
wlan0 Link encap:Ethernet  HWaddr AA:BB:CC:DD:EE:FF:GG
```

Then, edit the connection file

```
/etc/NetworkManager/system-connections/create-5ghz-network
```

Make the following changes:

- Where it says `interface-name=...`, put “`wlxAABBCCDDEEFFGG`”.
- Where it says `mac-address=...`, put “`AA:BB:CC:DD:EE:FF:GG`”.
- Where it says `ssid=duckiebot-not-configured`, put “`ssid=robot name`”.

Reboot.

At this point you should see a new network being created named “`robot name`”.

You can connect with the laptop to that network.

If the Raspberry Pi’s network interface is connected to the `duckietown` network and to the internet, the Raspberry Pi will act as a bridge to the internet.

## 18.7. Setting up wireless network configuration

This part should not be necessary anymore

The Duckiebot is configured by default to connect to a wireless network with SSID `duckietown`. If that is not your SSID then you will need to change the configuration.

You can add a new network by editing the file:

```
/etc/wpa_supplicant/wpa_supplicant.conf
```

You will see a block like the following:

```
network={  
    ssid="duckietown"  
    scan_ssid=1  
    psk="quackquack"  
    priority=10  
}
```

Add a new one with your SSID and password.

This assumes you have a roughly similar wireless network setup - if not then you might need to change some of the other attributes.

## 18.8. Update the system

Next, we need to update to bring the system up to date.

Use these commands



```
$ sudo apt update  
$ sudo apt dist-upgrade
```

## 18.9. Give a name to the Duckiebot

It is now time to give a name to the Duckiebot.

These are the criteria:

- It should be a simple alphabetic string (no numbers or other characters like “-”, “\_”, etc.).
- It will always appear lowercase.
- It cannot be a generic name like “duckiebot”, “robot” or similar.

From here on, we will refer to this string as “`robot name`”. Every time you see `robot name`, you should substitute the name that you chose.

## 18.10. Change the hostname

We will put the robot name in configuration files.

**Note:** Files in `/etc` are only writable by `root`, so you need to use `sudo` to edit them. For example:



```
$ sudo vi filename
```

Edit the file

```
/etc/hostname
```

and put “`robot name`” instead of `duckiebot-not-configured`.

Also edit the file

```
/etc/hosts
```

and put “`robot name`” where `duckiebot-not-configured` appears.

The first two lines of `/etc/hosts` should be:

```
127.0.0.1 localhost  
127.0.1.1 robot name
```

**Note:** there is a command `hostname` that promises to change the hostname. However, the change given by that command does not persist across reboots. You need to edit the files above for the changes to persist.

**Note:** Never add other hostnames in `/etc/hosts`. It is a tempting fix when DNS does not work, but it will cause other problems subsequently.

Then reboot the Raspberry Pi using the command

```
$ sudo reboot
```

After reboot, log in again, and run the command `hostname` to check that the change has persisted:

```
$ hostname  
robot name
```

## 18.11. Expand your filesystem

If your SD card is larger than the image, you’ll want to expand the filesystem on your robot so that you can use all of the space available. Achieve this with:



```
$ sudo raspi-config --expand-rootfs
```

and then reboot



```
$ sudo shutdown -r now
```

once rebooted you can test whether this was successful by doing



```
$ df -lh
```

the output should give you something like:

Filesystem	Size	Used	Avail	Use%	Mounted on
/dev/root	29G	7.8G	21G	28%	/
devtmpfs	427M	0	427M	0%	/dev
tmpfs	432M	316K	431M	1%	/dev/shm
tmpfs	432M	12M	420M	3%	/run
tmpfs	5.0M	4.0K	5.0M	1%	/run/lock
tmpfs	432M	0	432M	0%	/sys/fs/cgroup
/dev/mmcblk0p1	63M	21M	43M	34%	/boot
tmpfs	87M	24K	87M	1%	/run/user/1000
/dev/sda1	29G	5.3G	24G	19%	/media/ubuntu/44A7-9E91

You should see that the Size of your `/dev/sda1` partition is “close” to the side of your SD card.

## 18.12. Create your user

You must not use the `ubuntu` user for development. Instead, you need to create a new user.

Choose a user name, which we will refer to as `username`.

To create a new user:



```
$ sudo useradd -m username
```

Make the user an administrator by adding it to the group `sudo`:



```
$ sudo adduser username sudo
```

Make the user a member of the group `input` and `i2c`



```
$ sudo adduser username input
$ sudo adduser username video
$ sudo adduser username i2c
```

Set the shell `bash`:



```
$ sudo chsh -s /bin/bash username
```

To set a password, use:



```
$ sudo passwd username
```

At this point, you should be able to login to the new user from the laptop using the password:

 \$ ssh **username@robot name**

Next, you should repeat some steps that we already described.

### 1) Basic SSH config

Do the basic SSH config.

- The procedure is documented in [Section 100.3](#).

### 2) Create key pair for **username**

Next, create a private/public key pair for the user; call it **username@robot name**.

- The procedure is documented in [Section 100.5](#).

### 3) Add **username**'s public key to Github

Add the public key to your Github account.

- The procedure is documented in [Section 109.3](#).

If the step is done correctly, this command should succeed:

 \$ ssh -T git@github.com

### 4) Local Git configuration

- This procedure is in [Section 107.3](#).

### 5) Set up the laptop-Duckiebot connection

Make sure that you can login passwordlessly to your user from the laptop.

- The procedure is explained in [Section 100.6](#). In this case, we have: **local** = laptop, **local-user** = your local user on the laptop, **remote** = **robot name**, **remote-user** = **username**.

If the step is done correctly, you should be able to login from the laptop to the robot, without typing a password:

 \$ ssh **username@robot name**

### 6) Some advice on the importance of passwordless access

In general, if you find yourself:

- typing an IP
- typing a password
- typing ssh more than once
- using a screen / USB keyboard

it means you should learn more about Linux and networks, and you are setting yourself up for failure.

Yes, you “can do without”, but with an additional 30 seconds of your time. The 30 seconds you are not saving every time are the difference between being productive roboticians and going crazy.

Really, it is impossible to do robotics when you have to think about IPs and passwords...

### 18.13. Other customizations

If you know what you are doing, you are welcome to install and use additional shells, but please keep Bash as be the default shell. This is important for ROS installation.

For the record, our favorite shell is ZSH with `oh-my-zsh`.

### 18.14. Hardware check: camera

Check that the camera is connected using this command:



```
$ vcgencmd get_camera
supported=1 detected=1
```

If you see `detected=0`, it means that the hardware connection is not working.

You can test the camera right away using a command-line utility called `raspistill`.

Use the `raspistill` command to capture the file `out.jpg`:



```
$ raspistill -t 1 -o out.jpg
```

Then download `out.jpg` to your computer using `scp` for inspection.

- For instructions on how to use `scp`, see [Subsection 102.1.1](#).

#### 1) Troubleshooting

**Symptom:** `detected=0`

**Resolution:** If you see `detected=0`, it is likely that the camera is not connected correctly.

If you see an error that starts like this:

```
mmal: Cannot read camera info, keeping the defaults for OV5647
...
mmal: Camera is not detected. Please check carefully the camera module is installed correctly.
```

then, just like it says: “Please check carefully the camera module is installed correctly.”.

# CHAPTER 19

## Software setup and RC remote control

Assigned to: Andrea

Requires: Laptop configured, according to [Chapter 17](#).

Requires: You have configured the Duckiebot. The procedure is documented in [Chapter 18](#).

Requires: You have created a Github account and configured public keys, both for the laptop and for the Duckiebot. The procedure is documented in [Chapter 109](#).

Results: You can run the joystick demo.

### 19.1. Clone the Duckietown repository

Clone the repository in the directory `~/duckietown`:

 \$ git clone git@github.com:duckietown/Software.git ~/duckietown

For the above to succeed you should have a Github account already set up.

It should not ask for a password.

#### 1) Troubleshooting

**Symptom:** It asks for a password.

Resolution: You missed some of the steps described in [Chapter 109](#).

**Symptom:** Other weird errors.

Resolution: Probably the time is not set up correctly. Use `ntpdate` as above:

 \$ sudo ntpdate -u us.pool.ntp.org

### 19.2. Set up ROS environment on the Duckiebot

All the following commands should be run in the `~/duckietown` directory:

 \$ cd ~/duckietown

Now we are ready to make the workspace. First you need to source the baseline ROS environment:

 \$ source /opt/ros/kinetic/setup.bash

Then, build the workspace using:

 \$ catkin\_make -C catkin\_ws/

\* For more information about `catkin_make`, see [Section 110.6](#).

**Note:** there is a known bug, for which it fails the first time on the Raspberry Pi. Try again; it will work.

### 19.3. Add your vehicle to the scuderia file

Add your vehicle to the scuderia file.

→ See [Section 113.2](#).

### 19.4. Test that the joystick is detected

Plug the joystick receiver in one of the USB port on the Raspberry Pi.

To make sure that the joystick is detected, run:

```
raspberry $ ls /dev/input/
```

and check if there is a device called `js0` on the list.

#### Check before you continue

Make sure that your user is in the group `input` and `i2c`:

```
raspberry $ groups  
username sudo input i2c
```

If `input` and `i2c` are not in the list, you missed a step. Ohi oh! You are not following the instructions carefully!

→ Consult again [Section 18.12](#).

To test whether or not the joystick itself is working properly, run:

```
raspberry $ jstest /dev/input/js0
```

Move the joysticks and push the buttons. You should see the data displayed change according to your actions.

### 19.5. Run the joystick demo

SSH into the Raspberry Pi and run the following from the `duckietown` directory:

```
raspberry $ cd ~/duckietown  
$ source environment.sh
```

The `environment.sh` setups the ROS environment at the terminal (so you can use commands like `rosrun` and `roslaunch`).

Now make sure the motor shield is connected.

Run the command:



```
$ roslaunch duckietown joystick.launch veh:=robot_name
```

If there is no “red” output in the command line then pushing the left joystick knob controls throttle - right controls steering.

This is the expected result of the commands:

left joystick up	forward
left joystick down	backward
right joystick left	turn left (positive yaw)
right joystick right	turn right (negative yaw)

It is possible you will have to unplug and replug the joystick or just push lots of buttons on your joystick until it wakes up. Also make sure that the mode switch on the top of your joystick is set to “X”, not “D”.

Is all of the above valid with the new joystick?

Close the program using `Ctrl-C`.

## 1) Troubleshooting

**Symptom:** The robot moves weirdly (e.g. forward instead of backward).

**Resolution:** The cables are not correctly inserted. Please refer to the assembly guide for pictures of the correct connections. Try swapping cables until you obtain the expected behavior.

**Resolution:** Check that the joystick has the switch set to the position “x”. And the mode light should be off.

**Symptom:** The left joystick does not work.

**Resolution:** If the green light on the right to the “mode” button is on, click the “mode” button to turn the light off. The “mode” button toggles between left joystick or the cross on the left.

**Symptom:** The robot does not move at all.

**Resolution:** The cables are disconnected.

**Resolution:** The program assumes that the joystick is at `/dev/input/js0`. In doubt, see [Section 19.4](#).

## 19.6. The proper shutdown procedure for the Raspberry Pi

Generally speaking, you can terminate any `roslaunch` command with `Ctrl-C`.

To completely shutdown the robot, issue the following command:



```
$ sudo shutdown -h now
```

Then wait 30 seconds.

Warning: If you disconnect the power before shutting down properly using `shutdown`, the system might get corrupted.

Then, disconnect the power cable, at the **battery end**.

Warning: If you disconnect frequently the cable at the Raspberry Pi's end, you might damage the port.

# CHAPTER 20

## Reading from the camera



**Requires:** You have configured the Duckiebot. The procedure is documented in [Chapter 18](#).

**Requires:** You know the basics of ROS (launch files, `roslaunch`, topics, `rostopic`).

**TODO:** put reference

Results: You know that the camera works under ROS.



### 20.1. Check the camera hardware



It might be useful to do a quick camera hardware check.

- The procedure is documented in [Section 18.14](#).



### 20.2. Create two windows

On the laptop, create two Byobu windows.

- A quick reference about Byobu commands is in [Chapter 106](#).

You will use the two windows as follows:

- In the first window, you will launch the nodes that control the camera.
- In the second window, you will launch programs to monitor the data flow.

**Note:** You could also use multiple *terminals* instead of one terminal with multiple Byobu windows. However, using Byobu is the best practice to learn.



### 20.3. First window: launch the camera nodes

In the first window, we will launch the nodes that control the camera.

Activate ROS:



```
$ source environment.sh
```

Run the launch file called `camera.launch`:



```
$ rosrun duckietown camera.launch veh:=robot name
```



At this point, you should see the red LED on the camera light up continuously.

In the terminal you should not see any red message, but only happy messages like the following:

```
...
[INFO] [1502539383.948237]: [/robot_name/camera_node] Initialized.
[INFO] [1502539383.951123]: [/robot_name/camera_node] Start capturing.
[INFO] [1502539384.040615]: [/robot_name/camera_node] Published the first image.
```

\* For more information about `roslaunch` and “launch files”, see [Section 110.3](#).

## 20.4. Second window: view published topics

Switch to the second window.

Activate the ROS environment:

 \$ source environment.sh

### 1) List topics

You can see a list of published topics with the command:

 \$ rostopic list

\* For more information about `rostopic`, see [Section 110.5](#).

You should see the following topics:

```
/robot_name/camera_node/camera_info
/robot_name/camera_node/image/compressed
/robot_name/camera_node/image/raw
/rosout
/rosout_agg
```

### 2) Show topics frequency

You can use `rostopic hz` to see the statistics about the publishing frequency:

 \$ rostopic hz /robot\_name/camera\_node/image/compressed

On a Raspberry Pi 3, you should see a number close to 30 Hz:

```
average rate: 30.016
min: 0.026s max: 0.045s std dev: 0.00190s window: 841
```

### 3) Show topics data

You can view the messages in real time with the command `rostopic echo`:

 \$ rostopic echo /robot\_name/camera\_node/image/compressed

You should see a large sequence of numbers being printed to your terminal.  
That's the “image” — as seen by a machine.

If you are Neo, then this already makes sense. If you are not Neo, in [Chapter 22](#), you will learn how to visualize the image stream on the laptop using `rviz`.

use `Ctrl-C` to stop `rostopic`.

## CHAPTER 21

# RC control launched remotely



Assigned to: Andrea

**Requires:** You can run the joystick demo from the Raspberry Pi. The procedure is documented in [Chapter 19](#).

Results: You can run the joystick demo from your laptop.



### 21.1. Two ways to launch a program

ROS nodes can be launched in two ways:

1. “local launch”: log in to the Raspberry Pi using SSH and run the program from there.
2. “remote launch”: run the program directly from a laptop.

Which is better when is a long discussion that will be done later. Here we set up the “remote launch”.

**TODO:** draw diagrams



### 21.2. Download and setup Software repository on the laptop

As you did on the Duckiebot, you should clone the `Software` repository in the `~/duckietown` directory.

- The procedure is documented in [Section 19.1](#).

Then, you should build the repository.

- This procedure is documented in [Section 19.2](#).



### 21.3. Edit the `machines` files on your laptop

You have to edit the `machines` files on your laptop, as you did on the Duckiebot.

- The procedure is documented in [Section 19.3](#).



### 21.4. Start the demo

Now you are ready to launch the joystick demo remotely.

#### Check before you continue

Make sure that you can login with SSH without a password. From the laptop, run:



```
$ ssh username@robot_name.local
```

If this doesn't work, you missed some previous steps.

Run this *on the laptop*:

```
💻 $ source environment.sh  
$ roslaunch duckietown joystick.launch veh:=robot_name
```

You should be able to drive the vehicle with joystick just like the last example. Note that remotely launching nodes from your laptop doesn't mean that the nodes are running on your laptop. They are still running on the Raspberry Pi in this case.

\* For more information about `roslaunch`, see [Section 110.3](#).

## 21.5. Watch the program output using `rqt_console`

Also, you might have noticed that the terminal where you launch the launch file is not printing all the printouts like the previous example. This is one of the limitations of remote launch.

Don't worry though, we can still see the printouts using `rqt_console`.

On the laptop, open a new terminal window, and run:

```
💻 $ export ROS_MASTER_URI=http://robot_name.local:11311/  
$ rqt_console
```

AC: I could not see any messages in `rqt_console` - not sure what is wrong.

You should see a nice interface listing all the printouts in real time, completed with filters that can help you find that message you are looking for in a sea of messages.

You can use `Ctrl-C` at the terminal where `roslaunch` was executed to stop all the nodes launched by the launch file.

\* For more information about `rqt_console`, see [Section 110.2](#).

## 21.6. Troubleshooting

**Symptom:** `roslaunch` fails with an error similar to the following:

```
remote[robot_name.local-0]: failed to launch on robot_name:
```

```
Unable to establish ssh connection to [username@robot_name.local:22]:  
Server u'robot_name.local' not found in known_hosts.
```

**Resolution:** You have not followed the instructions that told you to add the `HostKeyAlgorithms` option. Delete `~/.ssh/known_hosts` and fix your configuration.

→ The procedure is documented in [Section 100.3](#).



# CHAPTER 22

## RC+camera remotely

Assigned to: Andrea

**Requires:** You can run the joystick demo remotely. The procedure is documented in [Chapter 21](#).

**Requires:** You can read the camera data from ROS. The procedure is documented in [Chapter 20](#).

**Requires:** You know how to get around in Byobu. You can find the Byobu tutorial in [Chapter 106](#).

**Results:** You can run the joystick demo from your laptop and see the camera image on the laptop.

### 22.1. Assumptions

We are assuming that the joystick demo in [Chapter 21](#) worked.

We are assuming that the procedure in [Chapter 20](#) succeeded.

We also assume that you terminated all instances of `roslaunch` with `Ctrl-C`, so that currently there is nothing running in any window.

### 22.2. Terminal setup

On the laptop, this time create four Byobu windows.

→ A quick reference about Byobu commands is in [Chapter 106](#).

You will use the four windows as follows:

- In the first window, you will run the joystick demo, as before.
- In the second window, you will launch the nodes that control the camera.
- In the third window, you will launch programs to monitor the data flow.
- In the fourth window, you will use `rviz` to see the camera image.

TODO: Add figures

### 22.3. First window: launch the joystick demo

In the first window, launch the joystick remotely using the same procedure in [Section 21.4](#).



```
$ source environment.sh  
$ roslaunch duckietown joystick.launch veh:=robot name
```

You should be able to drive the robot with the joystick at this point.

## 22.4. Second window: launch the camera nodes

In the second window, we will launch the nodes that control the camera.

The launch file is called `camera.launch`:

```
 $ source environment.sh  
$ roslaunch duckietown camera.launch veh:=robot name
```

You should see the red led on the camera light up.

## 22.5. Third window: view data flow

Open a third terminal on the laptop.

You can see a list of topics currently on the `ROS_MASTER` with the commands:

```
 $ source environment.sh  
$ export ROS_MASTER_URI=http://robot name.local:11311/  
$ rostopic list
```

You should see the following:

```
/diagnostics  
/robot name/camera_node/camera_info  
/robot name/camera_node/image/compressed  
/robot name/camera_node/image/raw  
/robot name/joy  
/robot name/wheels_driver_node/wheels_cmd  
/rosout  
/rosout_agg
```

## 22.6. Fourth window: visualize the image using `rviz`

Launch `rviz` by using these commands:

```
 $ source environment.sh  
$ source set_ros_master.sh robot name  
$ rviz
```

\* For more information about `rviz`, see [Section 110.4](#).

In the `rviz` interface, click “Add” on the lower left, then the “By topic” tag, then select the “Image” topic by the name

```
/.robot name/camera_node/image/compressed
```

Then click “ok”. You should be able to see a live stream of the image from the camera.

## 22.7. Proper shutdown procedure



To stop the nodes: You can stop the node by pressing `Ctrl-C` on the terminal where `roslaunch` was executed. In this case, you can use `Ctrl-C` in the terminal where you launched the `camera.launch`.

You should see the red light on the camera turn off in a few seconds.

Note that the `joystick.launch` is still up and running, so you can still drive the vehicle with the joystick.

## CHAPTER 23

### Interlude: Ergonomics



Assigned to: Andrea

So far, we have been spelling out all commands for you, to make sure that you understand what is going on.

Now, we will tell you about some shortcuts that you can use to save some time.

**Note:** in the future you will have to debug problems, and these problems might be harder to understand if you rely blindly on the shortcuts.

Requires: Time: ??? minutes.

Results: You will know about some useful shortcuts.

#### 23.1. set\_ros\_master.sh



Instead of using:

```
$ export ROS_MASTER_URI=http://robot name.local:11311/
```

You can use the “set\_ros\_master.sh” script in the repo:

```
$ source set_ros_master.sh robot name
```

Note that you need to use `source`; without that, it will not work.

#### 23.2. SSH aliases



Instead of using

```
$ ssh username@robot name.local
```

You can set up SSH so that you can use:

```
$ ssh my-robot
```

To do this, create a host section in `~/.ssh/config` with the following contents:

```
Host my-robot
  User username
  Hostname robot name.local
```

Here, you can choose any other string in place of “`my-robot`”.

Note that you **cannot** do

```
$ ping my-robot
```

You haven't created another hostname, just an alias for SSH.

However, you can use the alias with all the tools that rely on SSH, including `rsync` and `scp`.

## CHAPTER 24

# Wheel calibration



| Assigned to: Andrea

# CHAPTER 25

## Camera calibration



## CHAPTER 26

# Taking a log



| Assigned to: Andrea

PART 4

## Operation manual - Duckietowns

..

## CHAPTER 27

# Duckietown parts



Duckietowns are the cities where Duckiebots drive. Here, we provide a link to all bits and pieces that are needed to build a Duckietown, along with their price tag. Note that while the topography of the map is highly customizable, we recommend using the components listed below. Before purchasing components for a Duckietown, read [Chapter 31](#) to understand how Duckietowns are built.

In general, keep in mind that:

- The links might expire, or the prices might vary.
- Shipping times and fees vary, and are not included in the prices shown below.
- Substitutions are probably not OK, unless you are OK in writing some software.

**| Requires:** Cost (per  $m^2$ ): USD ??? + Shipping Fees

**| Requires:** Time: ??? days (average shipping time)

Results: A kit of parts ready to be assembled in a Duckietown.

Next Steps: [Assemblying](#) a Duckietown.

**TODO:** Figure out costs

### 27.1. Bill of materials



TABLE 10. BILL OF MATERIALS FOR DUCKIETOWN

<u>Duckies</u>	USD 17/100 pieces
<u>Floor Mats</u>	USD 37.5/6 pieces (24 sqft)
<u>Duct tape - Red</u>	USD 8.50/roll
<u>Duct tape - White</u>	USD 8.50/roll
<u>Duct tape - Yellow</u>	USD 8/roll
<u>Traffic signs</u>	USD 18.50/13 pieces
Total for Duckietown/ $m^2$	USD ??

**TODO:** Add suggestions for “small”, “medium”, “big” towns as a function of  $m^2$  and supported bots

### 27.2. Duckies



Duckies ([Figure 39](#)) are essential yet non functional.

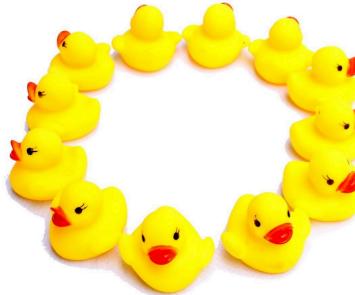


Figure 39. The Duckies

### 27.3. Floor Mats

The floor mats ([Figure 40](#)) are the ground on which the Duckiebots drive.

We choose these mats because they have desirable surface properties, are modular, and have the right size to be [street segments](#). Each square is (~61x61cm) and can connect on every side of other squares. There are 6 mats in each package.



Figure 40. The Floor Mats

Each mat can be a segment of road: straight, a curve, or an intersection (3, or 4 way). To design your Duckietown, see [Chapter 31](#).

### 27.4. Duck Tape

We use duck (duct) tape of different colors ([Figure 41](#)) for defining the roads and their signals. White indicates the road boundaries, yellow determines lane boundaries and red are stop signs.

The white and red tape we use are 2 inches wide, while the yellow one is 1 inch wide.



Figure 41. The Duck Tapes

To verify how much tape you need for each road segment type, see [Chapter 31](#).



## 27.5. Traffic Signs

Traffic signs ([Figure 42](#)) inform Duckiebots on the map of Duckietown, allowing them to make driving decisions.



Figure 42. The Signs

Depending on the chose road topography, the number of necessary road signal will vary. To design your Duckietown, see [Chapter 31](#).

# CHAPTER 28

## Traffic lights Parts



Traffic lights regulate intersections in Duckietown. Here, we provide a link to all bits and pieces that are needed to build a traffic light, along with their price tag. You will need one traffic per either three, or four way intersections. The components listed below meet the appearance specifications described in [Chapter 31](#).

In general, keep in mind that:

- The links might expire, or the prices might vary.
- Shipping times and fees vary, and are not included in the prices shown below.
- Substitutions are probably OK, if you are willing to write some software.

Requires: Cost: USD ?? + Shipping Fees

Requires: Time: ?? days (average shipping time)

Results: A kit of parts ready to be assembled in a traffic light.

Next Steps: - [Assemblying](#) a traffic light.

TODO: Estimate time and costs



### 28.1. Bill of materials

TABLE 11. BILL OF MATERIALS FOR TRAFFIC LIGHT

Raspberry Pi	USD ??
4 LEDs	USD ??
Wires	USD ??
Total for Traffic Light	USD ??

TODO: Complete table



### 28.2. Raspberry Pi

([Figure 43](#)) are essential yet non functional.

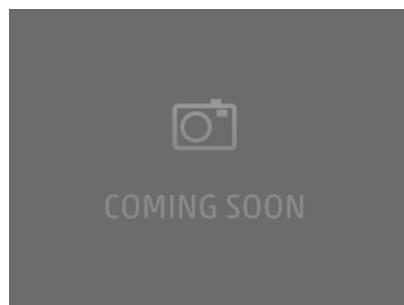


Figure 43. The placeholder

**CHAPTER 29**  
**Duckietown Assembly**

• •

| Assigned to: Shiying

# CHAPTER 30

## Traffic lights Assembly

..

| Assigned to: Shiying

## CHAPTER 31

# The Duckietown specification

| Assigned to: Liam?

### 31.1. Topology

#### 1) Topology constraints

---

### 31.2. Signs placement

## PART 5

# Operation manual - Duckiebot with LEDs



## CHAPTER 32

# Acquiring the parts for the Duckiebot C1



Upgrading your C0+wjd configuration to C1 starts here, with purchasing the necessary components. We provide a link to all bits and pieces that are needed to build a C1 Duckiebot, along with their price tag. If you are wondering what is the difference between different Duckiebot configurations, read [Chapter 11](#).

In general, keep in mind that:

- The links might expire, or the prices might vary.
- Shipping times and fees vary, and are not included in the prices shown below.
- Buying the parts for more than one Duckiebot makes each one cheaper than buying only one.
- A few components in this configuration are custom designed, and might be trickier to obtain.

Requires: - A Duckiebot in C0+wjd configuration. - Cost: USD 77 + Bumpers manufacturing solution - Time: 21 Days (LED board manufacturing and shipping time)

Results: - A kit of parts ready to be assembled in a C1 configuration Duckiebot.

Next Steps: - After receiving these components, you are ready to do some [soldering](#) before [assembling](#) your C1 Duckiebot.

### 32.1. Bill of materials



TABLE 12. BILL OF MATERIALS

<u>LEDs</u>	USD 10
<u>LED HAT</u>	USD 28.20 for 3 pieces
<u>Power Cable</u>	USD 7.80
<u>20 Female-Female Jumper Wires (300mm)</u>	USD 8
<u>Male-Male Jumper Wire (150mm)</u>	USD 1.95
<u>PWM/Servo HAT</u>	USD 17.50
<u>Bumpers</u>	TBD (custom made)
<u>40 pin female header</u>	USD 1.50
<u>5 4 pin female header</u>	USD 0.60/piece
<u>2 16 pin male header</u>	USD 0.61/piece
<u>12 pin male header</u>	USD 0.48/piece
<u>3 pin male header</u>	USD 0.10/piece
<u>2 pin female shunt jumper</u>	USD 2/piece
<u>5 200 Ohm resistors</u>	USD 0.10/piece
<u>10 130 Ohm resistors</u>	USD 0.10/piece
Total for C0+wjd configuration	USD 212
Total for C1 components	USD 77 + Bumpers
Total for C1 configuration	USD 299+Bumpers

TODO: add links to Bumpers: (a) bumper design files; (b) one-click purchasing option (?)

## 32.2. LEDs

The Duckiebot is equipped with 5 RGB LEDs ([Figure 44](#)). LEDs can be used to signal to other Duckiebots, or just make *fancy* patterns.

The pack of LEDs linked in the table above holds 10 LEDs, enough for two Duckiebots.

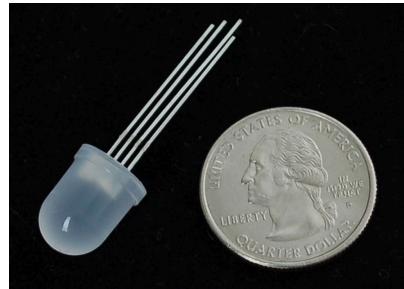


Figure 44. The RGB LEDs

### 1) LED HAT

The LED HAT ([Figure 45](#)) provides an interface for our RGB LEDs and the computational stack. This board is a daughterboard for the Adafruit 16-Channel PWM/Servo HAT, and enables connection with additional gadgets such as [ADS1015 12 Bit 4 Channel ADC](#), [Monochrome 128x32 I2C OLED graphic display](#), and [Adafruit 9-DOF IMU Breakout - L3GD20H+LSM303](#). This item will require [soldering](#).

This board is custom degined and can only be ordered in minimum runs of 3 pieces. The price scales down quickly with quantity, and lead times may be significant, so it is better to buy these boards in bulk.

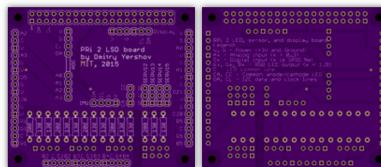


Figure 45. The LED HAT

### 2) PWM/Servo HAT

The PWM/Servo HAT ([Figure 46](#)) mates to the LED HAT and provides the signals to control the LEDs, without taking computational resources away from the Raspberry Pi itself. This item will require [soldering](#).

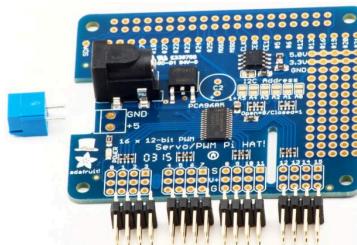


Figure 46. The PWM-Servo HAT

### 3) Power Cable

To power the PWM/Servo HAT from the battery, we use a short (30cm) angled male USB-A to 5.5/2.1mm DC power jack cable ([Figure 47](#)).



Figure 47. The 30cm angled USB to 5.5/2.1mm power jack cable.

### 4) Male-Male Jumper Wires

The Duckiebot needs one male-male jumper wire ([Figure 48](#)) to power the DC Stepper Motor HAT from the PWM/Servo HAT.

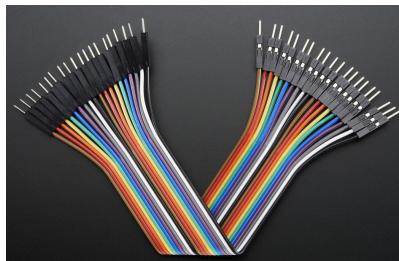


Figure 48. Premier Male-Male Jumper Wires

### 5) Female-Female Jumper Wires

20 Female-Female Jumper Wires ([Figure 49](#)) are necessary to connect 5 LEDs to the LED HAT.

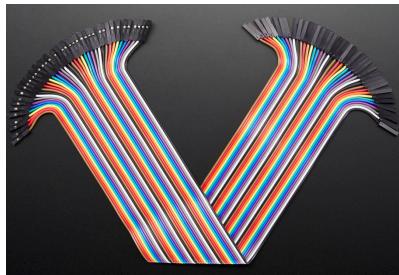


Figure 49. Premier Female-Female Jumper Wires

### 32.3. Bumpers

These bumpers are designed to keep the LEDs in place and are therefore used only in configuration C1. They are custom designed parts, so they must be produced and cannot be bought. We used laser cutting facilities. Our design files are available [here].

**TODO:** add links to .sldprt files once confirmed final version

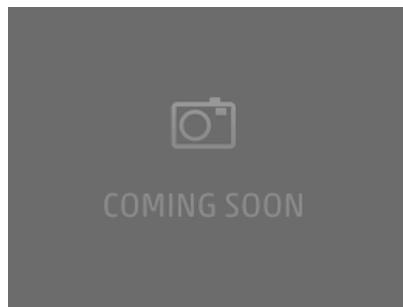


Figure 50. The Bumpers

### 32.4. Headers, resistors and jumper

Upgrading `c0+wjd` to `c1` requires several electrical bits: 5 of 4 pin female header, 2 of 16 pin male headers, 1 of 12 pin male header, 1 of 3 pin male header, 1 of 2 pin female shunt jumper, 5 of 200 Ohm resistors and finally 10 of 130 Ohm resistors.

These items require [soldering](#).

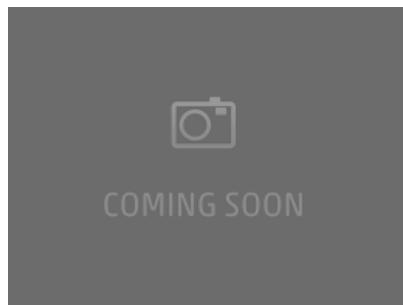


Figure 51. The Headers



Figure 52. The Resistors

**TODO:** Missing figures.

## CHAPTER 33

# Soldering boards for C1



Assigned to: Shiyeng

Resources necessary:

Requires: - Duckiebot C1 parts. The acquisition process is explained in [Chapter 32](#).  
The configurations are described in [Chapter 11](#).

Requires: - Time: ??? minutes

Results:

- ...

TODO: finish above

## CHAPTER 34

# Assembling the Duckiebot C1



Assigned to: Shiying

Requires: Duckiebot c1 parts. The acquisition process is explained in [Chapter 32](#).

Requires: Soldering c1 parts. The soldering process is explained in [Chapter 33](#).

Requires: Time: about ??? minutes.

TODO: estimate time.

Results:

- An assembled Duckiebot in configuration c1.

Shiying: here will be the instruction about assembling the Duckiebot.

## CHAPTER 35

### C1 (LEDs) setup



| Assigned to: Andrea

## PART 6

# Theory chapters

..

These are the theory chapters.

## CHAPTER 36

# Chapter template



Theory chapters benefit from a standardized exposition. Here, we define the template for these chapters. Rememeber to check [Chapter 7](#) for a comprehensive and up-to-date list of Duckiebook supported features.

### 36.1. Example Title: PID control



Start with a brief introduction of the discussed topic, describing its place in the bigger picture, justifying the reading constraints/guidelines below. Write it as if the reader knew the relevant terminology. For example:

PID control is the simplest approach to making a system behave in a desired way rather than how it would naturally behave. It is simple because the measured output is directly feedbacked, as opposed to, e.g., the system's states. The control signal is obtained as a weighted sum of the tracking error (*Proportional term*), its integral over time (*Integrative term*) and its instantaneous derivative (*Derivative term*), from which the appellative of PID control. The tracking error is defined as the instantaneous difference between a reference and a measured system output.

Knowledge necessary:

Required Reading: Insert here a list of topics and suggested resources related to *necessary* knowledge in order to understand the content presented. Example:

| Requires: Terminology: [autonomy overview](#)

| Requires: System Modeling: [basic kinematics](#), [basic dynamics](#), [linear algebra](#), [State space representations](#), [Linear Time Invariant Systems](#)

Suggested Reading: Insert here a list of topics and suggested resources related to *recommended* knowledge in order to better understand the content presented. Example:

| Recommended: Definitions of Stability, Performances and Robustness: [\[5\]](#), ...

| Recommended: observability/detectability and controllability/reachability: [\[5\]](#)

| Recommended: Discrete time PID: [\[5\]](#)

| Recommended: Bode diagrams: [\[5\]](#)

| Recommended: Nyquist plots: [\[5\]](#)

| Recommended: [...]

### 36.2. Problem Definition



In this section we crisply define the problem object of this chapter. It serves as a very brief recap of exactly what is needed from previous atoms as well. E.g.

Let:

$$\begin{aligned}\dot{\mathbf{x}}_t &= A\mathbf{x}_t + Bu_t \\ \mathbf{y} &= C\mathbf{x}_t + Du_t\end{aligned}\tag{1}$$

be the LTI model of the Duckiebot's plant, with  $\mathbf{x} \in \mathcal{X}$ ,  $\mathbf{y} \in \mathbb{R}^p$  and  $\mathbf{u} \in \mathbb{R}^m$ . We recall

([Duckiebot Modeling](#)) that:

$$\begin{aligned} A &= \begin{bmatrix} a_{11} & \dots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \dots & a_{nn} \end{bmatrix} \\ B &= [b_1 \ \dots \ b_m]^T \\ C &= [c_1 \ \dots \ c_p] \\ D &= 0. \end{aligned}$$

[...]

Remember you can use the `problem` environment of *LATEX* to formally state a problem:

**Problem 2.** (PID) Given a system [\(1\)](#) and measurements of the output [Undefined control sequence \textasciitilde](#), find a set of PID coefficients that meet the specified requirements for: - stability, - performance, - robustness.

as shown in ([Figure 53](#)).

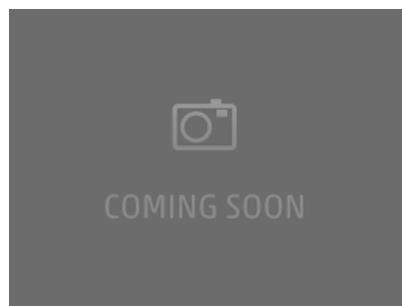


Figure 53. A classical block diagram for PID control. We like to use a lot of clear figures in the Duckiebook.

### 36.3. Introduced Notions

1) Section 1: title-1 (e.g.: Definitions)

**Definition 4.** (Reference signals) A reference signal  $\tilde{y}_t \in \mathcal{L}_2(\mathcal{T})$  is ...

[Definition 4](#) is very important.

#### Check before you continue

Insert ‘random’ checks to keep the reader’s attention up:

if you can’t be woken up in the middle of the night and rememeber the definition of  $\mathcal{L}_2(\cdot)$ , read: [\[5\]](#)

**Definition 5.** (Another definition) Lorem

2) Section 2: title-2 (e.g.: Output feedback)

Now that we know what we're talking about, let's get in the meat of the problem. Here is what is happening:

### *Corem*

#### 3) Section 3: title-3 (e.g.: Tuning the controller)

Introduce the 'synthesis through attempts' methodology (a.k.a. tweak until death)

#### 4) Section 4: title-4 (e.g.: Performance Metrics)

How do we know if the PID controller designed above is doing well? We need to define some performance metrics first:

Overshoot, Module at resonance, Settling Time, Rising Time

[...]

#### *example*

This is a 'think about it' interrupt, used as attention grabber:

When a Duckiebot 'overshoots', it means that [...] and the following will happen [...].

#### 5) Section N: title-N (e.g.: Saving the world with PID)

And finally, this is how you save the world, in theory.

## 36.4. Examples

This section serves as a collection of theoretical and practical examples that can clarify part or all of the above.

#### 1) Theoretical Examples

More academic examples

##### *T-Example 1:*

Imagine a spring-mass-damper system...

##### *T-Example M:*

[...]

#### 2) Implementation Examples

More Duckiebot related examples

##### *I-Example 1:*

##### *I-Example M:*

[...]

## 36.5. Pointers to Exercises

Here we just add references to the suggested exercises, defined in the appropriate [exer-](#)

[cise chapters.](#)

### 36.6. Conclusions

- What did we do? (recap)
- What did we find? (analysis)
- Why is it useful? (synthesis)
- Final Conclusions (what have we learned)

### 36.7. Next Steps

Strong of this new knowledge (what have we learned), we can now [...].

Further Reading: insert here reference resources for the interested reader:

- \* *learn all there is to know about PID: [\[5\]](#)*
- \* *become a linear algebra master: [Matrix cookbook](#)*

### 36.8. References

Do not include a reference chapter. References are automatically compiled to [the Bibliography Section](#).

Author: Jacopo Maintainer: Jacopo Point of Contact: Jacopo

## CHAPTER 37

# Symbols and conventions

Assigned to: Andrea

### 37.1. Conventions

If  $\mathbf{x}$  is a function of time, use  $\mathbf{x}_t$  rather than  $\mathbf{x}(t)$ .

- \* Consider the function  $\mathbf{x}(t)$ .
- ✓ Consider the function  $\mathbf{x}_t$ .

### 37.2. Table of symbols

Here are some useful symbols.

TABLE 13. SPACES

command	result	
<code>\SOthree</code>	<b>SO(3)</b>	Rotation matrices
<code>\SEthree</code>	<b>SE(3)</b>	Euclidean group
<code>\SEtwo</code>	<b>SE(2)</b>	Euclidean group
<code>\setwo</code>	<b>se(2)</b>	Euclidean group algebra

States and poses:

TABLE 14. POSES AND STATES

command	result	
<code>\pose</code>	$\mathbf{q}_t \in \mathbf{SE}(2)$	Pose of the robot in the plane
<code>\state_t \in \statesp</code>	$\mathbf{x}_t \in \mathcal{X}$	System state (includes the pose, and everything else)

# CHAPTER 38

## Linear algebra

**TODO:** This Section is work in progress.

Assigned to: Jacopo

Linear algebra provides the set of mathematical tools to (a) study linear relationships and (b) describe linear spaces. It is a field of mathematics with important ramifications.

Linearity is an important concept because it is powerful in describing the input-output behaviour of many natural phenomena (or *systems*). As a matter of fact, all those systems that cannot be modeled as linear, still can be approximated as linear to gain an intuition, and sometimes much more, of what is going on.

So, in a way or the other, linear algebra is a starting point for investigating the world around us, and Duckietown is no exception.

Knowledge necessary:

Requires: Real numbers are complex for you?: Number theory [addref](#)

Requires:  $\forall$  is a typo for A and  $\in$  are Euros? Mathematical symbolic language: [ad-dref](#)

**TODO:** find appropriate references and fill in above

### 38.1. Problem Definition

In this section we discuss vectors, matrices and linear spaces, along with their properties. Before introducing the these arguments, we need to formally define what we mean by linearity. The word *linear* comes from the latin *linearis*, which means *pertaining to or resembling a line*. You should recall that a line is represented by an equation like  $y = mx + q$ , but here we intend linearity as a property of maps, so there is a little more to linearity than lines (although lines *are* linear maps indeed). To avoid confusions, let us translate the concept of linearity in mathematical language.

First, let us define a *function*, as a mapping between *sets*.

**Definition 6.** (Set) A set  $\mathbb{X} = \{x_1, x_2, \dots\}$  is a well-defined collection of distinct *elements*, or *members* of the set,  $x_i, i = 1, 2, \dots$ . For the time being, we assume elements to (complex) numbers.

**Definition 7.** (Function) A function  $f : \mathbb{X} \rightarrow \mathbb{Y}$  is a mapping between the sets  $\mathbb{X}$  and  $\mathbb{Y}$ . For every input element  $x \in \mathbb{X}$ , the mapping will produce an output  $y = f(x) \in \mathbb{Y}$ .

Recommended: Functions can be classified by the nature of the relationship between inputs and outputs in: *injective*, *surjective* or *bijective* [add-ref](#).

**TODO:** add references

**Definition 8.** (Linearity) A function  $f : \mathbb{X} \rightarrow \mathbb{Y}$  is linear when,  $\forall x_i \in \mathbb{X}, i = \{1, 2\}$ , and  $\forall a \in \mathbb{R}$ :

$$f(ax_1) = af(x_1), \quad \text{and:} \tag{1}$$

$$f(x_1 + x_2) = f(x_1) + f(x_2) \tag{2}$$

Condition (1) is referred to as the property of *homogeneity* (of order 1), while condition (2) is referred to as *additivity*.

**Remark 2.** (Superposition Principle) Conditions (1) and (2) can be merged to express the same meaning through:

$$f(ax_1 + bx_2) = af(x_1) + bf(x_2), \forall x_i \in \mathbb{X}, i = \{1, 2\}, \forall a, b \in \mathbb{R}. \quad (3)$$

This equivalent condition (3) is instead referred to as *superposition principle*, which unveils the bottom line of the concept of linearity: adding up (equivalently, scaling up) inputs results in an added up (equivalently, scaled up) output.

## 38.2. Vectors

Let  $n$  belong to the set of natural numbers  $\mathbb{N}$ , i.e.,  $n \in \mathbb{N}$ , and let  $a_i \in \mathbb{R}, i = \{1, \dots, n\}$  be real coefficients. While  $\mathbb{R}$  is the set of real numbers,  $\mathbb{R}^n$  is the set of all  $n$ -tuples of real numbers.

**Definition 9.** (Vector and components) An  $n$ -dimensional *vector* is an  $n$ -tuple:

$$\mathbf{v} = \begin{bmatrix} v_1 \\ \vdots \\ v_n \end{bmatrix} \in \mathbb{R}^{n \times 1} \equiv \mathbb{R}^n, \quad (4)$$

of components  $v_1, \dots, v_n \in \mathbb{R}$ .

You can imagine a vector as a “directional number”, or an arrow that starts a certain point and goes in a certain direction (in  $\mathbb{R}^n$ ). In this representation, the *number* is the length of the arrow, or the *modulus* of the vector, and it can be derived through the vector’s components.

**Definition 10.** (Length of a vector) We define the length, or *modulus*, of a vector  $\mathbf{v} \in \mathbb{R}^n$  as:

$$\|\mathbf{v}\| = \sqrt{v_1^2 + \dots + v_n^2} \in \mathbb{R}. \quad (5)$$

**Remark 3.** (2-norm) Generally speaking, it is not always possible to define the length of a vector ([addref](#)). But when it is possible (e.g., [Hilbert spaces](#)), and in Duckietown it always is, there are many ways to define it. The most common and intuitive definition is the *Euclidian*- or *2-norm*, which is defined above in (5).

- Definition of:
- norms
- p-norm,  $\infty$ -norm
- unit vector

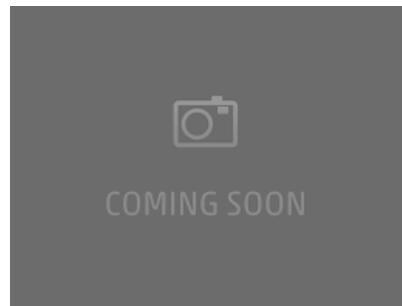


Figure 54. A vector and its components.

### 1) Vector algebra

---

- sum of vectors
- dot product / inner product
- cross product
- 

*Orthogonality between vectors:*

## 38.3. Matrices

Definitions:

- matrix dimensions
- flat and tall matrix
- adjoint matrix
- inverse matrix
- rank of a matrix
- condition number of a matrix (?)
- identity matrix
- null matrix
- diagonal matrix
- symmetric matrix
- unit matrix
- trace of a matrix

### 1) Matrix algebra

---

- sum of matrices
- product of matrices
- matrix transpose
- matrix scalar product
- matrix Hadamard product
- matrix concatenation
- matrix-vector product
- matrix power
- matrix exponential

*Determinant:*

- 2x2
- 3x3

- $n \times n$

*Inverse:*

- general expression

*Left and Right Inverse (topic for advanced-linear-algebra?):*

- what if the matrix is not square? (topic for advanced-linear-algebra?)
- Moore-Penrose pseudo-inverse

*Eigenvalues and Eigenvectors:*

- for square matrices
- for rectangular matrices (topic for advanced-linear-algebra?)
- singular value decomposition SVD (topic for advanced-linear-algebra?)

## 38.4. Matrix as representation of linear (vector) spaces

- linear system to matrix representation
- linearly dependent and independent spaces

### 1) Fundamental spaces

---

- Null space
- Range/image

### 2) Preferred spaces (matrix diagonalization)

---

- show how to diagonalize matrices and why it is relevant (it will come in handy for state space representation chapter chapter)

## 38.5. Examples

### 1) Theoretical Examples

---

*Calculate a (square) Matrix Inverse:*

*Find eigenvalues and eigenvectors:*

*Find range and null spaces of a matrix:*

### 2) Implementation Examples

---

*Inverting a well conditioned matrix:*

*Inverting a ill conditioned matrix:*

## 38.6. Pointers to Exercises

Here we just add references to the suggested exercises, defined in the appropriate [exercise chapters](#).

## 38.7. Conclusions

In this section we have defined the fundamental concept of linearity and introduced the mathematical tools pertaining to it, in particular vectors and matrices. Moreover,

we have introduced their properties and interpretations as linear spaces.

We have found that matrices are a very convenient way to represent linear spaces, and that the properties of the matrices such as eigenvalues and eigenvectors have important implications in characterizing these spaces.

These tools are useful because they are at the foundation of *modeling* of natural phenomena. Modeling will be invaluable in understanding the behaviour of systems, and a powerful tool to *predict* future behaviours of the system, and *control* them when needed.

We have learned that ...

### 38.8. Next Steps

- linearization of non linear equations
- state space representations
- basic kinematics
- basic dynamics

\* [\[13\]](#)

\* [Matrix cookbook](#)

Author: Jacopo Maintainer: Jacopo Point of Contact: Jacopo

## CHAPTER 39

# Probability basics



| Assigned to: Liam?

# CHAPTER 40

## Dynamics

..

| Assigned to: Jacopo

TODO: this is a repetition of [Chapter 50](#).

## CHAPTER 41

# Coordinate systems



Assigned to: Falcon

**TODO:** Provide a basic description of coordinate systems. The description of general coordinate systems should be brief, with the majority of the text focusing on Cartesian coordinate systems (2D and 3D), polar coordinate systems, and spherical coordinate systems.

# CHAPTER 42

## Reference frames



Assigned to: TBD

### Check before you continue

Required Reading: The following assumes a working familiarity with 2D and 3D Cartesian coordinate systems. If you are not familiar with Cartesian coordinate systems, please read the [chapter on coordinate systems](#).

**TODO:** Provide a basic description of reference frames. This section is dependent upon the [coordinate systems](#) chapter and could be moved there.

## CHAPTER 43

# Transformations



Assigned to: TBD

### Check before you continue

Required Reading: The following assumes a working familiarity with 2D and 3D Cartesian reference frames. If you are not familiar with Cartesian reference frames, please read the [chapter on reference frames](#).

TODO: Provide a basic description of transformations (rotations and translations) in 2D and 3D Cartesian reference frames.

# CHAPTER 44

## Autonomy overview

| Assigned to: Liam

### 44.1. Perception, planning, control

## CHAPTER 45

# Autonomy architectures



Assigned to: Andrea

### 45.1. Contracts



API: Types, messages  
Latency, frequency  
computation  
semantics  
reliability / probability

# CHAPTER 46

## Representations

Assigned to: Matt

### Check before you continue

Required Reading: The following assumes working knowledge of 2D and 3D Cartesian coordinate systems, reference frames, and coordinate transformations. If you are not familiar with these topics, please see the chapters on [coordinate systems](#), [reference frames](#), and [coordinate transformations](#).

### Discuss:

- Introduction to the notion of *state* as a sufficient statistic that represents the agent (robot) and environment.
- Describe qualities: sufficient statistic; compact (i.e., not conveying unnecessary information); and readily interpretable.
- Define notion of *static* and *dynamic* states.
- Provide examples of robot and environment states.

The planning and control capabilities necessary for autonomy rely upon shared representations of the agent (i.e., the robot) and the environment in which it operates. Referred to as the *state*, this representation consists of a compilation of all knowledge about the robot and its environment that is *sufficient* both to perform a particular task as well as to predict the future. Ignoring prior information, this knowledge is often extracted from the robot's multimodal sensor streams (e.g., wheel encoders and cameras). Consequently, a natural choice is to formulate the state as the collection of all of the measurements that the robot acquires over time. Indeed, the use of low-level sensor measurements as the representation of the state has a long history in robotics and artificial intelligence (cite) and has received renewed attention of-late (cite).

However, while measurement history is a sufficient representation of the robot and its operating environment, several limitations limit its utility for planning and control. First, measurement history is redundant within individual and across successive observations. Second, the observations contain a large amount of unnecessary information (e.g., pixel intensities associated with clouds are not useful for self-driving vehicles). Third, measurement history is very inefficient: its size grows linearly with time (i.e., as the robot acquires new measurements), and it may be computationally intractable to access and process such a large amount of data. This motivates the desire for a *minimal* representation that expresses knowledge that is both necessary and sufficient for the robot to perform a given task. More concretely, we will consider parameterized (symbolic) formulations of the state and will prefer representations that involve as small a number of parameters as possible, subject to the constraints imposed by the task.

### 46.1. Preliminaries

I've created (currently empty) chapters for each of the following

- [Coordinate systems](#))

- [Reference frames](#)
- [Coordinate transformations](#)

## 46.2. Robot Representations



Define the notion of:

- *pose* for mobile robots;
- *configuration* for manipulators
- robot and joint velocities

Discuss specific robot state representation for Duckietown.

## 46.3. Environment Representations



Discuss:

- Difference between topological and metric environment representations;
- Details of topological representation;
- Common metric representations, notably feature-based maps and gridmaps;

### 1) Duckietown Environment Representation



Discuss specific environment representation for Duckietown.

# CHAPTER 47

## Software architectures and middlewares



| Assigned to: Andrea

## CHAPTER 48

# Modern signal processing



| Assigned to: Andrea

# CHAPTER 49

## Basic Kinematics



| Assigned to: Jacopo

CHAPTER 50

## Basic Dynamics



| Assigned to: Jacopo

# CHAPTER 51

## Odometry Calibration

..

| Assigned to: Jacopo

## CHAPTER 52

# Computer vision basics



| Assigned to: Matt

# CHAPTER 53

## Illumination invariance

..

| Assigned to: Matt

## CHAPTER 54

# Line Detection



| Assigned to: Matt

# CHAPTER 55

## Feature extraction

..

| Assigned to: Matt

## CHAPTER 56

# Place recognition



| Assigned to: Matt

# CHAPTER 57

## Filtering 1

..

| Assigned to: Liam

## CHAPTER 58

# Filtering 2

..

| Assigned to: Liam

# CHAPTER 59

## Mission planning

..

| Assigned to: ETH

## CHAPTER 60

# Planning in discrete domains



| Assigned to: ETH

# CHAPTER 61

## Motion planning

..

| Assigned to: ETH

CHAPTER 62  
RRT

..

| Assigned to: ETH

# CHAPTER 63

## Feedback control

..

| Assigned to: Jacopo

## CHAPTER 64

# PID Control



| Assigned to: Jacopo

# CHAPTER 65

## MPC Control

..

| Assigned to: Jacopo

## CHAPTER 66

# Object detection



| Assigned to: Nick and David

# CHAPTER 67

## Object classification

| Assigned to: Nick and David

## CHAPTER 68

# Object tracking



| Assigned to: Nick and David

## CHAPTER 69

# Reacting to obstacles



| Assigned to: Jacopo

## CHAPTER 70

# Semantic segmentation



| Assigned to: Nick and David

# CHAPTER 71

## Text recognition

| Assigned to: Nick

## CHAPTER 72

# SLAM - Problem formulation



| Assigned to: Liam

# CHAPTER 73

## SLAM - Broad categories

| Assigned to: Liam



CHAPTER 74  
VINS

..

| Assigned to: Liam

# CHAPTER 75

## Advanced place recognition

..

| Assigned to: Liam

## CHAPTER 76

# Fleet level planning (placeholder)



| Assigned to: ETH

# CHAPTER 77

## Fleet level planning (placeholder)

..

| Assigned to: ETH

## CHAPTER 78

# Bibliography



- [1] [Jacopo Tani](#), [Liam Paull](#), [Maria Zuber](#), [Daniela Rus](#), [Jonathan How](#), [John Leonard](#), and Andrea Censi. Duckietown: an innovative way to teach autonomy. In *EduRobotics 2016*. Athens, Greece, December 2016.  [pdf](#)
- [2] [Liam Paull](#), [Jacopo Tani](#), Heejin Ahn, Javier Alonso-Mora, Luca Carlone, Michal Cap, Yu Fan Chen, Changhyun Choi, Jeff Dusek, Daniel Hohener, Shih-Yuan Liu, Michael Novitzky, Igor Franzoni Okuyama, Jason Pazis, Guy Rosman, Valerio Varricchio, Hsueh-Cheng Wang, Dmitry Yershov, Hang Zhao, Michael Benjamin, [Christopher Carr](#), [Maria Zuber](#), [Sertac Karaman](#), [Emilio Frazzoli](#), [Domitilla Del Vecchio](#), [Daniela Rus](#), [Jonathan How](#), [John Leonard](#), and Andrea Censi. Duckietown: an open, inexpensive and flexible platform for autonomy education and research. In *IEEE International Conference on Robotics and Automation (ICRA)*. Singapore, May 2017.  [pdf](#)
- [3] Bruno Siciliano and Oussama Khatib. *Springer Handbook of Robotics*. Springer-Verlag New York, Inc., Secaucus, NJ, USA, 2007.
- [4] Tosini, G., Ferguson, I., Tsubota, K. *Effects of blue light on the circadian system and eye physiology*. Molecular Vision, 22, 61–72, 2016 ([online](#)).
- [5] Albert Einstein. Zur Elektrodynamik bewegter Körper. (German) On the electrodynamics of moving bodies. *Annalen der Physik*, 322(10):891–921, 1905. [DOI](#)
- [13] Ivan Savov. Linear algebra explained in four pages. [https://minireference.com/static/tutorials/linear\\_algebra\\_in\\_4\\_pages.pdf](https://minireference.com/static/tutorials/linear_algebra_in_4_pages.pdf), 2017. Online; accessed 23 August 2017.
- [12] Kaare Brandt Petersen and Michael Syskind Pedersen. The matrix cookbook. [.pdf](#)

## PART 7

# Exercises

..

These are the exercises.

## CHAPTER 79

# ROS Exercises



Progression of ROS skills:

### 79.1. Parameters



- Reading parameters
- Dynamic modification of parameters

### 79.2. Running from a log



- Running from a log

### 79.3. Unit tests



- Unit tests
- Integration with ROS tests

### 79.4. Analytics



- Measure the latency and frequency of the node
- Measure the latency of another node

### 79.5. Visualization



- Making a plot displayed using topic
- Using ROS parameters

# CHAPTER 80

## Line detection

..

CHAPTER 81  
Data processing

..

## CHAPTER 82

# Git and conventions

..

## PART 8

# Software reference



This part describes things that you should know about UNIX/Linux environments.

Documentation writers: please make sure that every command used has a section in these chapters.

# CHAPTER 83

## Ubuntu packaging with APT

### 83.1. apt install

TODO: to write

### 83.2. apt update

TODO: to write

1) apt dist-upgrade

---

TODO: hold back packages

### 83.3. apt-key

TODO: to write

### 83.4. apt-mark

TODO: to write

### 83.5. add-apt-repository

TODO: to write

### 83.6. wajig

TODO: to write

### 83.7. dpigs

TODO: to write

## CHAPTER 84

# GNU/Linux general notions



| Assigned to: Andrea

### 84.1. Background reading



- UNIX
- Linux
- free software; open source software.

# CHAPTER 85

## Every day Linux

### 85.1. cd

TODO: to write

### 85.2. sudo

TODO: to write

### 85.3. ls

TODO: to write

### 85.4. cp

TODO: to write

### 85.5. mkdir

TODO: to write

### 85.6. touch

TODO: to write

### 85.7. reboot

TODO: to write

### 85.8. shutdown

TODO: to write

### 85.9. rm

TODO: to write

## CHAPTER 86

# Users

### 86.1. passwd

TODO: to write

# CHAPTER 87

## UNIX tools

..

### 87.1. cat

..

TODO: to write

..

### 87.2. tee

..

TODO: to write

..

### 87.3. truncate

..

TODO: to write

..

## CHAPTER 88

# Linux disks and files

### 88.1. `fdisk`

TODO: to write

### 88.2. `mount`

TODO: to write

### 88.3. `umount`

TODO: to write

### 88.4. `losetup`

TODO: to write

### 88.5. `gparted`

TODO: to write

### 88.6. `dd`

TODO: to write

### 88.7. `sync`

TODO: to write

### 88.8. `df`

TODO: to write

# CHAPTER 89

## Other administration commands

### 89.1. visudo

TODO: to write

### 89.2. update-alternatives

TODO: to write

### 89.3. udevadm

TODO: to write

### 89.4. systemctl

TODO: to write

## CHAPTER 90

# Make

### 90.1. make

TODO: to write

# CHAPTER 91

## Python-related tools

..

### 91.1. `virtualenv`

..

**TODO:** to write

..

### 91.2. `pip`

..

**TODO:** to write

..

## CHAPTER 92

# Raspberry-PI commands

### 92.1. raspi-config

TODO: to write

### 92.2. vcgencmd

TODO: to write

### 92.3. raspistill

TODO: to write

### 92.4. jstest

TODO: to write

### 92.5. swapon

TODO: to write

### 92.6. mkswap

TODO: to write

# CHAPTER 93

## Users and permissions

### 93.1. chmod

TODO: to write



### 93.2. groups

TODO: to write



### 93.3. adduser

TODO: to write



### 93.4. useradd

TODO: to write

## CHAPTER 94

# Downloading

### 94.1. curl

TODO: to write

### 94.2. wget

TODO: to write

### 94.3. sha256sum

TODO: to write

### 94.4. xz

TODO: to write

## CHAPTER 95

# Shells and environments

..

### 95.1. source

..

TODO: to write

..

### 95.2. which

..

TODO: to write

..

### 95.3. export

..

TODO: to write

..

## CHAPTER 96

### Other misc commands

#### 96.1. pgrep

TODO: to write

#### 96.2. npm

TODO: to write

#### 96.3. nodejs

TODO: to write

#### 96.4. ntpdate

TODO: to write

#### 96.5. chsh

TODO: to write

#### 96.6. echo

TODO: to write

#### 96.7. sh

TODO: to write

#### 96.8. fc-cache

TODO: to write

# CHAPTER 97

## Linux resources usage

### 97.1. Measuring CPU usage using htop

You can use `htop` to monitor CPU usage.

```
$ sudo apt install htop
```

TODO: to write

### 97.2. Measuring I/O usage using iotop

Install using:

```
$ sudo apt install iotop
```

TODO: to write

### 97.3. How fast is the SD card?

→ [Section 98.1.](#)

## CHAPTER 98

### SD Cards tools

#### 98.1. Testing SD Card and disk speed

Test SD Card (or any disk) speed using the following commands, which write to a file called `filename`.

```
$ dd if=/dev/zero of=filename bs=500K count=1024
$ sync
$ echo 3 | sudo tee /proc/sys/vm/drop_caches
$ dd if=filename of=/dev/null bs=500K count=1024
$ rm filename
```

Note the `sync` and the `echo` command are very important.

Example results:

```
524288000 bytes (524 MB, 500 MiB) copied, 30.2087 s, 17.4 MB/s
524288000 bytes (524 MB, 500 MiB) copied, 23.3568 s, 22.4 MB/s
```

That is write 17.4 MB/s, read 22 MB/s.

#### 98.2. How to burn an image to an SD card

Requires:

- A blank SD card.
- An image file to burn.
- An Ubuntu computer with an SD reader.

Results:

- A burned image.

##### 1) Finding your device name for the SD card

First, find out what is the device name for the SD card.

Insert the SD Card in the slot.

Run the command:

```
$ sudo fdisk -l
```

Find your device name, by looking at the sizes.

For example, the output might contain:

```
Disk /dev/mmcblk0: 14.9 GiB, 15931539456 bytes, 31116288 sectors
Units: sectors of 1 * 512 = 512 bytes
Sector size (logical/physical): 512 bytes / 512 bytes
I/O size (minimum/optimal): 512 bytes / 512 bytes
```

In this case, the device is `/dev/mmcblk0`. That will be the `device` in the next commands.

You may see `/dev/mmcblk0pX` or a couple of similar entries for each partition on the card, where `X` is the partition number. If you don't see anything like that, take out the SD card and run the command again and see what disappeared.

## 2) Unmount partitions

Before proceeding, unmount all partitions.

Run `df -h`. If there are partitions like `/dev/mmcblk0p1`, then unmount each of them. For example:



```
$ sudo umount /dev/mmcblk0p1
$ sudo umount /dev/mmcblk0p2
```

## 3) Burn the image

Now that you know that the device is `device`, you can burn the image to disk.

Let the image file be `image file`.

Burn the image using the command `dd`:



```
$ sudo dd of=device if=image file status=progress bs=4M
```

**Note:** Use the name of the device, without partitions. i.e., `/dev/mmcblk0`, not `/dev/mmcblk0pX`.

### 98.3. How to shrink an image

Requires:

- An image file to burn.
- An Ubuntu computer.

Results:

- A shrunk image.

**Note:** Majority of content taken from [here](#)

We are going to use the tool `gparted` so make sure it's installed



```
$ sudo apt install gparted
```

Let the image file be `image file`. Run the command:



```
$ sudo fdisk -l image file
```

It should give you something like:

Device	Boot	Start	End	Sectors	Size	Id	Type
duckiebot-RPI3-LP-aug15.img1		2048	131071	129024	63M	c	W95 FAT32 (LBA)
duckiebot-RPI3-LP-aug15.img2		131072	21219327	21088256	10.1G	83	Linux

Take note of the start of the Linux partition (in our case 131072), let's call it `start`. Now we are going to mount the Linux partition from the image:

```
💻 $ sudo losetup /dev/loop0 imagedname.img -o $(($start*512))
```

and then run `gparted`:

```
💻 $ sudo gparted /dev/loop0
```

In `gparted` click on the partition and click “Resize” under the “Partition” menu. Resize drag the arrow or enter a size that is equal to the minimum size plus 20MB

**Note:** This didn't work well for me - I had to add much more than 20MB for it to work. Click the “Apply” check mark. Before closing the final screen click through the arrows in the dialogue box to find a line such a “`resize2fs -p /dev/loop0 1410048K`”. Take note of the new size of your partition. Let's call it `new size`.

Now remove the loopback on the second partition and setup a loopback on the whole image and run `fdisk`:

```
💻 $ sudo losetup -d /dev/loop0
$ sudo losetup /dev/loop0 image file
$ sudo fdisk /dev/loop0

Command (m for help): enter d
Partition number (1,2, default 2): enter 2
Command (m for help): enter n
Partition type
p primary (1 primary, 0 extended, 3 free)
e extended (container for logical partitions)
Select (default p): enter p
Partition number (2-4, default 2): enter 2
First sector (131072-62521343, default 131072): start
Last sector, +sectors or +size{K,M,G,T,P} (131072-62521343, default 62521343): +new sizeK
```

**Note:** on the last line include the `+` and the `K` as part of the size.

```
Created a new partition 2 of type 'Linux' and of size 10.1 GiB.
```

```
Command (m for help): enter w
```

```
The partition table has been altered.
```

```
Calling ioctl() to re-read partition table.
```

```
Re-reading the partition table failed.: Invalid argument
```

```
The kernel still uses the old table. The new table will be used at the next reboot or after  
you run partprobe(8) or kpartx(8).
```

Disregard the final error.

You partition has now been resized and the partition table has been updated. Now we will remove the loopback and then truncate the end of the image file:



```
$ fdisk -l /dev/loop0
```

Device	Boot	Start	End	Sectors	Size	Id	Type
/dev/loop0p1		2048	131071	129024	63M	c	W95 FAT32 (LBA)
/dev/loop0p2		131072	21219327	21088256	10.1G	83	Linux

Note down the end of the second partition (in this case 21219327). Call this **end**.



```
$ sudo losetup -d /dev/loop0  
$ sudo truncate -s $(((end+1)*512)) image file
```

You now have a shrunken image file. A further idea is to compress it:



```
$ xz image file
```

## CHAPTER 99

# Networking tools



Assigned to: Andrea

Preliminary reading:

- Basics of networking, including
  - what are IP addresses
  - what are subnets
  - how DNS works
  - how .local names work
  - ...

→ (ref to find).

TODO: to write

Make sure that you know:

### 99.1. hostname



TODO: to write

### 99.2. Visualizing information about the network



1) ping: are you there?



TODO: to write

2) ifconfig



TODO: to write

```
$ ifconfig
```

# CHAPTER 100

## Accessing computers using SSH

Assigned to: Andrea

### 100.1. Background reading

TODO: to write

- Encryption
- Public key authentication

### 100.2. Installation of SSH

This installs the client:

```
$ sudo apt install ssh
```

This installs the server:

TODO: to write

This enables the server:

TODO: to write

### 100.3. Local configuration

The SSH configuration as a client is in the file

```
~/.ssh/config
```

Create the directory with the right permissions:

```
$ mkdir ~/.ssh  
$ chmod 0700 ~/.ssh
```

Then add the following lines:

```
HostKeyAlgorithms ssh-rsa
```

The reason is that Paramiko, used by `roslaunch`, [does not support the ECDSA keys](#).

### 100.4. How to login with SSH and a password

To log in to a remote computer `remote` with user `remote-user`, use:

```
$ ssh remote-user@remote
```

## 1) Troubleshooting

**Symptom:** “Offending key error”.

If you get something like this:

```
Warning: the ECDSA host key for ... differs from the key for the IP address '...'
```

```
Offending key for IP in /home/user/.ssh/known_hosts:line
```

then remove line `line` in `~/.ssh/known_hosts`.

## 100.5. Creating an SSH keypair

This is a step that you will repeat twice: once on the Duckiebot, and once on your laptop.

The program will prompt you for the filename on which to save the file.

Use the convention

```
/home/username/.ssh/username@host_name  
/home/username/.ssh/username@host_name.pub
```

where:

- `username` is the current user name that you are using (`ubuntu` or your chosen one);
- `host name` is the name of the host (the Duckiebot or laptop);

An SSH key can be generated with the command:

```
$ ssh-keygen -h
```

The session output will look something like this:

```
Generating public/private rsa key pair.  
Enter file in which to save the key (/home/username/.ssh/id_rsa):
```

At this point, tell it to choose this file:

```
/home/username/.ssh/username@host_name
```

Then:

```
Enter passphrase (empty for no passphrase):
```

Press enter; you want an empty passphrase.

Enter same passphrase again:

Press enter.

Note that the program created two files.

The file that contains the private key is

/home/username/.ssh/username@host\_name

The file that contains the public key has extension .pub:

/home/username/.ssh/username@host\_name.pub

Next, tell SSH that you want to use this key.

Make sure that the file `~/.ssh/config` exists:

```
$ touch ~/.ssh/config
```

Add a line containing

IdentityFile PRIVATE\_KEY\_FILE

(using the filename for the private key).

Check that the config file is correct:

```
$ cat ~/.ssh/config
...
IdentityFile PRIVATE_KEY_FILE
...
```

## 100.6. How to login without a password



Assumptions:

- You have two computers, called “`local`” and “`remote`”, with users “`local-user`” and “`remote-user`”.
- The two computers are on the same network.
- You have created a keypair for `local-user` on `local`.
  - This procedure is described in [Section 100.5](#).

Results:

- From the `local` computer, `local-user` will be able to log in to `remote` computer without a password.

First, connect the two computers to the same network, and make sure that you can ping `remote` from `local`:

```
local $ ping remote.local
```

Do not continue if you cannot do this successfully.

If you have created a keypair for `local-user`, you will have a public key in this file on the `local` computer:

```
/home/local-user/.ssh/local-user@local.pub
```

This file is in the form:

```
ssh-rsa long list of letters and numbers local-user@local
```

You will have to copy the contents of this file on the `remote` computer, to tell it that this key is authorized.

On the `remote` computer, edit or create the file:

```
/home/remote-user/.ssh/authorized_keys
```

and add the entire line as above containing the public key.

Now, from the `local` computer, try to log in into the `remote` one:

```
local $ ssh remote-user@remote
```

This should succeed, and you should not be asked for a password.

### 100.7. Fixing SSH Permissions

Sometimes, SSH does not work because you have the wrong permissions on some files. In doubt, these lines fix the permissions for your `.ssh` directory.

```
$ chmod 0700 ~/.ssh  
$ chmod 0700 ~/.ssh/*
```

### 100.8. ssh-keygen

TODO: to write

# CHAPTER 101

## Wireless networking in Linux

### 101.1. iwconfig

**TODO:** to write

### 101.2. iwlist

#### 1) Getting a list of WiFi networks

---

What wireless networks do I have around?

```
$ sudo iwlist interface scan | grep SSID
```

#### 2) Do I have 5 GHz?

---

Does the interface support 5 GHz channels?

```
$ sudo iwlist interface freq
```

Example output:

```
wlx74da38c9caa0 20 channels in total; available frequencies :
Channel 01 : 2.412 GHz
Channel 02 : 2.417 GHz
Channel 03 : 2.422 GHz
Channel 04 : 2.427 GHz
Channel 05 : 2.432 GHz
Channel 06 : 2.437 GHz
Channel 07 : 2.442 GHz
Channel 08 : 2.447 GHz
Channel 09 : 2.452 GHz
Channel 10 : 2.457 GHz
Channel 11 : 2.462 GHz
Channel 36 : 5.18 GHz
Channel 40 : 5.2 GHz
Channel 44 : 5.22 GHz
Channel 48 : 5.24 GHz
Channel 149 : 5.745 GHz
Channel 153 : 5.765 GHz
Channel 157 : 5.785 GHz
Channel 161 : 5.805 GHz
Channel 165 : 5.825 GHz
Current Frequency:2.437 GHz (Channel 6)
```

Note that in this example only *some* 5Ghz channels are supported (36, 40, 44, 48, 149, 153, 157, 161, 165); for example, channel 38, 42, 50 are not supported. This means that you need to set up the router not to use those channels.

## CHAPTER 102

# Moving files between computers

### 102.1. SCP

TODO: to write

- 1) Download a file with SCP

---

TODO: to write

### 102.2. RSync

TODO: to write

# CHAPTER 103

## VIM

Assigned to: Andrea

To do quick changes to files, especially when logged remotely, we suggest you use the VI editor, or more precisely, VIM (“VI iMproved”).

### 103.1. External documentation

→ [A VIM tutorial.](#)

### 103.2. Installation

Install like this:

```
$ sudo apt install vim
```

### 103.3. vi

TODO: to write

### 103.4. Suggested configuration

Suggested `~/.vimrc`:

```
syntax on
set number
filetype plugin indent on
highlight Comment ctermfg=Gray
autocmd FileType python set complete isk+=.,(
```

### 103.5. Visual mode

TODO: to write

### 103.6. Indenting using VIM

Use the `>` command to indent.

To indent 5 lines, use `5 > >`.

To mark a block of lines and indent it, use `v >`.

For example, use `v J J >` to indent 3 lines.

Use `<` to dedent.



## CHAPTER 104

# Atom

..

**TODO:** to write

## CHAPTER 105

# Eclipse

TODO: to write

### 105.1. Installing LiClipse

TODO: to write

# CHAPTER 106

## Byobu

Assigned to: Andrea

You need to learn to use Byobu. It will save you much time later.

(Alternatives such as [GNU Screen](#) are fine as well.)

### 106.1. Advantages of using Byobu

TODO: To write

### 106.2. Installation

On Ubuntu, install using:

```
$ sudo apt install byobu
```

### 106.3. Documentation

\* See the screencast on the website <http://byobu.co/>.

### 106.4. Quick command reference

You can change the escape sequence from **[Ctrl]-[A]** to something else by using the configuration tool that appears when you type **[F9]**.

Commands to use windows:

TABLE 15. WINDOWS

	Using function keys	Using escape sequences
Create new window	<b>F2</b>	<b>[Ctrl]-[A]</b> then <b>C</b>
Previous window	<b>F3</b>	
Next window	<b>F4</b>	
Switch to window		<b>[Ctrl]-[A]</b> then a number
Close window	<b>F6</b>	
Rename window		<b>[Ctrl]-[A]</b> then <b>R</b>

Commands to use panes (windows split in two or more):

TABLE 16. COMMANDS FOR PANES

	Using function keys	Using escape sequences
Split horizontally	<b>Shift-[F2]</b>	<b>[Ctrl]-[A]</b> then <b>I</b>
Split vertically	<b>Ctrl-[F2]</b>	<b>[Ctrl]-[A]</b> then <b>%</b>
Switch focus among panes	<b>Ctrl-[↑↓↔]</b>	<b>[Ctrl]-[A]</b> then one of <b>[↑↓↔]</b>
Break pane		<b>[Ctrl]-[A]</b> then <b>I</b>

Other commands:

TABLE 17. OTHER

Using function keys	Using escape sequences
Help	<code>Ctrl-A</code> then <code>?</code>
Detach	<code>Ctrl-A</code> then <code>D</code>

### 106.5. Commands on OS X

Scroll up and down using `fn option ↑` and `fn option ↓`.

Highlight using `alt`



# CHAPTER 107

## Source code control with Git

Assigned to: Andrea

### 107.1. Background reading

TODO: to write

- Git
- GitFlow

### 107.2. Installation

The basic Git program is installed using

```
$ sudo apt install git
```

Additional utilities for `git` are installed using:

```
$ sudo apt install git-extras
```

This include the `git-ignore` utility.

### 107.3. Setting up global configurations for Git

This should be done twice, once on the laptop, and later, on the robot.

These options tell Git who you are:

```
$ git config --global user.email "email"  
$ git config --global user.name "full name"
```

Also do this, and it doesn't matter if you don't know what it is:

```
$ git config --global push.default simple
```

### 107.4. Git tips

#### 1) Shallow clone

You can clone without history with the command:

```
$ git clone --depth 1 repository URL
```

## 107.5. Git troubleshooting

### 1) Problem 1: https instead of ssh:

The symptom is:

```
$ git push  
Username for 'https://github.com':
```

Diagnosis: the `remote` is not correct.

If you do `git remote` you get entries with `https`:

```
$ git remote -v  
origin https://github.com/duckietown/Software.git (fetch)  
origin https://github.com/duckietown/Software.git (push)
```

Expectation:

```
$ git remote -v  
origin git@github.com:duckietown/Software.git (fetch)  
origin git@github.com:duckietown/Software.git (push)
```

Solution:

```
$ git remote remove origin  
$ git remote add origin git@github.com:duckietown/Software.git
```

### 2) Problem 1: `git push` complains about upstream

The symptom is:

```
fatal: The current branch [branch name] has no upstream branch.
```

Solution:

```
$ git push --set-upstream origin [branch name]
```

## 107.6. git

TODO: to write

## CHAPTER 108

# Git LFS



This describes Git LFS.

### 108.1. Generic installation instructions



See instructions at:

<https://git-lfs.github.com/>

### 108.2. Ubuntu 16 installation (laptop)



Following [these instructions](#), run the following:

```
$ sudo add-apt-repository ppa:git-core/ppa  
$ curl -s https://packagecloud.io/install/repositories/github/git-lfs/script.deb.sh | sudo bash  
$ sudo apt update  
$ sudo apt install git-lfs
```

### 108.3. Ubuntu 16 Mate installation (Raspberry Pi 3)



**Note:** unresolved issues.

The instructions above do not work.

Following [this](#), the error that appears is that golang on the Pi is 1.6 instead it should be 1.7.

#### 1) Troubleshooting



**Symptom:** The binary files are not downloaded. In their place, there are short “pointer” files.

If you have installed LFS after pulling the repository and you see only the pointer files, do:

```
$ git lfs pull --all
```

## CHAPTER 109

# Setup Github access



Assigned to: Andrea

This chapter describes how to create a Github account and setup SSH on the robot and on the laptop.

### 109.1. Create a Github account



Our example account is the following:

```
Github name: greta-p
E-mail: greta-p@duckietown.com
```

Create a Github account ([Figure 55](#)).



Figure 55

Go to your inbox and verify the email.

### 109.2. Become a member of the Duckietown organization



Give the administrators your account name. They will invite you.

Accept the invitation to join the organization that you will find in your email.

### 109.3. Add a public key to Github



You will do this procedure twice: once for the public key created on the laptop, and later with the public key created on the robot.

Requires:

- A public/private keypair already created and configured.
  - This procedure is explained in [Section 100.5](#).

Result:

- You can access Github using the key provided.

Go to settings ([Figure 56](#)).

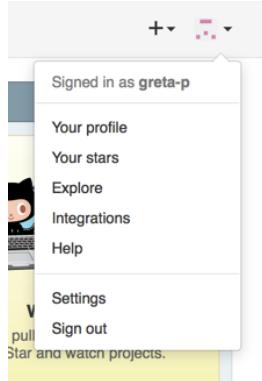


Figure 56

Add the public key that you created:



Figure 57

Need help? Check our guide to generating SSH keys or troubleshooting common SSH problems.	
<a href="#">SSH Keys</a>	<a href="#">Add SSH Key</a>
There are no SSH keys with access to your account.	
<a href="#">Add an SSH key</a>	
Title: <input type="text" value="Gretas SSH key"/> Key: <pre>-----BEGIN RSA PRIVATE KEY----- MIIEowIENQIBAAQEAQDgA... -----END RSA PRIVATE KEY-----</pre>	
<input type="button" value="Add Key"/>	

Figure 58

SSH Keys	
This is a list of SSH keys associated with your account. Remove any keys that you do not recognize.	
<a href="#">Gretas SSH key</a> <small>Added on Jun 17, 2016 - IP address: 72.36.37.123 (80.21.39.45)</small>	<a href="#">Edit</a> <a href="#">Delete</a>

Figure 59

To check that all of this works, use the command

```
$ ssh -T git@github.com
```

The command tries to connect to Github using the private keys that you specified. This is the expected output:

```
Warning: Permanently added the RSA host key for IP address 'ip address' to the list of known hosts.  
Hi username! You've successfully authenticated, but GitHub does not provide shell access.
```

If you don't see the greeting, stop.

Repeat what you just did for the Duckiebot on the laptop as well, making sure to change the name of the file containing the private key.

## CHAPTER 110

# ROS installation and reference



Assigned to: Liam

### 110.1. Install ROS



This part installs ROS. You will run this twice, once on the laptop, once on the robot. The first commands are copied from [this page](#).

Tell Ubuntu where to find ROS:

```
$ sudo sh -c 'echo "deb http://packages.ros.org/ros/ubuntu $(lsb_release -sc) main" > /etc/apt/sources.list.d/ros-latest.list'
```

Tell Ubuntu that you trust the ROS people (they are nice folks):

```
$ sudo apt-key adv --keyserver hkp://ha.pool.sks-keyservers.net:80 --recv-key  
421C365BD9FF1F717815A3895523BAEEB01FA116
```

Fetch the ROS repo:

```
$ sudo apt update
```

Now install the mega-package `ros-kinetic-desktop-full`.

```
$ sudo apt install ros-kinetic-desktop-full
```

There's more to install:

```
$ sudo apt install  
ros-kinetic-{tf-conversions,cv-bridge,image-transport,camera-info-manager,theora-image-transport,joy,image-proc,...
```

**Note:** Do not install packages by the name of `ros-X`, only those by the name of `ros-kinetic-X`. The packages `ros-X` are from another version of ROS.

: not done in aug20 image:

Initialize ROS:

```
$ sudo rosdep init  
$ rosdep update
```

### 110.2. rqt\_console



TODO: to write

### 110.3. `roslaunch`

TODO: to write



### 110.4. `rviz`

TODO: to write



### 110.5. `rostopic`

TODO: to write



1) `rostopic hz`

---

TODO: to write



2) `rostopic echo`

---

TODO: to write



### 110.6. `catkin_make`

TODO: to write



### 110.7. `rosrun`

TODO: to write



### 110.8. `rostest`

TODO: to write



### 110.9. `rospack`

TODO: to write



### 110.10. `rosparam`

TODO: to write



### 110.11. rosdep

TODO: to write



### 110.12. rosrtf

TODO: to write



### 110.13. rosbag

```
$ rosbag reindex bag file
```



### 110.14. roscore

TODO: to write



## 110.15. Troubleshooting ROS



| **Symptom:** `computer` is not in your SSH `known_hosts` file

See [this thread](#). Remove the `known_hosts` file and make sure you have followed the instructions in [Section 100.3](#).

## 110.16. Other materials about ROS.



- \* [\*A gentle introduction to ROS\*](#)

## PART 9

# Software development guide



This part is about how to develop software for the Duckiebot.

## CHAPTER 111

# Python

### 111.1. Background reading

- Python
- Python tutorial

### 111.2. Python virtual environments

Install using:

```
$ sudo apt install virtualenv
```

### 111.3. Useful libraries

```
matplotlib  
seaborn  
numpy  
panda  
scipy  
opencv  
...
```

### 111.4. Context managers

TODO: to write

# CHAPTER 112

## Duckietown code conventions

### 112.1. Python

#### 1) Tabs

Never use tabs in Python file.

The tab characters are evil in Python code. Please be very careful in changing them.

Do *not* use a tool to do it (e.g. “Convert tabs to spaces”); it will get it wrong.

- ✓ checked by `what-the-duck`.

#### 2) Spaces

Indentation is 4 spaces.

#### 3) Line lengths

Lines should be below 85 characters.

- ✓ `what-the-duck` report those above 100 characters.

This is just a symptom of a bigger problem.

The problem here is that you do not do how to program well, therefore you create programs with longer lines.

Do not go and try to shorten the lines; the line length is just the symptom. Rather, ask somebody to take a look at the code and tell you how to make it better.

#### 4) Spaces

Indentation is 4 spaces.

#### 5) The encoding line

All files must have an encoding declared, and this encoding must be `utf-8`:

```
# -*- coding: utf-8 -*-
```

#### 6) Sha-bang lines

Executable files start with:

```
#!/usr/bin/env python
```

#### 7) Comments

Comments refer to the next line.

Comments, bad:

```
from std_msgs.msg import String # This is my long comment
```

Comments, better:

```
# This is my long comment
from std_msgs.msg import String
```

## 112.2. Logging

For logging, import this logger:

```
from duckietown_utils import logger
```

## 112.3. Exceptions

```
DTConfigException
raise_wrapped
compact = True
```

## 112.4. Scripts

```
def summary():
    fs = get_all_configuration_files()

if __name__ == '__main__':
    wrap_script_entry_point(summary)
```

### 1) Imports

Do not do a star import, like the following:

```
from rostest_example.Quacker import *
```

# CHAPTER 113

## Configuration



This chapter explains what are the assumptions about the configuration.

While the “Setup” parts are “imperative” (do this, do that); this is the “declarative” part, which explains what are the properties of a correct configuration (but it does not explain how to get there).

The tool `what-the-duck` ([Section 160.1](#)) checks some of these conditions. If you make a change from the existing conditions, make sure that it gets implemented in `what-the-duck` by filing an issue.



### 113.1. Environment variables

You need to have set up the variables in [Table 18](#).

TABLE 18. ENVIRONMENT VARIABLES USED BY THE SOFTWARE

variable	reasonable value	contains
DUCKIETOWN_ROOT	<code>~/duckietown</code>	Software repository
DUCKIEFLEET_ROOT	<code>~/duckiefleet</code>	A repository that contains <code>scuderia.yaml</code> and other team-specific configuration.
DUCKIETOWN_DATA	<code>~/duckietown-data</code>	Contains data for unit tests (Dropbox folder)
DUCKIETOWN_CONFIG_SEQUENCE	<code>defaults:baseline:vehicle:user</code>	The <a href="#">configuration sequence for EasyNode</a>

1) Duckietown root directory `DUCKIETOWN_ROOT`



**TODO:** to write

2) Duckiefleet directory `DUCKIEFLEET_ROOT`



For Fall 2017, this is the the repository [duckiefleet-fall2017](#).

For self-guided learners, this is an arbitrary repository to create.



### 113.2. The scuderia file



In the  `${DUCKIEFLEET_ROOT}`  directory, there needs to exist a file called:

`${DUCKIEFLEET_ROOT}/scuderia.yaml`

The file must contain YAML entries of the type:

```
robot-name:  
  username: username  
  owner_duckietown_id: owner duckietown ID
```

A minimal example is in [Listing 5](#).

```
emma:
  username: andrea
  owner_duckietown_id: censi
```

Listing 5. Minimal scuderia file

Explanations of the fields:

- **robot\_name**: the name of the robot, also equal to the host name.
- **username**: the name of the Linux user on the robot, from which to run programs.
- **owner\_duckietown\_id**: the owner's globally-unique Duckietown ID.

**TODO:** I am still not satisfied. We should have a separate file for every robot, called `robot_name.vehicle.yaml`. In this way, people don't have to work on the same file. Then `scuderia.yaml` can be autogenerated from those files.

### 113.3. The machines file

The `machines` file is created using:

```
$ rosrun duckietown create-machines-file
```

### 113.4. People database

Assigned to: Andrea

**TODO:** Describe the people database; this is the evolution of the yaml files

#### 1) The globally-unique Duckietown ID

This is a globally-unique ID for people in the Duckietown project.

It is equal to the Slack username.

### 113.5. Modes of operation

There are 3 modes of operation:

1. **MODE-normal**: Everything runs on the robot.
2. **MODE-offload**: Drivers run on the robot, but heavy computation runs on the laptop.
3. **MODE-bag**: The data is provided from a bag file, and computation runs on the laptop.

TABLE 19. OPERATION MODES

mode name	who is the ROS master	where data comes from	where heavy computation happen
MODE-normal	duckiebot	Drivers on Duckiebot	duckiebot
MODE-offload	duckiebot	Drivers on Duckiebot	laptop
MODE-bag	laptop	Bag file	laptop

## CHAPTER 114

# Node configuration mechanisms

..

**TODO:** Where the config files are, how they are used.

## CHAPTER 115

### Minimal ROS node - `pkg_name`

Assigned to: Andrea

This document outline the process of writing a ROS package and nodes in Python. To follow along, it is recommend that you duplicate the `pkg_name` folder and edit the content of the files to make your own package.

#### 115.1. The files in the package

##### 1) `CMakeLists.txt`

We start with [`CMakeLists.txt`](#).

Every ROS package needs a file `CMakeLists.txt`, even if you are just using Python code in your package.

\* documentation about `CMakeLists.txt`

For a Python package, you only have to pay attention to the following parts.

The line:

```
project(pkg_name)
```

defines the name of the project.

The `find_package` lines:

```
find_package(catkin REQUIRED COMPONENTS
  roscpp
  rospy
  duckietown_msgs # Every duckietown packages must use this.
  std_msgs
)
```

You will have to specify the packages on which your package is dependent.

In Duckietown, most packages depend on `duckietown_msgs` to make use of the customized messages.

The line:

```
catkin_python_setup()
```

tells `catkin` to setup Python-related stuff for this package.

\* [ROS documentation about `setup.py`](#)

## 2) package.xml

The file `package.xml` defines the meta data of the package.

Catkin makes use of it to flush out the dependency tree and figures out the order of compiling.

Pay attention to the following parts.

`<name>` defines the name of the package. It has to match the project name in `CMakeLists.txt`.

`<description>` describes the package concisely.

`<maintainer>` provides information of the maintainer.

`<build_depend>` and `<run_depend>`. The catkin packages this package depends on. This usually match the `find_package` in `CMakeLists.txt`.

## 3) setup.py

The file `setup.py` configures the Python modules in this package.

The part to pay attention to is

```
setup_args = generate_distutils_setup(  
    packages=['pkg_name'],  
    package_dir={'': 'include'},  
)
```

The `packages` parameter is set to a list of strings of the name of the folders inside the `include` folder.

The convention is to set the folder name the same as the package name. Here it's the `include/pkg_name` folder.

You should put ROS-independent and/or reusable module (for other packages) in the `include/pkg_name` folder.

Python files in this folder (for example, the `util.py`) will be available to scripts in the catkin workspace (this package and other packages too).

To use these modules from other packages, use:

```
from pkg_name.util import *
```

## 115.2. Writing a node: talker.py

Let's look at `src/talker.py` as an example.

ROS nodes are put under the `src` folder and they have to be made executable to function properly.

→ You use `chmod` for this; see [Section 93.1](#).

### 1) Header

Header:

```
#!/usr/bin/env python
import rospy
# Imports module. Not limited to modules in this package.
from pkg_name.util import HelloGoodbye
# Imports msg
from std_msgs.msg import String
```

The first line, `#!/usr/bin/env python`, specifies that the script is written in Python.

Every ROS node in Python must start with this line.

The line `import rospy` imports the `rospy` module necessary for all ROS nodes in Python.

The line `from pkg_name.util import HelloGoodbye` imports the class `HelloGoodbye` defined in the file [pkg\\_name/util.py](#).

Note that you can also include modules provided by other packages, if you specify the dependency in `CMakeLists.txt` and `package.xml`.

The line `from std_msgs.msg import String` imports the `String` message defined in the `std_msgs` package.

Note that you can use `rosmg show std_msgs/String` in a terminal to lookup the definition of `String.msg`.

## 2) Main

---

This is the main file:

```
if __name__ == '__main__':
    # Initialize the node with rospy
    rospy.init_node('talker', anonymous=False)

    # Create the NodeName object
    node = Talker()

    # Setup proper shutdown behavior
    rospy.on_shutdown(node.on_shutdown)

    # Keep it spinning to keep the node alive
    rospy.spin()
```

The line `rospy.init_node('talker', anonymous=False)` initializes a node named `talker`.

Note that this name can be overwritten by a launch file. The launch file can also push this node down namespaces. If the `anonymous` argument is set to `True` then a random string of numbers will be append to the name of the node. Usually we don't use anonymous nodes.

The line `node = Talker()` creates an instance of the `Talker` object. More details in the next section.

The line `rospy.on_shutdown(node.on_shutdown)` ensures that the `node.on_shutdown` will be called when the node is shutdown.

The line `rospy.spin()` blocks to keep the script alive. This makes sure the node stays alive

and all the publication/subscriptions work correctly.

### 115.3. The Talker class

We now discuss the `Talker` class in [talker.py](#).

#### 1) Constructor

In the constructor, we have:

```
self.node_name = rospy.get_name()
```

saves the name of the node.

This allows to include the name of the node in printouts to make them more informative. For example:

```
rospy.loginfo("[%(s] Initializing." % (self.node_name))
```

The line:

```
self.pub_topic_a = rospy.Publisher("~topic_a", String, queue_size=1)
```

defines a publisher which publishes a `String` message to the topic `~topic_a`. Note that the `~` in the name of topic under the namespace of the node. More specifically, this will actually publish to `talker/topic_a` instead of just `topic_a`. The `queue_size` is usually set to 1 on all publishers.

→ For more details see [rospy overview: publisher and subscribers](#).

The line:

```
self.sub_topic_b = rospy.Subscriber("~topic_b", String, self.cbTopic)
```

defines a subscriber which expects a `String` message and subscribes to `~topic_b`. The message will be handled by the `self.cbTopic` callback function. Note that similar to the publisher, the `~` in the topic name puts the topic under the namespace of the node. In this case the subscriber actually subscribes to the topic `talker/topic_b`.

It is strongly encouraged that a node always publishes and subscribes to topics under their `node_name` namespace. In other words, always put a `~` in front of the topic names when you define a publisher or a subscriber. They can be easily remapped in a launch file. This makes the node more modular and minimizes the possibility of confusion and naming conflicts. See [the launch file section](#) for how remapping works.

The line

```
self.pub_timestep = self.setupParameter("~pub_timestep", 1.0)
```

Sets the value of `self.pub_timestep` to the value of the parameter `~pub_timestep`. If the parameter doesn't exist (not set in the launch file), then set it to the default value `1.0`. The `setupParameter` function also writes the final value to the parameter server. This means that you can `rosparam list` in a terminal to check the actual values of parameters being set.

The line:

```
self.timer = rospy.Timer(rospy.Duration.from_sec(self.pub_timestep), self.cbTimer)
```

defines a timer that calls the `self.cbTimer` function every `self.pub_timestep` seconds.

## 2) Timer callback

Contents:

```
def cbTimer(self,event):
    singer = HelloGoodbye()
    # Simulate hearing something
    msg = String()
    msg.data = singer.sing("duckietown")
    self.pub_topic_name.publish(msg)
```

Everyt ime the timer ticks, a message is generated and published.

## 3) Subscriber callback

Contents:

```
def cbTopic(self,msg):
    rospy.loginfo("[{} {}] {}".format(self.node_name, msg.data))
```

Every time a message is published to `~topic_b`, the `cbTopic` function is called. It simply prints the messae using `rospy.loginfo`.

## 115.4. Launch File

You should always write a launch file to launch a node. It also serves as a documentation on the I/O of the node.

Let's take a look at `launch/test.launch`.

```
<launch>
  <node name="talker" pkg="pkg_name" type="talker.py" output="screen">
    <param name="~pub_timestep" value="0.5"/>
    <remap from="~topic_b" to="~topic_a"/>
  </node>
</launch>
```

For the `<node>`, the `name` specify the name of the node, which overwrites `rospy.init_node()` in the `__main__` of `talker.py`. The `pkg` and `type` specify the package and the script of the node, in this case it's `talker.py`.

Don't forget the `.py` in the end (and remember to make the file executable through `chmod`).

The `output="screen"` direct all the `rospy.loginfo` to the screen, without this you won't see any printouts (useful when you want to suppress a node that's too talkative.)

The `<param>` can be used to set the parameters. Here we set the `~pub_timestep` to `0.5`. Note that in this case this sets the value of `talker/pub_timestep` to `0.5`.

The `<remap>` is used to remap the topic names. In this case we are replacing `~topic_b` with `~topic_a` so that the subscriber of the node actually listens to its own publisher. Replace the line with

```
<remap from="~topic_b" to="talker/topic_a"/>
```

will have the same effect. This is redundant in this case but very useful when you want to subscribe to a topic published by another node.

## 115.5. Testing the node

First of all, you have to `catkin_make` the package even if it only uses Python. `catkin` makes sure that the modules in the include folder and the messages are available to the whole workspace. You can do so by

```
$ cd ${DUCKIETOWN_ROOT}/catkin_ws  
$ catkin_make
```

Ask ROS to re-index the packages so that you can auto-complete most things.

```
$ rospack profile
```

Now you can launch the node by the launch file.

```
$ rosrun pkg_name test.launch
```

You should see something like this in the terminal:

```
... logging to /home/username/.ros/log/d4db7c80-b272-11e5-8800-5c514fb7f0ed/roslaunc-robot
name-15961.log
Checking log directory for disk usage. This may take awhile.
Press Ctrl-C to interrupt
Done checking log file disk usage. Usage is 1GB.

started roslaunc server http://robot name.local:33925/

SUMMARY
=====

PARAMETERS
* /rosdistro: $ROS_DISTRO
* /rosversion: 1.11.16
* /talker/pub_timestep: 0.5

NODES
/
    talker (pkg_name/talker.py)

auto-starting new master
process[master]: started with pid [15973]
ROS_MASTER_URI=http://localhost:11311

setting /run_id to d4db7c80-b272-11e5-8800-5c514fb7f0ed
process[rosout-1]: started with pid [15986]
started core service [/rosout]
process[talker-2]: started with pid [15993]
[INFO] [WallTime: 1451864197.775356] [/talker] Initialzing.
[INFO] [WallTime: 1451864197.780158] [/talker] ~pub_timestep = 0.5
[INFO] [WallTime: 1451864197.780616] [/talker] Initialzed.
[INFO] [WallTime: 1451864198.281477] [/talker] Goodbye, duckietown.
[INFO] [WallTime: 1451864198.781445] [/talker] Hello, duckietown.
[INFO] [WallTime: 1451864199.281871] [/talker] Goodbye, duckietown.
[INFO] [WallTime: 1451864199.781486] [/talker] Hello, duckietown.
[INFO] [WallTime: 1451864200.281545] [/talker] Goodbye, duckietown.
[INFO] [WallTime: 1451864200.781453] [/talker] Goodbye, duckietown.
```

Open another terminal and run:

```
$ rostopic list
```

You should see

```
/rosout
/rosout_agg
/talker/topic_a
```

In the same terminal, run:

```
$ rosparam list
```

You should see the list of parameters, including `/talker/pub_timestep`.

You can see the parameters and the values of the `talker` node with

```
$ rosparam get /talker
```

## 115.6. Documentation

You should document the parameters and the publish/subscribe topic names of each node in your package. The user should not have to look at the source code to figure out how to use the nodes.

## 115.7. Guidelines

- Make sure to put all topics (publish or subscribe) and parameters under the name-space of the node with `~`. This makes sure that the IO of the node is crystal clear.
- Always include the name of the node in the printouts.
- Always provide a launch file that includes all the parameters (using `<param>`) and topics (using `<remap>`) with each node.

## CHAPTER 116

# ROS package verification

This chapter describes formally what makes a conforming ROS package in the Duckietown software architecture.

### 116.1. Naming

- For exercises packages, the name of the package must be `package_handle`.

### 116.2. `package.xml`

- There is a `package.xml` file.
- ✓ Checked by `what-the-duck`.

### 116.3. Messages

- The messages are called ....

### 116.4. Readme file

- There is a `README.md` file
- ✓ Checked by `what-the-duck`.

### 116.5. Launch files

- there is the first launch file

### 116.6. Test files

TODO: to write

CHAPTER 117

## Creating unit tests with ROS



## PART 10

# Duckietown system



This part describes the Duckietown algorithms and system architecture.

We do not go in the software details. The implementation details have been already talked about at length in [Part 9](#).

We do give links to the ROS packages implementing the functionality.

# CHAPTER 118

## Teleoperation

TODO: add video here

### 118.1. Implementation

Drivers:

- [Chapter 161 - Package adafruit\\_drivers](#)
- [Chapter 171 - Package pi\\_camera](#)

Operator interface:

- [Chapter 166 - Package joy\\_mapper](#)

### 118.2. Camera

TODO: to write

### 118.3. Actuators

TODO: to write

### 118.4. IMU

TODO: to write

CHAPTER 119  
Parallel autonomy



TODO: to write

# CHAPTER 120

## Lane control



TODO: video here



### 120.1. Implementation

Perception:

- [Chapter 162 - Package anti\\_instagram](#)
- [Chapter 165 - Package ground\\_projection](#)
- [Chapter 170 - Package line\\_detector](#), [Chapter 169 - Package line\\_detector2](#)
- [Chapter 168 - Package lane\\_filter](#)

Control:

- [Chapter 167 - Package lane\\_control](#)
- [Chapter 163 - Package car\\_supervisor](#)
- [Chapter 164 - Package dagu\\_car](#)

## CHAPTER 121

# Indefinite navigation

TODO: add video here

### 121.1. Implementation

The packages involved in this functionality are:

- [Chapter 172 - Package `apriltags\_ros`](#)
- [Chapter 173 - Package `fsm`](#)
- [Chapter 174 - Package `indefinite\_navigation`](#)
- [Chapter 175 - Package `intersection\_control`](#)
- [Chapter 176 - Package `navigation`](#)

| **Note:** we don't discuss the details of the packages here; we just give pointers to them.

# CHAPTER 122

## Planning



**TODO:** add video here



### 122.1. Implementation

The packages involved in this functionality are:

- [Chapter 179 - Package localization](#)
- [Chapter 178 - Package duckietown\\_description](#)

**Note:** we don't discuss the details of the packages here; we just give pointers to them.

## CHAPTER 123

# Coordination

TODO: add video here

### 123.1. Implementation

- [Chapter 180 - Package led\\_detection](#)
- [Chapter 181 - Package led\\_emitter](#)
- [Chapter 182 - Package led\\_interpreter](#)
- [Chapter 183 - Package led\\_joy\\_mapper](#)
- [Chapter 185 - Package traffic\\_light](#)
- [Chapter 184 - Package rgb\\_led](#)

# CHAPTER 124

## Duckietown ROS Guidelines

### 124.1. Node and Topics

In the source code, a node must only publish/subscribe to private topics.

In `rospy`, this means that the topic argument of `rospy.Publisher` and `rospy.Subscriber` should always have a leading `~`. ex: `~wheels_cmd`, `~mode`.

In `roscpp`, this means that the node handle should always be initialized as a private node handle by supplying with a `"~"` agrument at initialization. Note that the leading `"~"` must then be obmited in the topic names of. ex:

```
ros::NodeHandle nh("~");
sub_lineseglist_ = nh_.subscribe("lineseglist_in", 1, &GroundProjection::lineseglist_cb, this);
pub_lineseglist_ = nh_.advertise<duckietown_msgs::SegmentList> ("lineseglist_out", 1);
```

### 124.2. Parameters

All the parameters of a node must be private parameters to that node.

All the nodes must write the value of the parameters being used to the parameter server at initialization. This ensures transparency of the parameters. Note that the `get_param(name,default_value)` does not write the default value to the parameter server automatically.

The default parameter of `pkg_name/node_name` should be put in `/duckietown/catkin_ws/src/duckietown/config/baseline/pkg_name/node_name/default.yaml`. The elemental launch file of this node should load the parameter using `<rosparam>`.

### 124.3. Launch file

Each node must have a launch file with the same name in the `launch` folder of the package. ex: `joy_mapper.py` must have a `joy_mapper.launch`. These are referred to as the elemental launch files.

Each elemental launch file must only launch one node.

The elemental launch file should put the node under the correct namespace through the `veh` arg, load the correct configuration and parameter file throught `config` and `param_file_name` args respectively. `veh` must not have a default value. This is to ensure the user to always provide the `veh` arg. `config` must be default to `baseline` and `param_file_name` must be default to `default`.

When a node can be run on the vehicle or on a laptop, the elemental launch file should provide a `local` arg. When set to true, the node must be launch on the launching machine, when set to false, the node must be launch on a vehicle throught the `machine` attribute.

A node should always be launched by calling its corresponding launch file instead of using `rosrun`. This ensures that the node is put under the correct namespace and all the necessary parameters are provided.

Do not use `<remapp>` in the elemental launch files.

Do not use `<param>` in the elemental launch files.

## PART 11

# Fall 2017



This is the first time that a class is taught jointly across 3 continents!

There are 4 universities involved in the joint teaching for the term:

- ETH Zürich (ETHZ), with instructors Emilio Frazzoli, Andrea Censi, Jacopo Tani.
- University of Montreal (UdeM), with instructor Liam Paull.
- TTI-Chicago (TTIC), with instructor Matthew Walter.
- National CT University (NCTU), with instructor Nick Wang.

This part of the Duckiebook describes all the information that is needed by the students of the four institutions.

## CHAPTER 125

### General remarks



Assigned to: Andrea

#### 125.1. The rules of Duckietown



##### **The first rule of Duckietown**

The first rule of Duckietown is: you don't talk about Duckietown, *using email*.

Instead, we use a communication platform called Slack.

There is one exception: inquiries about "meta" level issues, such as course enrollment and other official bureaucratic issues can be communicated via email.

##### **The second rule of Duckietown**

The second rule of Duckietown is: be kind and respectful, and have fun.

##### **The third rule of Duckietown**

The third rule of Duckietown is: read the instructions carefully.

Do not blindly copy and paste.

Only run a command if you know what it does.

#### 125.2. Synchronization between classes



At ETHZ, UdeM, TTIC, the class will be more-or-less synchronized. The materials are the same; there is some slight variation in the ordering.

Moreover, there will be some common groups for the projects.

The NCTU class is undergraduate level. Students will learn slightly simplified materials. They will not collaborate directly with the classes.

#### 125.3. Accounts for students



To participate in Duckietown, students must use two accounts: Slack and Github.

##### 1) Slack



You need a Slack account, for team discussion and organization.

**TODO:** Sign up link here:

**TODO:** Account naming convention

##### 2) Github



**TODO:** Account naming convention

- A Github account;
- Membership in the Duckietown organization.

## 125.4. Accounts for all instructors and TAs

As an instructor/TA for the Fall 2017 class, in addition to the accounts above, there are two more accounts that you need.

### 1) Twist

---

Twist is used for class organization (such as TAs, logistics);

TODO:

### 2) Google docs

---

Google Docs is used to maintain TODOs and other coordination materials.

TODO: how to be authorized?

In particular:

- This is the schedule: XXX
- This is the calendar in which to annotate everything: XXX

## CHAPTER 126

## Additional information for ETH Zürich students



Assigned to: Andrea

This section describes information specific for ETH Zürich students.

**TODO:** to write

1) Website



All really important information, such as deadlines, is in the authoritative website:

2) Duckiebox distribution



**TODO:** to write

3) Lab access



**TODO:** To write

4) The local TAs



**TODO:** to write

# CHAPTER 127

## Additional information for UdeM students

..

| Assigned to: Liam

TODO: to write

## CHAPTER 128

## Additional information for TTIC students



Assigned to: Matt

TODO: to write

## CHAPTER 129

# Additional information for NCTU students



| Assigned to: Nick

TODO: to write

CHAPTER 130

## Milestone: ROS node working



CHAPTER 131

Homework: Take and process a log

..

CHAPTER 132

Milestone: Calibrated robot



CHAPTER 133

Homework: Camera geometry

..

**CHAPTER 134****Milestone: Illumination invariance**

## CHAPTER 135

### Homework: Place recognition

..

## CHAPTER 136

**Milestone: Lane following**

CHAPTER 137  
Homework: localization

..

CHAPTER 138

Milestone: Navigation



CHAPTER 139

Homework: group forming

..

CHAPTER 140  
Milestone: Ducks in a row

• •

CHAPTER 141

# Homework: Comparison of PID

..

CHAPTER 142  
Homework: RRT

• •

# CHAPTER 143

## Caffe tutorial

..

CHAPTER 144

## Milestone: Object Detection



CHAPTER 145

# Homework: Object Detection

..

**CHAPTER 146****Milestone: Semantic perception**

CHAPTER 147

Homework: Semantic perception

..

**CHAPTER 148****Milestone: Reacting to obstacles**

CHAPTER 149

Homework: Reacting to obstacles

..

## CHAPTER 150

**Milestone: SLAM demo**

CHAPTER 151  
Homework: SLAM

..

CHAPTER 152

Milestone: fleet demo

•

•

CHAPTER 153  
Homework: fleet

..

CHAPTER 154  
Project proposals

• •

# CHAPTER 155

## Template of a project

### 155.1. Checklist for students

- Have a Github account. See [Chapter 109](#). See name conventions (TODO).
- Be part of the Duckietown Github organization. You are sure only when you commit and push one change to one of our repositories.
- Be part of the Duckietown Slack. See name conventions (TODO).

### 155.2. Checklist for TAs

- Be signed up on

## PART 12

# Packages - Infrastructure



**TODO:** to write

# CHAPTER 156

## Package duckietown

..

**TODO:** to write

## CHAPTER 157

Package `duckietown_msgs`

**TODO:** to write

# CHAPTER 158

## Package easy\_node



`easy_node` is a framework to make it easier to create and document ROS nodes. It allows a *declarative approach* to declaring subscriptions, publishers, and parameters.

The user can directly describe what are the subscription, the publishers, the parameters in a YAML file. The framework then takes care of calling the necessary boilerplate ROS commands for subscribing, publishing, etc.

In addition, `easy_node` can also create the Markdown documentation from the YAML file.

Using `easy_node` allows to cut 40%-50% of the code required for programming a node. For an example, see the package [line\\_detector2](#), which contains a re-implementation of `line_detector` using the new framework.



### 158.1. Transition plan

The plan is to first use `easy_node` just for documentation of the nodes; then, later, convert all the nodes to use it.



### 158.2. YAML file format

If you have a node with the name `my_node`, implemented in the file `my_node.py` you must create a file by the name `my_node.easy_node.yaml` somewhere in the package.

The YAML file must contain 4 sections, each of which is a dictionary.

This is the smallest example of an empty configuration:

```
parameters:  
subscriptions:  
publishers:  
contracts:
```

#### 1) Configuring parameters

---



This is the syntax:

```
parameters:  
  name parameter:  
    type: type  
    desc: description  
    default: default value
```

where:

- `![type]` is one of `float`, `int`, `bool`, `str`.
- `![description]` is a description that will appear in the documentation.
- The optional field `default` gives a default value for the parameter.

For example:

```
parameters:
  k_d:
    type: float
    desc: The derivative gain for $\theta$.
    default: 1.02
```

## 2) Describing publishers and subscriptions

The syntax for describing subscribers is:

```
subscriptions:
  name subscription:
    topic: topic name
    type: message type
    desc: description

    queue_size: queue size
    latch: latch
```

where:

- **topic name** is the name of the topic to subscribe.
- **message type** is a ROS message type name, such as `sensor_msgs/Joy`.
- **description** is a Markdown description string.
- **queue size**, **latch** are optional parameters for ROS publishing/subscribing functions.

The syntax for describing publishers is similar.

Example:

```
subscriptions:
  segment_list:
    topic: ~segment_list
    type: duckietown_msgs/SegmentList
    desc: Line detections
    queue_size: 1

publishers:
  lane_pose:
    topic: ~lane_pose
    type: duckietown_msgs/LanePose
    desc: Estimated pose
    queue_size: 1
```

## 3) Describing contracts

This is not implemented yet. The idea is to have a place where we can describe constraints such as:

- “This topic must publish at least at 30 Hz.”
- “Panic if you didn’t receive a message for 2 seconds.”

- “The maximum latency for this is 0.2 s”

Then, we can implement all these checks once and for all in a proper way, instead of relying on multiple broken implementations

### 158.3. Automatic docs generation



Generate the docs for each node using this command:

```
$ rosrun easy_node generate_docs.py
```

## CHAPTER 159

# Duckietown ROS Gudieline

### 159.1. Node and Topics

In the source code, a node must only publish/subscribe to private topics.

In `rospy`, this means that the topic argument of `rospy.Publisher` and `rospy.Subscriber` should always have a leading `~`. ex: `~wheels_cmd`, `~mode`.

In `roscpp`, this means that the node handle should always be initialized as a private node handle by supplying with a `"~"` agrument at initialization. Note that the leading `"~"` must then be obmited in the topic names of. ex:

```
ros::NodeHandle nh_("~");
sub_lineseglist_ = nh_.subscribe("lineseglist_in", 1, &GroundProjection::lineseglist_cb, this);
pub_lineseglist_ = nh_.advertise<duckietown_msgs::SegmentList> ("lineseglist_out", 1);
```

### 159.2. Parameters

All the parameters of a node must be private parameters to that node.

All the nodes must write the value of the parameters being used to the parameter server at initialization. This ensures transparency of the parameters. Note that the `get_param(name,default_value)` does not write the default value to the parameter server automatically.

The default parameter of `pkg_name/node_name` should be put in `~/duckietown/catkin_ws/src/duckietown/config/baseline/pkg_name/node_name/default.yaml`. The elemental launch file of this node should load the parameter using `<rosparam>`.

### 159.3. Launch file

Each node must have a launch file with the same name in the `launch` folder of the package. ex: `joy_mapper.py` must have a `joy_mapper.launch`. These are referred to as the elemental launch files.

Each elemental launch file must only launch one node.

The elemental launch file should put the node under the correct namespace through the `veh` arg, load the correct configuration and parameter file throught `config` and `param_file_name` args respectively. `veh` must not have a default value. This is to ensure the user to always provide the `veh` arg. `config` must be default to `baseline` and `param_file_name` must be default to `default`.

When a node can be run on the vehicle or on a laptop, the elemental launch file should provide a `local` arg. When set to true, the node must be launch on the launching machine, when set to false, the node must be launch on a vehicle throught the `machine` attribute.

A node should always be launched by calling its corresponding launch file instead of using `rosrun`. This ensures that the node is put under the correct namespace and all the necessary parameters are provided.

Do not use `<remapp>` in the elemental launch files.

Do not use `<param>` in the elemental launch files.

## CHAPTER 160

### Package what\_the\_duck



`what-the-duck` is a program that tests *dozens* of configuration inconsistencies that can happen on a Duckiebot.

#### 160.1. What the duck



To use it, first compile the repository, and then run:

```
$ ./what-the-duck
```

#### 160.2. Adding more tests to what-the-duck



The idea is to add to `what-the-duck` all the tests that can be automated.

The documentation about to do that is not ready yet.

#### 160.3. Tests already added



Here is the list of tests already added:

- ✓ Camera is detected
- ✓ Scipy is installed
- ✓ sklearn is installed
- ✓ Date is set correctly
- ✓ Not running as root
- ✓ Not running as ubuntu
- ✓ Member of group sudo
- ✓ Member of group input
- ✓ Member of group video
- ✓ Member of group i2c
- ✓ ~/.ssh exists
- ✓ ~/.ssh permissions
- ✓ ~/.ssh/config exists
- ✓ SSH option HostKeyAlgorithms is set
- ✓ At least one key is configured.
- ✓ ~/.ssh/authorized\_keys exists
- ✓ Git configured
- ✓ Git email set
- ✓ Git name set
- ✓ Git push policy set
- ✓ Edimax detected
- ✓ The hostname is configured
- ✓ /etc/hosts is sane
- ✓ Correct kernel version
- ✓ Messages are compiled
- ✓ Shell is bash
- ✓ Working internet connection
- ✓ Github configured
- ✓ Joystick detected
- ✓ Environment variable DUCKIETOWN\_ROOT
- ✓ \${DUCKIETOWN\_ROOT} exists
- ✓ Environment variable DUCKIETOWN\_FLEET
- ✓ \${DUCKIETOWN\_FLEET} exists
- ✓ \${DUCKIETOWN\_FLEET}/scuderia.yaml exists
- ✓ \${DUCKIETOWN\_FLEET}/scuderia.yaml is valid
- ✓ machines file is valid
- ✓ Wifi network configured
- ✓ Python: No CamelCase
- ✓ Python: No tab chars
- ✓ Python: No half merges

#### 160.4. List of tests to add

Please add below any configuration test that can be automated:

- Editor is set to vim.
- Syntax on in ~/.vimrc
- They put the right MAC address in the network configuration
- Ubuntu user is in group video, input, i2c (even if run from other user.)
- There is at least X.YGB of free disk space.

- If the SD is larger than 8GB, the disk has been resized.

## PART 13

# Packages - Lane control

TODO: to write

# CHAPTER 161

## Package adafruit\_drivers



**TODO:** to write

# CHAPTER 162

## Package anti\_instagram



**TODO:** to write



### 162.1. Unit tests integrated with rostest



Unit tests are integrated with [ rostest ][#rostest].

To run manually, use:

```
$ rostest anti_instagram antiinstagram_correctness_test.test  
$ rostest anti_instagram antiinstagram_stub_test.test  
$ rostest anti_instagram antiinstagram_performance_test.test
```



### 162.2. Unit tests needed external files



These are other unittest that require the logs in DUCKIETOWN\_DATA:

```
$ rosrun anti_instagram annotations_test.py
```



### 162.3. Node anti\_instagram\_node



#### 1) Parameters



**Parameter** publish\_corrected\_image: bool ; default value: False

Whether to compute and publish the corrected image.



#### 2) Subscriptions



**Subscription** image: topic ~uncorrected\_image ( CompressedImage )

This is the compressed image to read.

**Subscription** click: topic ~click ( BoolStamped )

Activate the calibration phase with this switch.



#### 3) Published topics



**Publisher** image: topic ~corrected\_image ( Image )

The corrected image.

**Publisher** health: topic ~colorSegment ( AntiInstagramHealth )

The health of the process.

**Publisher** transform: topic ~transform ( AntiInstagramTransform )

The computed transform.



# CHAPTER 163

## Package car\_supervisor

TODO: to write

## CHAPTER 164

### Package dagu\_car



**TODO:** to write

# CHAPTER 165

## Package ground\_projection

**TODO:** to write

# CHAPTER 166

## Package joy\_mapper

**TODO:** to write

### 166.1. Testing

To test run:

1) connect joystick 2) `roslaunch launch/joy_mapper_test.launch` 3) the robot should move when you push buttons

### 166.2. Dependencies

- `rospy`
- `sensor_msgs`: for the `Joy.msg`
- `duckietown_msgs`: for the `CarControl.msg`

### 166.3. Node: joy\_mapper.py

This node takes a `sensor_msgs/Joy.msg` and converts it to a `duckietown_msgs/CarControl.msg`.

It publishes at a fixed interval with a zero-order hold.

#### 1) Parameters

---

Parameter `v_gain`: `float`; default value: `0.41`

**TODO:** Missing description for entry “`v_gain`”.

Parameter `omega_gain`: `float`; default value: `8.3`

**TODO:** Missing description for entry “`omega_gain`”.

Parameter `bicycle_kinematics`: `int`; default value: `0`

**TODO:** Missing description for entry “`bicycle_kinematics`”.

Parameter `simulated_vehicle_length`: `float`; default value: `0.18`

**TODO:** Missing description for entry “`simulated_vehicle_length`”.

Parameter `steer_angle_gain`: `int`; default value: `1`

**TODO:** Missing description for entry “`steer_angle_gain`”.

#### 2) Subscriptions

---

Subscription `joy`: topic `joy` (`Joy`)

The `Joy.msg` from `joy_node` of the `joy` package. The vertical axis of the left stick maps to speed. The horizontal axis of the right stick maps to steering.

### 3) Published topics

---

Publisher avoidance: topic `~start_avoidance` (`BoolStamped`)

TODO: Missing description for entry “`avoidance`”.

Publisher car\_cmd: topic `~car_cmd` (`Twist2DStamped`)

TODO: Missing description for entry “`car_cmd`”.

Publisher joy\_override: topic `~joystick_override` (`BoolStamped`)

TODO: Missing description for entry “`joy_override`”.

Publisher parallel\_autonomy: topic `~parallel_autonomy` (`BoolStamped`)

TODO: Missing description for entry “`parallel_autonomy`”.

Publisher e\_stop: topic `wheels_driver_node/emergency_stop` (`BoolStamped`)

TODO: Missing description for entry “`e_stop`”.

Publisher anti\_instagram: topic `anti_instagram_node/click` (`BoolStamped`)

TODO: Missing description for entry “`anti_instagram`”.

## CHAPTER 167

### Package `lane_control`

**TODO:** to write

#### 167.1. `lane_controller_node`

**Note:** there is some very funny business inside. It appears that `k_d` and `k_theta` are switched around.

##### 1) Parameters

---

**Parameter** `k_theta`: float

Proportional gain for  $\theta$ .

**Parameter** `theta_thres`: float

Maximum desired  $\theta$ .

**Parameter** `d_offset`: float

A configurable offset from the lane position.

**Parameter** `d_thres`: float

Cap for error in  $d$ .

**Parameter** `v_bar`: float

Nominal linear velocity (m/s).

**Parameter** `k_d`: float

Proportional gain for  $d$ .

##### 2) Subscriptions

---

**Subscription** `lane_reading`: topic `~lane_pose` (`LanePose`)

**TODO:** Missing description for entry “`lane_reading`”.

##### 3) Published topics

---

**Publisher** `car_cmd`: topic `~car_cmd` (`Twist2DStamped`)

**TODO:** Missing description for entry “`car_cmd`”.

# CHAPTER 168

## Package lane\_filter

Assigned to: Liam

TODO: to write

### 168.1. lane\_filter\_node

#### 1) Parameters

Parameter `peak_val`: float ; default value: `10.0`

TODO: Missing description for entry “`peak_val`”.

Parameter `l_max`: float ; default value: `2.0`

TODO: Missing description for entry “`l_max`”.

Parameter `lanewidth`: float ; default value: `0.4`

TODO: Missing description for entry “`lanewidth`”.

Parameter `mean_d_0`: float ; default value: `0.0`

TODO: Missing description for entry “`mean_d_0`”.

Parameter `min_max`: float ; default value: `0.3`

Expressed in nats.

Parameter `d_max`: float ; default value: `0.5`

TODO: Missing description for entry “`d_max`”.

Parameter `use_distance_weighting`: bool ; default value: `False`

For use of distance weighting (dw) function.

Parameter `linewidth_white`: float ; default value: `0.04`

TODO: Missing description for entry “`linewidth_white`”.

Parameter `cov_omega`: float ; default value: `0.01`

Angular velocity “input”.

which units?

Parameter `use_max_segment_dist`: bool ; default value: `False`

For use of maximum segment distance.

Parameter `delta_d`: float ; default value: `0.02`

(meters)

Parameter `min_segs`: int ; default value: `10`

For use of minimum segment count.

Parameter `phi_min`: float ; default value: `-1.5707`

TODO: Missing description for entry “`phi_min`”.

Parameter `sigma_d_θ`: float ; default value: `0.0`

TODO: Missing description for entry “`sigma_d_θ`”.

Parameter `phi_max`: float ; default value: `1.5707`

TODO: Missing description for entry “`phi_max`”.

Parameter `zero_val`: float ; default value: `1.0`

TODO: Missing description for entry “`zero_val`”.

Parameter `delta_phi`: float ; default value: `0.0`

(radians)

Parameter `l_peak`: float ; default value: `1.0`

TODO: Missing description for entry “`l_peak`”.

Parameter `cov_v`: float ; default value: `0.5`

Linear velocity “input”.

which units?

Parameter `sigma_phi_mask`: float ; default value: `0.05`

TODO: Missing description for entry “`sigma_phi_mask`”.

Parameter `sigma_d_mask`: float ; default value: `0.05`

TODO: Missing description for entry “`sigma_d_mask`”.

Parameter `mean_phi_θ`: float ; default value: `0.0`

TODO: Missing description for entry “`mean_phi_θ`”.

Parameter `sigma_phi_θ`: float ; default value: `0.0`

TODO: Missing description for entry “`sigma_phi_θ`”.

Parameter `d_min`: float ; default value: `-0.7`

TODO: Missing description for entry “`d_min`”.

Parameter `linewidth_yellow`: float ; default value: `0.02`

TODO: Missing description for entry “`linewidth_yellow`”.

Parameter `use_min_segs`: bool ; default value: `False`

For use of minimum segment count.

Parameter `use_propagation`: bool ; default value: `False`

For propagation.

Parameter `max_segment_dist`: float ; default value: `1.0`

For use of maximum segment distance.

## 2) Subscriptions

---

Subscription `velocity`: topic `~velocity` (`Twist2DStamped`)

**TODO:** Missing description for entry “velocity”.

**Subscription** segment\_list: topic ~segment\_list (SegmentList)

**TODO:** Missing description for entry “segment\_list”.

### 3) Published topics

---

**Publisher** belief\_img: topic ~belief\_img (Image)

**TODO:** Missing description for entry “belief\_img”.

**Publisher** switch: topic ~switch (BoolStamped)

**TODO:** Missing description for entry “switch”.

**Publisher** lane\_pose: topic ~lane\_pose (LanePose)

**TODO:** Missing description for entry “lane\_pose”.

**Publisher** entropy: topic ~entropy (Float32)

**TODO:** Missing description for entry “entropy”.

**Publisher** in\_lane: topic ~in\_lane (BoolStamped)

**TODO:** Missing description for entry “in\_lane”.

## CHAPTER 169

### Package `line_detector2`



This is a re-implementation of the package `line_detector` using the new facilities provided by `easy_node`.

#### 169.1. Testing the line detector using visual inspection



The following are instructions to test the line detector from bag files.

You can run from a bag with the following:

```
 $ rosrun line_detector line_detector2_bag veh:=vehicle bagin:=bag_in bagout:=bag_out verbose:=true
```

Where:

- `bag in` is the **absolute path** of the input bag.
- `vehicle` is the name of the vehicle that took the log.
- `bag out` is the **absolute path** if the output bag.

**Note:** you always need to use absolute paths for bag files.

You can let this run for a few seconds, then stop using `Ctrl-C`.

You can then inspect the result using:

```
$ roscore &
$ rosbag play -l bag_out
$ rviz &
```

In `rviz` click “add”, click “by topic” tab, expand “`line_detector`” and click “`image_with_lines`”.

Observe on the result that:

1. There are *lots* of detections.
2. Predominantly white detections (indicated in black) are on white lines, yellow detections (shown in blue) are on blue lines, and red detections (shown in green) are on red lines.

These are some sample logs on which to try:

```
$ wget -O 160122-manual1_ferrari.bag https://www.dropbox.com/s/8bpi656j7qox5kv?dl=1
https://www.dropbox.com/s/vwznjke4xvnh19o/160122_manual2-ferrari.bag?dl=1
https://www.dropbox.com/s/y7ulj198punj0mp/160122_manual3_corner-ferrari.bag?dl=1
https://www.dropbox.com/s/d4n9otmlans4i62/160122-calibration-good_lighting-tesla.bag?dl=1
```

Sample output:

```
From cmd:roslaunch duckietown camera.launch veh:=${VEHICLE_NAME}
[INFO] [WallTime: 1453839555.948481] [LineDetectorNode] number of white lines = 14
[INFO] [WallTime: 1453839555.949102] [LineDetectorNode] number of yellow lines = 33
[INFO] [WallTime: 1453839555.986520] [LineDetectorNode] number of white lines = 18
[INFO] [WallTime: 1453839555.987039] [LineDetectorNode] number of yellow lines = 34
[INFO] [WallTime: 1453839556.013252] [LineDetectorNode] number of white lines = 14
[INFO] [WallTime: 1453839556.013857] [LineDetectorNode] number of yellow lines = 29
[INFO] [WallTime: 1453839556.014539] [LineDetectorNode] number of red lines = 2
[INFO] [WallTime: 1453839556.047944] [LineDetectorNode] number of white lines = 18
[INFO] [WallTime: 1453839556.048672] [LineDetectorNode] number of yellow lines = 28
[INFO] [WallTime: 1453839556.049534] [LineDetectorNode] number of red lines = 2
[INFO] [WallTime: 1453839556.081400] [LineDetectorNode] number of white lines = 13
[INFO] [WallTime: 1453839556.081944] [LineDetectorNode] number of yellow lines = 34
[INFO] [WallTime: 1453839556.082479] [LineDetectorNode] number of red lines = 1
```

The output from `rviz` looks like [Figure 60](#).

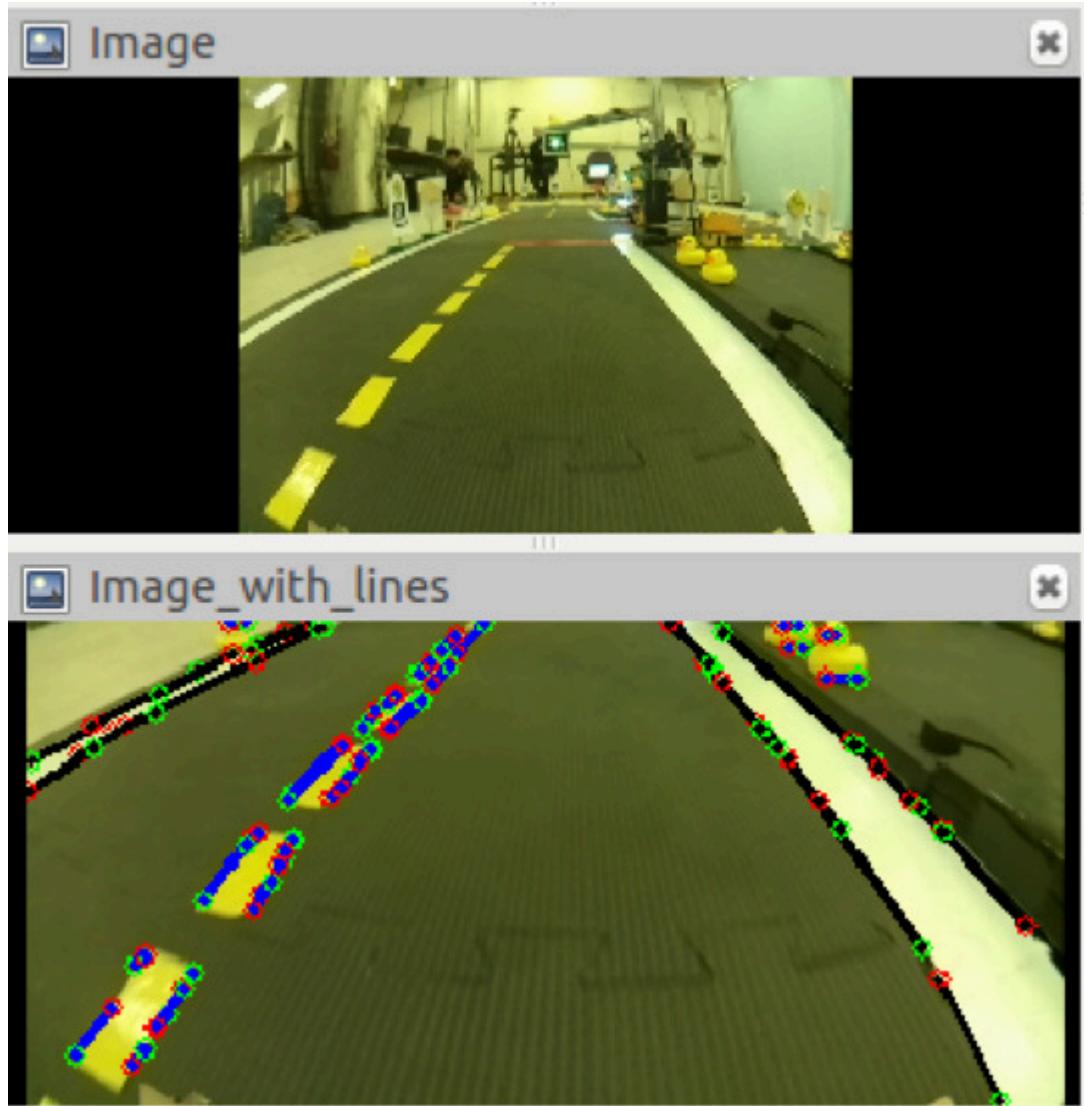


Figure 60

## 169.2. Quantitative tests

TODO: Something more quantitative (to be filled in by Liam or Hang)

## 169.3. line\_detector\_node2

This is a rewriting of `line_detector_node` using the EasyNode framework.

### 1) Parameters

Parameter `top_cutoff`: int ; default value: `None`

This parameter decides how much of the image we should cut off. This is a performance improvement.

**Parameter detector:** not known

This parameter defines the line detector instantiation. It consists of an array of two elements, where the first is a classname or function, and the second is a dictionary of parameters to pass to the function.

**Parameter img\_size:** not known

**TODO:** Missing description for entry “`img_size`”.

**Parameter verbose:** `bool`; default value: `True`

Whether the node is verbose or not. If set to `True`, the node will write timing statistics to the log.

## 2) Subscriptions

---

**Subscription switch:** topic `~switch (BoolStamped)`

This is a switch that allows to control the activity of this node. If the message is true, the node becomes active. If false, it switches off. The node starts as active.

**Subscription image:** topic `~image (CompressedImage)`

This is the compressed image to read. Note that it takes a long time to simply decode the image JPG.

**Note:** The data is processed *asynchronously* in a different thread.

**Subscription transform:** topic `~transform (AntiInstagramTransform)`

The anti-instagram transform to apply. See [Chapter 162](#).

## 3) Published topics

---

**Publisher color\_segment:** topic `~colorSegment (Image)`

**TODO:** Missing description for entry “`color_segment`”.

**Publisher edge:** topic `~edge (Image)`

**TODO:** Missing description for entry “`edge`”.

**Publisher segment\_list:** topic `~segment_list (SegmentList)`

**TODO:** Missing description for entry “`segment_list`”.

**Publisher image\_with\_lines:** topic `~image_with_lines (Image)`

**TODO:** Missing description for entry “`image_with_lines`”.

## CHAPTER 170

### Package `line_detector`



This package is being replaced by the cleaned-up version, [`line\_detector2`](#). Do not write documentation here.

However, at the moment, all the launch files still call this one.

# CHAPTER 171

## Package pi\_camera

**TODO:** to write

PART 14

## Packages - Indefinite navigation



**TODO:** to write

# CHAPTER 172

## Package apriltags\_ros

..

AprilTags for ROS.

build passing

## CHAPTER 173

### Package fsm



**TODO:** to write

# CHAPTER 174

## Package `indefinite_navigation`

..

**TODO:** to write

## CHAPTER 175

### Package intersection\_control



**TODO:** to write

# CHAPTER 176

## Package navigation

..

**TODO:** to write

## CHAPTER 177

### Package stop\_line\_filter



**TODO:** to write

## PART 15

# Packages - Localization and planning

..

TODO: to write

## CHAPTER 178

# Package `duckietown_description`

**TODO:** to write

# CHAPTER 179

## Package localization

..

**TODO:** to write

## PART 16

### Packages - Coordination



**TODO:** to write

# CHAPTER 180

## Package led\_detection

**TODO:** to write

### 180.1. LED detector

Pick your favourite duckiebot as the observer-bot. Refer to it as `robot name` for this step. If you are in good company, this can be tried on all the available duckiebots. First, activate the camera on the observer-bot:

```
$ rosrun duckietown camera.launch veh:=robot name
```

In a separate terminal, fire up the LED detector and the custom GUI by running:

```
$ rosrun led_detector LED_detector_with_gui.launch veh:=robot name
```

**Note:** to operate without a GUI:

```
💻 $ rosrun led_detector LED_detector.launch veh:=robot name
```

The `LED_detector_node` will be launched on the robot, while `LED_visualizer` (a simple GUI) will be started on your laptop. Make sure the camera image from the observer-bot is visualized and updated in the visualizer (tip: check that your camera cap is off).

Hit on Detect and wait to trigger a detection. This will not have any effect if `LED_detector_node` is not running on the duckiebot (it is included in the above launch file). After the capture and processing phases, the outcome will look like:

The red numbers represent the frequencies directly inferred from the camera stream, while the selected detections with the associated signaling frequencies will be displayed in green. You can click on the squares to visualize the brightness signals and the Fourier amplitude spectra of the corresponding cells in the video stream. You can also click on the camera image to visualize the variance map.

### 180.2. Unit tests

To run the unit tests for the LED detector, you need to have the F23 rosbags on your hard disk. These bag files should be synced from [this dropbox link] ([https://www.dropbox.com/sh/5kx8qwggtu69fhr/AAASLpOVjV5r1xpzeW7xWZh\\_a?dl=0](https://www.dropbox.com/sh/5kx8qwggtu69fhr/AAASLpOVjV5r1xpzeW7xWZh_a?dl=0)).

For the test to locate the bag files, you should have the `DUCKIETOWN_DATA` environment variable set, pointing to the location of your duckietown-data folder. This can be achieved by:

```
$ export DUCKIETOWN_DATA=local-path-to-duckietown-data-folder
```

All the available tests are specified in file `all_tests.yaml` in the scripts/ folder of the package led\_detection in the duckietown ROS workspace. To run these, use the command:

```
$ rosrun led_detection unittests.py algorithm name-of-test
```

Currently, `algorithm` can be either ‘baseline’ or ‘LEDDetector\_plots’ to also display the plot in the process.

To run all test with all algorithms, execute:

```
$ rosrun led_detection unittests.py '*' '*'
```

More in general:

```
$ rosrun led_detection unittests.py tests algorithms
```

where:

- `tests` is a comma separated list of algorithms. May use “\*”.
- `algorithms` is a comma separated list of algorithms. May use “\*”.

The default algorithm is called “`baseline`”, and its tests are invoked using:

```
$ rosrun led_detection <script> '*' 'baseline'
```

# CHAPTER 181

## Package led\_emitter



The coordination team will use 3 signals: CAR\_SIGNAL\_A, CAR\_SIGNAL\_B, CAR\_SIGNAL\_C. To test the LED emitter with your joystick, run the following command:

```
$ rosrun led_joy_mapper led_joy_with_led_emitter_test.launch veh:=robot_name
```

This launches the joy controller, the mapper controller, and the led emitter nodes. You should not need to run anything external for this to work. Use the joystick buttons A, B and C to change your duckiebot's LED's blinking frequency.

Button A broadcasts signal CAR\_SIGNAL\_A (2.8hz), button B broadcasts signal CAR\_SIGNAL\_B (4.1hz), and button CAR\_SIGNAL\_C (Y on the controller) broadcasts signal C(5hz).The LB button will make the LEDs all white, the RB button will make some LEDs blue and some LEDs green, and the logitek button (middle button) will make the LEDs all red

Repeat this for each vehicle at the intersection that you wish to be blinking. Use previous command replacing `robot name` the names of the vehicles and try command different blinking patterns on different duckiebots.

(optional tests) For a grasp of the low level LED emitter, run:

```
$ rosrun led_emitter led_emitter_node.launch veh:=robot_name
```

You can then publish to the topic manually by running the following command in another screen on the duckiebot:

```
$ rostopic pub /robot_name/led_emitter_node/change_to_state std_msgs/Float32 float_value
```

Where `float-value` is the desired blinking frequency, e.g. 1.0, .5, 3.0, etc. If you wish to run the LED emitter test, run the following:

```
$ rosrun led_emitter led_emitter_node_test.launch veh:=robot_name
```

This will cycle through frequencies of 3.0hz, 3.5hz, and 4hz every 5 seconds. Once done, kill everything and make sure you have joystick control as described above.

## CHAPTER 182

## Package led\_interpreter



**TODO:** to write

# CHAPTER 183

## Package led\_joy\_mapper

**TODO:** to write

## CHAPTER 184

### Package `rgb_led`

**TODO:** to write

#### 184.1. Demos

To test the traffic light:

```
$ rosrun rgb_led blink trafficlight4way
```

Fancy test:

```
$ rosrun rgb_led blink trafficlight4way
```

To do other tests:

```
$ rosrun rgb_led blink
```

# CHAPTER 185

## Package traffic\_light

TODO: to write

**PART 17****Packages - Additional functionality**

**TODO:** to write

## PART 18

# Packages - Templates

..

These are templates.

## CHAPTER 186

### Package `pkg_name`



The package `pkg_name` is a template for ROS packages.

For the tutorial, see [Chapter 115](#).



#### 186.1. Status

Given an honest assessment of the status of this package.

# CHAPTER 187

## Package rostest\_example

**TODO:** to write

**PART 19****Packages - Convenience**

**TODO:** to write

# CHAPTER 188

## Package duckietown\_demos

TODO: to write

## CHAPTER 189

### Package duckietown\_unit\_test



**TODO:** to write

## PART 20

# Packages - To sort

..

We need to decide where these packages go.

## CHAPTER 190

### Package `adafruit_imu`

#### 190.1. Testing

To test run:

TODO

#### 190.2. Dependencies

- `rospy`
- `sensor_msgs`: for the `Joy.msg`
- `duckietown_msgs`: for the `CarControl.msg`

#### 190.3. Node `adafruit_imu`

This node reads sensor data from adafruit IMU and publishes it to `sensor_msgs.Imu` and `sensor_msgs.MagneticField`.

---

##### 1) Parameters

- `~pub_timestep`: Time steps (in seconds) between publishings of `CarControl` msgs. Default to 0.02 (50 Hz).

---

##### 2) Publish Topics

- `~adafruit_imu`: `sensor_msgs.Imu`

`Imu.angular_velocity`: Vector3 of angular velocity vector.

`Imu.linear_acceleration`: Vector3 of linear acceleration.

- `~adafruit_mag`: `sensor_msgs.MagneticField`

`MagneticField.magnetic_field`: Vector3 of magnetic field.

---

##### 3) Services

None

# CHAPTER 191

## Package duckie\_rr\_bridge

TODO: to write

## CHAPTER 192

### Package `duckiebot_visualizer`



**TODO:** to write

# CHAPTER 193

## Package duckietown\_logs



**TODO:** to write.

Until we fix the dependencies:

```
sudo pip install SystemCmd==1.2 ros_node_utils==1.0 ConfTools==1.8 QuickApp==1.2.2  
sudo apt-get install -y mplayer mencoder  
  
sudo add-apt-repository ppa:mc3man/trusty-media  
sudo apt-get update  
sudo apt-get install -y ffmpeg gstreamer0.10-ffmpeg
```

## CHAPTER 194

### Package bag\_stamper



**TODO:** to write

# CHAPTER 195

## Package kinematics

..

**TODO:** to write

## CHAPTER 196

### Package `visual_odometry`



**TODO:** to write

# CHAPTER 197

## Package mdoap

..

**TODO:** to write

## CHAPTER 198

### Package parallel\_autonomy



**TODO:** to write

# CHAPTER 199

## Package scene\_segmentation

**TODO:** to write

## CHAPTER 200

Package `veh_coordinator`

**TODO:** to write

# CHAPTER 201

## Package vehicle\_detection

..

**TODO:** to write

## CHAPTER 202

### Package `visual_odometry_line`



**TODO:** to write

## PART 21

# Packages - Failed projects

..

These packages are abandoned failed projects.

## CHAPTER 203

### Package `mouse_encoder`



Use a mouse as encoder. Requires read permission to `/dev/input/mice`.

#### 203.1. Publish Topic



- `mouse_encoder/tick: geometry_msg/Point` message with number of ticks in the x and y direction.

#### 203.2. Parameters



- `~dev_path`: Default to `/dev/input/mice`. Point to the device path of the mouse.

#### 203.3. Getting access to `/dev/input/mice`.



- Create a group named `input`

```
$ sudo groupadd input
```
* Add yourself to the `input` group
```
$ sudo adduser your_user_name input
```

- Log out and log back in for the change to take effect
- Put all devices under `/dev/input/` into the `input` group to grant the group read/write permission. Can be done by adding a file name `99-pure-data.rules` under `/etc/udev/rules.d` with the following line:

```
SUBSYSTEM=="input", GROUP="input", MODE="660"
```

- Reboot for the rule to take effect.

# CHAPTER 204

## Package simcity - Map Editor Version 0.1

All ./ references point to duckietown(Software)/catkin\_ws/src/simcity A good reference for duckietown packages in general is catkin\_ws/src/pkg\_name/howto.md

### 204.1. How to run the map editor

(V0.1)

Inside ./launch is basic\_map\_tiler.launch. Ensure that the map file's path is correct for your machine. We start simcity, given a specific map file. We also start rviz, ROS' common gui.

### 204.2. How to edit the map

(V0.1)

The map is contained in ./maps as a YAML file. map.yaml is a small example of some circular streets, and censi\_map.yaml is the map of the duckietown currently up and running.

### 204.3. What am I looking at, anyway?

(V0.1)

The magenta arrows point in the direction of traffic. These arrows are lines indicating where traffic flows.

### 204.4. What else is there to do?

(V0.1)

Lots of things. This part is mostly for rmata (1/11/16)

- (1) Beautify it. Arrows are straight and ugly. Roads in duckietown can be curved, have not-so-subtle lane markings, stop signs, grass, and potentially cones and duckies.....
- (2) Make it interactive. MarkerArrays consist of Markers. What does an InteractiveMarker consist of?
- (3) Establish consistency and validation when adding a tile to a map. This would involve:
  - checking node positions at adjacent tiles
  - multiplying the sparse lane matrices and checking that number of lanes is consistent
  - having a perhaps separate node receive messages from the interactive server, or the basic\_map\_tiler node, and doing these computations for each change

## CHAPTER 205

# Package slam



**TODO:** to write

## CHAPTER 206

### Package `street_name_detector`

..

**TODO:** to write

Page left blank